The Cashew



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ICAR

Indian Council of Agricultural Research
New Delhi

THE CASHEW

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Foreword

THE cashew (*Anacardium occidentale* L.) has emerged asone of the most important commercial horticultural crop in India which has become possible because of the sustained research and development efforts by different research organizations in the country. Today, India is one of the major players in cashew trade and exporting processed cashew kernel to international market and thereby earning a substantial amount as foreign exchange. The cashew processing industries in India is generating ample job opportunities especially to the womenfolk. However, the productivity of raw cashewnut in the country is far below than the potential productivity which needs sincere efforts at all levels.

The research and development programmes conducted at Directorate of Cashew, Research, Puttur, and also at different centres of All India Coordinated Research Project on Cashew under State Agricultural Universities have resulted in the development and release of a number of high-yielding varieties and location specific production technologies. The work done in the area of crop-improvement, crop management, crop-protection and post-harvest technology so far has been compiled which will serve as bench mark in formulating future research and development strategies. The commendable efforts made by the authors who have contributed chapters for this book are appreciated.

I hope this publication will serve as a valuable reference to the researchers, teachers, policy planners, students, line departments and extension workers engaged in cashew research and development in the country. I take this opportunity to congratulate editors for their efforts in compiling the information and publishing it in the form of a monograph 'The Cashew'.

New Delhi
110 001

(Trilochan Mohapatra)
Secretary, DARE & DG, ICAR

Preface

TREE nuts are important source of nutritious food for the mankind. Among important nine tree nuts, cashew occupies third place in global tree nut market after almond and pistachio. Cashew is produced commercially in as many as 32 countries in the tropical regions of Asia, Africa and Latin America. Asiatic zone comprising of India, Indonesia, Philippines, Sri Lanka, Thailand, Vietnam and Malaysia for the last three decades accounting for 53% of total global production. In India, cashew was introduced by Portuguese travellers in 16th century but naturalized so much and found Indian soil homelier than its homeland Brazil. Now, cashew has moved from forest confine to commercial horticulture crop. Today, India is largest processor, exporter and also consumer of cashew in the world and emerged as key player in global cashew trade of cashew kernels.

Cashew research in India started dates back to 1950's when Indian Council of Agricultural Research (ICAR) sanctioned *ad-hoc* scheme on cashew improvement. Thus, Kottarakkara (Kerala) in 1952; Ullal (Karnataka) in 1953 and Vengurla (Maharashtra) in 1957 came into existence as pioneering cashew centres in the country. With the assistance of ICAR, Bapatla (Andhra Pradesh) in 1955 and Deragaon (Asom) in 1956 were also established. Cashew research got impetus with the establishment of Central Plantation Crops Research Institute (CPCRI) at Kasaragod in 1970, and the All India Coordinated Spices and Cashewnut Improvement Project in 1971. Moreover, implementation of the World Bank aided multi-state cashew project (MSCP) from 1982 to 1986 in Kerala, Karnataka, Andhra Pradesh and Odisha had given cashew research a new direction. The Quinquennial Review Team (QRT) constituted by the ICAR in 1982, after reviewing the entire research work on cashew, recommended delinking of cashew research from CPCRI and establishing an independent National Research Centre on Cashew (NRCC) at Puttur, Karnataka. Working group on Agricultural Research and Education constituted by the Planning Commission for VII Five-Year Plan and the Task Force on Horticulture constituted by ICAR also made recommendations which paved the way for the establishment of National Research Centre for Cashew (NRCC) at Puttur on 18th June 1986. The All India Coordinated Research Project on Cashew was also delinked from AICRP on Spices and Cashewnut Improvement. During XI Five-Year Plan, National Research Centre for Cashew was upgraded and renamed as Directorate of Cashew Research in 2009. The AICRP on Cashew has now 14 centres spread all over cashew growing states of the country to undertake location specific research programmes.

With sincere efforts of Directorate of Cashew Research, Puttur; AICRP on

Cashew centres and Development/Line departments; large number of varieties and production as well as processing technologies have been developed but still India is far behind in cashewnut productivity than potential productivity. This necessitates reorienting our research and development strategies to address the growing demand of raw cashewnut by the processing industries. Therefore, it was thought to have stock of research and development information available in the country in form of a book 'The Cashew' which will serve as bench mark to decide way forward in cashew sector. We hope that the publication will serve as a valuable reference to the academicians, policy planners, development departments and extension workers engaged in cashew research and development in the country.

Authors take this opportunity to express their sincere gratitude to Dr Trilochan Mohapatra (Secretary, DARE and Director General, ICAR, New Delhi) for his inspiring guidance to bring out this publication. Authors also pay their tribute to all former Directors of Directorate of Cashew Research, Puttur for their research and management contributions. The references cited in this compilation of several respected researchers are thankfully acknowledged. The massive support of Smt. Neelam Saroj w/o Dr P.L. Saroj and Mr O.G. Varghese (Private Secretary to the Director, DCR) in bringing out this publication is also acknowledged. Authors are also thankful to all personnel associated with Directorate of Cashew Research, and All India Co-ordinated Research Project on Cashew for their help in various ways.

Authors

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The Cashew: An Indian Scenario

CASHEW (*Anacardium occidentale* L.) is a precious gift of nature to mankind, which is grown mainly for its delicious kernel. The English name 'Cashew' is derived from the Portugese word '*Caju*'. It is known by different names in different countries such as Acajaiba (Brazil), Acajou (France), Acote maranon (Guatemala), Gajus (Malaya Peninsula), Kasoy (Philippines), Pajuil (Porto-Rico), Mananon (Spain), Acajua (Tupi), Merey (Venezuela). The other vernacular Indian names are *Kashuvandi* or *Parangi andi* (Malayalam), *Gerubeeja* or *Godambi* (Kannada), *Jeedi Pappu* (Telugu), *Mundhiri Paruppu* (Tamil), *Caju badam* (Assamese), *Hilji badam* (Bengali), *Lenka beeja* (Odiya) etc. Cashew belongs to the family Anacardiaceae, the genus *Anacardium* and species *occidentale*. About 21 species of *Anacardium* are reported to exist, viz., *Anacardium amilcarianum, A. brasiliense, A. ciratellaefolium, A. corymlosum, A.encardium, A. excelsum, A. gigantum, A. humile, A. kuhlanannianum, A. mediterraneum, A. microcarpum, A. microsepalum, A. nanum, A. negrense, A. orthonianum, A. parvifolium, A. pumilum, A. rhinocarpus, A. rondonianum, A. spruceanum* and *A. tenuifolium.* However, only 4 species available in India i.e. *Anarcardiume occidentale*, *A. pumilum*, *A. orthonianum*, *A. microcarpum*, besides *Semecarpus prainii* a related wild species of cashew with small fruit size has been collected recently from Andaman. The chromosome number of *Anacardium occidentale* is reported to be 2n=42 (Darlington and Janaki Ammal, 1945). Cashew is a medium size woody perennial, primarily cross-pollinated and andromonoecious tree with staminate and hermaphrodite flowers appearing on the same panicle (Rao and Hassan, 1957; Damodaran *et al.,* 1965). Flowering lasts for 2 to 3 months. It takes 50 to 70 days from pollination to maturity of the fruit. The cashew fruit has two distinct parts, viz. the swollen and pear shaped peduncle (cashew apple) and a kidney-shaped nut attached to the lower end of the apple. The nut contains the outer hard shell and the inside seed; the seed is consisting of the outer testa and the edible kernel.

Cashew is a tropical plant and grown in wide range of soils including loamy red and lateritic soils, mixed red and black soils, coastal and deltaic alluvium derived soils etc., but it prefers well drained brown forest soils, red sandy loam and light coastal soil with medium acidic to near neutral pH (6.3 to 7.5) and rich in organic matter. It can be cultivated up to 1,000 m above mean sea level (MSL). The mean annual rainfall distribution in cashew growing areas ranges from low rainfall (300-600 mm in Gujarat) to high rainfall (2,700 to 3,000 mm in West coast, and NEH region) and the mean annual temperature ranges from 20.0 to even more than 27.5°C. The productivity is highest in regions with a mean annual rainfall distribution of 600 to 1,500 mm and a mean annual temperature of 22.5 to 27.5°C. Similarly, the productivity is higher in regions where the minimum temperature ranged from 10 to 22°C and was lower in regions where the minimum temperature drops below 10°C. Cashew requires relatively dry weather and mild winter (15-20°C minimum temperature) coupled with moderate dew during night for profuse flowering. High temperature (>34.4°C) and low RH (<20%) during afternoon results in drying of flowers and subsequent yield reduction. Though, cashew is relatively considered hardy plant to biotic and abiotic stresses but prolonged and unseasonal rainfall accompanied with high wind velocity, high temperature and moisture stress during flowering, fruit setting and nut development stages results in heavy yield loss and adversely affects the nut quality even under better management conditions. Besides, most of the cashew plantations are in ecologically sensitive areas such as coastal belts, hilly terrain and under rainfed conditions, hence weather aberrations particularly during reproductive phase adversely affects the cashew productivity in India. Cashew productivity is also affected significantly by attack of tea mosquito bug (TMB) and cashew stem and root borer (CSRB). Similarly, there are some diseases like; root rot in nursery, powdery mildew, leaf and fruit spot, wilt etc. are also affecting cashew cultivation.

Importance of cashew

The cashew, which was once considered as most appropriate plant for soil conservation, afforestation and waste land development has now become an important horticultural crop of the country in terms of nutritional security, earnings of foreign exchange and employment generation. It is said that cashew can convert wastelands into gold mines, if managed properly (Saroj *et al.*, 2013). Cashew trees were grown in first instance for their kernels, which when roasted, have a pleasant taste and flavour. In tropical countries, the cashew nut is often one of the ingredients in various kinds of dishes. The so-called cashew butter, similar to peanut butter, is made from broken kernels, while the smaller pieces find their application in the confectionery. Furthermore, cashew kernels are used in the preparation of chocolate. The cashew kernels contain a unique combination of fats, proteins, carbohydrates, minerals and vitamins. Cashew contains 47% fat, but 82% of this fat is unsaturated fatty acids. The unsaturated fat content of cashew not only eliminates the possibility of the increase of cholesterol, but also balances or reduces the cholesterol level in the blood. Cashew also contains 21% proteins and 22% carbohydrates and the right combination of amino acids, minerals and vitamins and therefore nutritionally, it stands on par with milk, eggs and meat. As cashew has a very low content of carbohydrates, almost as low as 1% soluble sugar, the consumer of cashew is privileged to get a sweet taste without having to worry about excess calories. Besides these, it contains minerals such as Ca, P, Na, K, Mg, Fe, Cu, Zn and Mn. Cashewnuts do not lead to obesity and help to control diabetes. Precisely, it is a good appetizer, an excellent nerve tonic, a stimulant and a body builder. Besides nutritional value, cashew kernels are rich in nutraceuticals also, owing to helpful in lowering the risk of heart diseases. Kernels are good source of potassium, which is essential to upkeep of human kidney. The selenium content present in kernels could help in protecting against lung, liver, skin, brain and gastrointestinal cancer.

Cashew is an export oriented crop and India is the largest processor of raw cashew nut with processing capacity of 20 lakh tonnes and also largest exporter of cashew kernel (about 1.5 lakh tonnes/annum). Country is earning foreign exchange of ₹ 5,489/annum through export of cashew kernel and cashew nut shell liquid (CNSL). Edible oil can also be extracted from cashew kernel. The kernel oil is pale-yellow coloured, somewhat sweetish and of excellent quality. The testa covering the kernel consists for about 25% of tannins, which may be utilized in leather industries. The liquid extracted or expelled from the cashew shell as cashew nut shell liquid (CNSL), is used for many industrial purposes such as making paints, varnishes and lacquers. Another main product of the cashew trees is the 'apple', used for making jam, jelly, syrup, juice, candy, pickle as well as other alcoholic and non-alcoholic beverages. Cashew apple contains sugars, tannins, phenols, amino acids, ascorbic acid, minerals and fiber. Besides these, it also contains riboflavin and fairly good amount of ascorbic acid (240 mg/100 g). The pomace of cashew apple can be utilized for making cookies after converting into powder form. It can be used as supplement in animal feed. However, the processing of cashew apple is of minor importance so far, except in form of cashew '*feni*' in Goa state. Cashew cultivation and processing also generate better employment opportunities. As an estimate, there are more than 10 lakh people involved in cashew sector, out of which about 90% are women.

Historical perspective

The cashew has a long history as a useful plant but only in the present century it has become an important tropical tree nut crop. The French naturalist and monk, Thevet (1558) was the first to describe the cashew tree by referring to its occurrence as follows: The country from Cape St. Augustine to near Maragnon, dividing the territory of the King of Spain from that of Portugal, is far too good to belong to the cannibals as it numbers of the tree called "acajous", which bears fruit as large as your fist and shaped like a goose-egg. Some make from these a beverage, though the fruit itself is scarcely edible, having an unpleasant flavour. At the base of the fruit hangs a sort of nut, as big as a chestnut and with the shape of a kidney. As to the kernel therein, it is excellent to eat when lightly cooked. The rind is full of oil, very bitter tasting, of which the savages can extract a far greater quantity than we can from any of our nut shells'. Thevet accompanied his text with illustration showing Indians harvesting a tree and apparently preparing juice from the false fruit or 'apple' to which the nuts are attached. He further mentioned that cashew apple and their juice were consumed and that the nuts were roasted in fires and the kernels eaten. Thevet provided the first drawing of the cashew showing the local people harvesting fruits and squeezing juice from the cashew apples into a large jar (Johnson, 1973; Nair *et al.,* 1979; NOMISMA, 1994).

Small-scale local exploitation of the cashew for its nuts and cashew apples appears to have been the pattern for more than 300 years in Asia and Africa. It was not until the early years of the 20th century that international trade in cashew kernels began with the first exports from India. A very slow beginning, but recent decades have seen the cashew become an important commercial tree crop (Johnson, 1973). In India, use of cashew apples and nuts was adopted by local peoples and accounts from Africa are similar; making cashew wine appears to have been a common practice in both Asia and Africa (Johnson, 1973).

In Mozambique, the Maconde tribe calls it the Devil's nut. It was offered at wedding banquets as a token of fertility and research carried out at the University of Bologna, Italy has in fact indicated the presence of numerous vitamins including vitamin E in cashew kernel, considered by many to be aphrodisiac (Massari, 1994). At the time of the first Portuguese colonization, the name used by local populations (Tupi Natives of Brazil) for the cashew was "acaju" (nut), which turned into "caju", in Portuguese spelling and "cashew" in English. Most of the names for cashew in Indian languages are also derived from the Portuguese name "caju" (Johnson, 1973).

In Venezuela, cashew is called 'merey', but in all other Spanish-speaking countries of Latin America it is called 'mara-non', which may be derived from one of the first regions where the fruit was seen, viz. the State of Maranhao in northern Brazil. The earliest reports of cashew are from Brazil by French, Portuguese and Dutch observers (Johnson, 1973). There are indications that the local Tupi Indians had used cashew fruits for centuries. They probably played a major role in the species dispersion in their temporary migrations towards the coast of north-eastern Brazil, where a considerable intraspecific variation has been recorded (Ascenso, 1986).

According to Steven *et al.*(2007) cashewnuts have been identified among compression fossils from the early Middle Eocene lake sediments of Messel, Germany. These fossil fruits confirm that the cashew genus, *Anacardium*, was formerly distributed in Europe, remote from the modern native distribution in Central and South America. *Anacardium germanicum* sp. shows that the characteristic inflated pedicel, or "cashew apple," which facilitates biotic dispersal of cashew nuts, evolved at least 47 million years ago. It was previously proposed that *Anacardium* and its African sister genus, *Fegimanra,* diverged from their common ancestor when the landmasses of Africa and South America separated. However, the paleobotanical data indicate a connection via the Northern Hemisphere with Europe as an important footstep in the spread of this clade (i.e., a group of plants that consists of a common ancestor and all its lineal descendants, and represents a single "branch" on the "tree of life") between Africa and the New World. The former North Atlantic landbridge connecting North America and Europe via Greenland (Denmark) is implicated in the phytogeographic spread of *Anacardium* during the early and Middle Eocene.

Origin and distribution

Anacardium occidentale is native to tropical America where its natural distribution is unclear because of its long and intimate association with man. The problem of its origin and distribution has been investigated by Johnson (1973) who suggested that it originated in the *restinga* (low vegetation found in sandy soil along the eastern Brazil) of northeastern Brazil. Johnson is probably correct in assuming that the cultivated form of *A.occidentale* came from eastern Brazil, because cashew trees cultivated in the Old and New Worlds are identical in appearance to native trees found in *restinga* vegetation. *A. occidentale* is probably an indigenous element of the savannas of Colombia, Venezuela and the Guyanas. It is clearly a native and occasionally a dominant feature of the *cerrados* (savanna-like vegetation) of central and Amazonian Brazil. The *cerrado* populations of *A.occidentale* differ from the restinga populations by having undulate, thickly coriaceous leaves with short, stout petioles. The hypocarps (cashew apples) of *cerrado* trees are usually smaller and sometimes have a more acidic flavour than those of the *restinga*.

The natural distribution of *A. occidentale* extends from northern South America to Sao Paulo, Brazil. It is probably not native to Central America, the West Indies, or South America west of the Andes. It is believed that *Anacardium occidentale* originally evolved in the *cerrados* of Central Brazil and later colonized the more recent *restingas* of the coast. Central Brazil is a center of diversity for *Anacardium* where the distribution of *A. occidentale* overlaps the ranges of *A. humile, A. nanum* and *A. corymbosum. Anacardium humile*, the closest relative of the cultivated cashew, is closer morphologically to the *cerrado* ecotype than it is to the *restinga* and cultivated populations of *A.occidentale* (Mitchell and Mori, 1987).

The Eastern portion of the Amazon river figures prominently in distributions of many plants and animals, many of which are found either exclusively to the north or south of the river. However, in case of *Anacardium*, all Amazonian species are found on both sides of the Amazon river. The reason for this is probably the ease with which bats, large birds, and water (in the case of *A.microsepalum*) carry fruits across water barriers (Mitchell and Mori, 1987). The entire cashew fruit, nut and peduncle, will float when mature. This could account, in Brazil, for coastward dispersal of the species by rivers draining north and east. Fruit bats may also have been involved in seed movement. Within the Amazon forests fruit bats are the most important agents of seed dispersal of tree species (Johnson, 1973). The spreading of the cashew within the South American continent was gradual and spontaneous (NOMISMA, 1994).

According to Agnoloni and Giuliani (1977), cashew arrived in Africa during the second half of the 16^{th} century, first on the east coast and then on the west and lastly in the *islands*. In Africa, although it can be guessed that the cashew was introduced at an early period by the Portuguese, there are no records which provide specific dates. Dispersal of the cashew in East Africa may in part be due to the elephant, whose fondness for fruits is well known (Johnson, 1973). Attracted by the colour of the false fruit, they swallowed this together with the nut which was too hard to be digested. This was then expelled with their droppings, a natural manure, and trodden far enough into the ground by the animals following along behind to root and grow, into a seedling first and then a tree. This is how the cashew was spread along the east coast of Africa facing the Indian ocean (Massari, 1994).

Anacardium occidentale is cultivated and adventives throughout the Old and New World Tropics where the geographical limits of its cultivation are latitudes 27°N and 28°S, respectively (Nambiar, 1977). From its origin in north-eastern Brazil, cashew spread into South and Central America (Van Eijnatten, 1991). The presence of cashew in other continents is to be attributed to man's intervention

(Johnson, 1973). According to De Castro (1994), Portuguese discovered cashew in Brazil and spread first to Mozambique (Africa) and later into India between sixteenth and seventeenth centuries. However, it is believed that the Portuguese brought the cashew to India, between 1563 and 1578. It was first described in gardens in Cochin on the Malabar coast. It is also said that the state of Goa which was under the Portuguese occupation was the first one to take up large scale plantation of cashew from where it spread to other parts of the country. Following its introduction into south-western India, the cashew probably diffused throughout the Indian subcontinent to some degree by means of birds, bats, but most importantly, human elements. Cochin served as a dispersal point for the cashew in India, and perhaps for Southeast Asia as well (Johnson, 1973). The role of the Portuguese in spreading the nuts in this part of the world is clearly illustrated by the fact that in South India cashew is still called 'parangi andi' or Portuguese nut. In East Africa, the Portuguese found that ecological conditions are very favorable for growing this tree and today it is growing sub spontaneously in large areas of Mozambique, Tanzania and to a lesser extent in Kenya (Nair *et al.,* 1979).

According to Johnson (1973) the reason for the introduction is not documented, although the popular explanation is that it was for the purpose of checking soil erosion in the coastal areas of India. This interpretation, however, smacks of a twentieth century concept being applied to a sixteenth century event. Portuguese learned of the reported medicinal properties of the cashew and also that the juice of the cashew apple could be fermented into a good wine. It seems possible, therefore, that they visualized the cashew as a crop of potential value to India.

After India, it was introduced into South-Eastern Asia (NOMISMA, 1994). Dispersal in South-east Asia appears to have been aided by monkeys. Whether the cashew reached the Philippines via India is uncertain. It may have come directly from the New World on the Manila Galleons (Johnson, 1973). The cashew later spreads to Australia and some parts of the North-American continent, such as Florida. Finally, its present diffusion can be geographically located between 31° North latitude and 31° South latitude, both as a wild species and under cultivation (NOMISMA, 1994).

Though cashew is indigenous to Brazil, India is the country that nourished this crop and made it a commodity of international trade and acclaim. Even today, India is playing a pivotal role in cashew production, processing and export of cashew kernels in the world. At present cashew is cultivated in many tropical countries, mainly in coastal areas (Van Eijnatten, 1991; Ascenso, 1986). It was one of the first fruit trees from the New World to be widely distributed throughout the tropics by the early Portuguese and Spanish adventurers (Purseglove, 1988). In the 19^{th} century, proper plantations were planted and the tree then spread to a number of other countries in Africa, Asia and Latin America (Massari, 1994). Traditionally cashew has been cultivated on commercial scale in Brazil, India, Tanzania, Mozambique, Kenya and Madagascar, while in the recent years plantations are also raised in Australia and Southeast Asian countries like Vietnam, Myanmar and Thailand on commercial scale. Cashew trees can flourish in hot humid conditions and hence are distributed in countries near the equatorial region (Fig 1.1.). Cashew trees have no cold tolerance and are susceptible to frost damage

Fig. 1.1. Major cashew growing counties in the world

below 10°C. Cashew trees can be grown in areas of high rainfall and humidity, but it will not produce well in soil with water-logging as it may damage the roots.

In India, cashew cultivation is confined to coastal ecosystem. The major cashew growing states in India are; Kerala, Karnataka, Goa and Maharashtra along the west coast region and Tamil Nadu, Andhra Pradesh, Odisha and West Bengal along the east coast (Fig. 1.2). It is also being cultivated in non-traditional areas of Gujarat, Jharkhand, Chhattisgarh, North-Eastern states like Asom, Manipur, Tripura, Meghalaya and Nagaland and also in Andaman & Nicobar Islands.All 54 varieties of cashew grown in India, including 33 selections and 21 hybrids are derived from *Anacardium occidentale* L. only.

Fig. 1.2. Major cashew growing states in India

Current status

Area, production and productivity: Cashew is the third largest edible tree nut in the world and is produced in over 32 countries on commercial scale. Most of the cashew plantations are located in Asia, Africa and South America. India, Vietnam, Thailand, Indonesia, Malaysia, Mozambique, Nigeria, Tanzania, Kenya, Cafe and Ivoiri and Brazil are the major producers of cashew. In recent years several South-East Asian countries and Australia also started commercial plantation of cashew. In India, The Indian Council of Agricultural Research (ICAR) gave impetus on cashew research during 1951, through an *adhoc* research scheme on cashew. Thereafter, National Research Centre on Cashew (presently renamed as

Directorate of Cashew Research) was started in 1986 with the prime mandate of enhancing production of cashew in India and to serve as national repository for pertinent information on cashew. Location specific research programmes are conducted by All India Coordinated Research Project on Cashew (AICRP) functioning at 14 centers in different cashew growing states in the country. Centrally aided programmes were also initiated to improve cashew productivity by Directorate of Cashew and Cocoa Development (DCCD) which was set up in 1966. Certain programmes like area expansion, replanting, demonstration, regional nurseries etc. were supported during the plan periods towards growth of cashew production, processing and trade in India. The National Horticulture Mission (NHM), a centrally sponsored scheme was launched to promote horticulture sector through end-to-end holistic approach covering production, post-harvest management, processing and marketing. Exclusively for promotion of cashew trade, a separate organization namely Cashew Export Promotion Council of India was established as early as in 1955.

At present, India occupies largest area and also highest production in the world. As per *Cashew Hand Book*: 2014; the share of India in raw cashew nut production is highest (22%) in the world, followed by Cote d Ivoire (19%), Brazil (16.4%), Indonesia ((13%), Vietnam (7%), Tanzania (2%), Mozambique (1%) and others (20%). At present, cashew is grown in an area of about 10.27 lakh ha with a production of 7.25 lakh tonnes of raw cashew nutsand a productivity of 706 kg/ha (Table 1.1). Though, area and production of cashew in India is increasing continuously but growth in productivity is at very slow rate. The trend on area, production and productivity of cashew from the last 60 years (Fig. 1.3) revealed that the average national productivity of raw cashew nut is in between 600 and 800 kg/ha. However, there is great regional imbalance in productivity of raw cashewnut in the country which varies from as low as 303 kg/ha in Jharkhand to 1,262 kg/ha in Maharashtra. Andhra Pradesh and Maharashtra both are having individually more than 18% area under cashew but Maharashtra alone contributing 32.42% of total raw cashewnut production while Andhra Pradesh contributes only 13.78%. This is only because of the adoption of new varieties and production technologies in

Table 1.1. State-wise area, production and productivity of cashew in India: 2014-15

States	Area ('000 ha)	Production ('000 tonnes)	Productivity (kg/ha)
Kerala	84.53	80.00	946
Karnataka	124.71	80.50	645
Goa	58.17	32.00	550
Maharashtra	186.20	235.20	1262
Tamil Nadu	140.42	67.00	478
Andhra Pradesh	185.45	100.00	539
Odisha	180.41	85.50	474
West Bengal	11.36	13.00	1096
Chhattisgarh	13.70	8.50	620
Jharkhand	14.83	4.50	303
Gujarat	7.22	8.50	1177
Puducherry	5.00	3.00	600
Asom	1.05	0.57	543
Tripura	4.25	2.50	588
Meghalaya	8.50	4.50	529
Manipur	0.90	0.15	167
Nagaland	0.50	0.20	400
Total	**1,027.20**	**725.45**	**706**

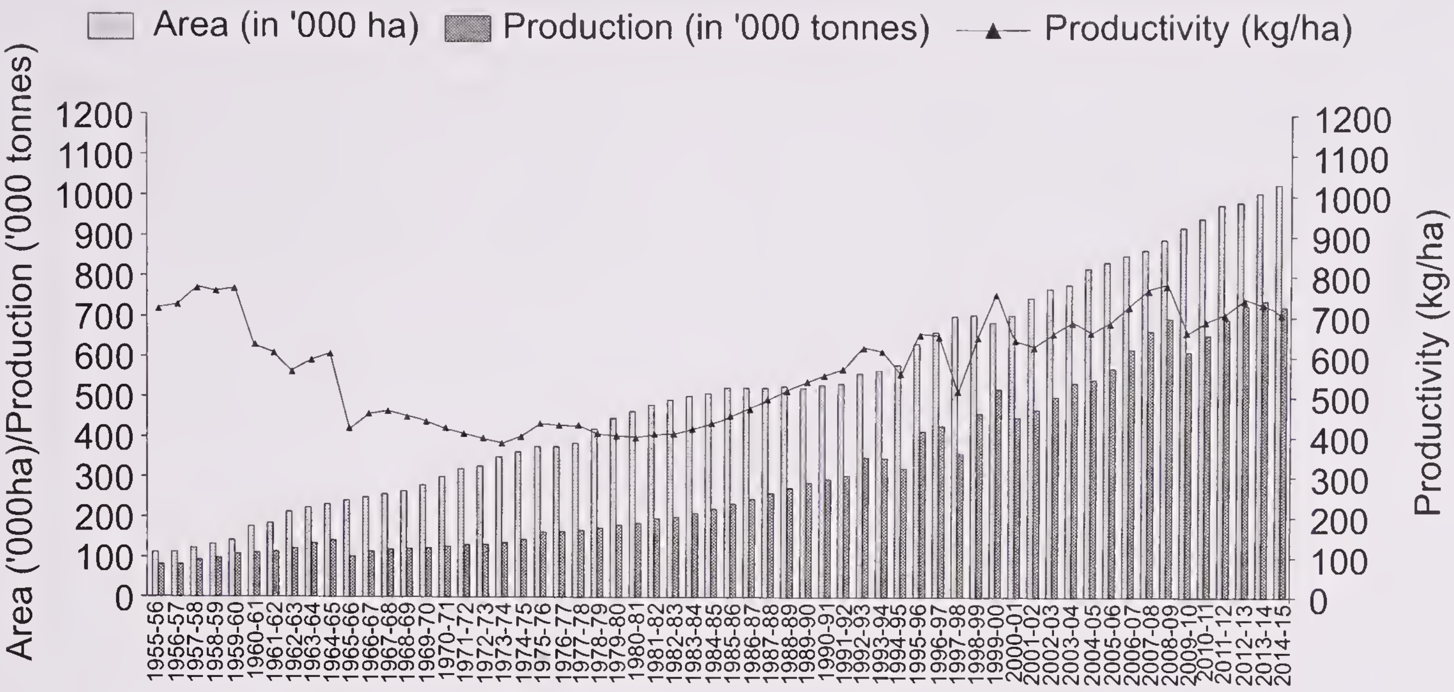

Fig. 1.3. Trends in area, production and productivity of cashew in India

Maharashtra. The productivity level of traditional cashew growing states like Tamil Nadu, Andhra Pradesh and Karnataka is low. There is a good scope of area expansion under cashew in non-traditional states like, Chhattisgarh, Jharkhand, Gujarat and North-Eastern states.

Processing and Export: In India, cashew processing was first started at Kollam (Kerala) in mid1920's. Indeed Mr Roch Victoria, a Sri Lankan who migrated to Kollam in Kerala, has started cashew processing on a commercial scale in mid 1920's. The processing of sun-dried raw cashew nut is done by Drum Roasting, Oil Bath Roasting and Steam Boiling methods. Cashew processing involves roasting/boiling, moisture conditioning, shelling, drying, peeling, grading, and packing. With the advent of new technologies and mechanical inputs, the

Table 1.3. Distribution of cashewnut processing industries in India

Processing units		Capacity (000' MT)	Processing Utilization (000' MT)		
States	Units (Nos.)		Indigenous	Import	Total
Kerala	432	700	67	320	387
Karnataka	266	65	45	20	65
Goa	45	21	21	–	21
Maharashtra*	2200	20	20	–	20
Tamil Nadu	417	565	294	225	519
Andhra Pradesh	175	95	92	–	92
Odisha	60	11	11	–	11
West Bengal	30	8	8	–	8
Chattisgarh	3	–	–	–	–
North-eastern States	22	15	15	–	15
Total	3,650	1,500	573	565	1,138

*Includes 1850 numbers of small-scale processing units

Source: DCCD, Cochin, India.

processing industry has seen a sea change in processing sector of cashew and extraction of kernel and CNSL, in recent times. Now, cashew processing units in India are providing job opportunities to the womenfolk of the country in a large-scale. About 90 to 95% of women force is employed in these industries at different stages of operation. Total employees strength varied from 50 to 400 per unit. There are about 3,650 processing industries (Table 1.3) constituting processing sector in this country. The estimated processing capacity is over 15 to 20 lakh tonnes/ annum.

Cashew is considered as one of the main export earning nut fruits. Though, India is importing raw nuts to the tune of 7-8 lakh tonnes every year for processing but at the same time exporting cashew kernel about 1.0-1.30 lakh tonnes to various destinations like USA, UK, UAE, Netherland, Japan etc. for earning of sizeable amount of foreign exchange. During 2014-15, the export earnings from cashew kernel was 54,330 million rupees. Besides, India is also earning about ₹ 25-30 crore from the export of cashew nut shell liquid (CSNL). It is also pertinent to mention that the domestic consumption of cashew kernel in India from the last few years is increasing at faster rate. A vivid account of import of raw cashew nuts,

Table 1.4. Import of raw nuts, export of kernel and export earnings from cashew in India

Year	Import of raw cashew nuts ('000 tonnes)	Export of cashew kernels ('000 tonnes)	Export earnings (million ₹)
1955-56	63	31	12.9
1956-57	51	31	14.5
1957-58	99	36	15.1
1958-59	125	41	15.8
1959-60	95	39	16.1
1960-61	118	44	18.9
1961-62	102	42	18.1
1962-63	155	49	19.3
1963-64	157	51	21.4
1964-65	191	56	29.0
1965-66	161	51	27.4
1966-67	141	51	42.8
1967-68	168	51	43.0
1968-69	196	63	60.9
1969-70	163	60	57.4
1970-71	169	50	52.0
1971-72	169	60	61.3
1972-73	197	66	68.8
1973-74	150	52	74.4
1974-75	160	65	108.1
1975-76	137	54	96.1
1976-77	74	52	105.9
1977-78	60	40	147.6
1978-79	20	27	80.0
1979-80	24	38	118.0
1980-81	16	32	140.0
1981-82	16	31	181.0
1982-83	1	31	135.0
1983-84	27	37	151.0
1984-85	33	32	180.0
1985-86	23	35	215.0
1986-87	40	42	334.0
1987-88	550	35	112.0
1988-89	30	34	2739.0
1989-90	59	45	3650.7
1990-91	833	49	4422.4
1991-92	106	48	6690.9
1992-93	135	56	7454.9
1993-94	190	69	10451.4
1994-95	231	77	12449.6
1995-96	222	68.0	12829.5
1996-97	192	68.7	12855.0

(Contd...)

(Contd. table 1.4)

Year	Import of raw cashew nuts ('000 tonnes)	Export of cashew kernels ('000 tonnes)	Export earnings (million ₹)
1997-98	225	76.6	13961.0
1998-99	181	75.0	16100.0
1999-00	201	92.5	24514.0
2000-01	249	81.7	18785.0
2001-02	355	97.6	17768.0
2002-03	401	127.2	20064.0
2003-04	452	100.8	18546.0
2004-05	578	127.0	27092.0
2005-06	565	114.1	25149.0
2006-07	593	118.5	24551.5
2007-08	606	114.3	22889.0
2008-09	606	109.5	29884.0
2009-10	753	108.1	29058.2
2010-11	529.37	105.76	28193.9
2011-12	809.37	131.76	43906.8
2012-13	892.00	104.02	40672.0
2013-14	771.00	114.79	50957.3
2014-15	940.00	119.00	54330.0

Source: CEPCI, Kollam (Kerala).

export of kernels and export earnings in India from 1955-56 to 2014-15 has shown 3.8-fold increase in export of cashew kernels and 4,211-fold in export earning in the same period (Table 1.4).

Growth and projections

Cashew nut production has increased from 2.34 lakh tonnes (1985-86) to 7.25 lakh tonnes (2014-15). The increase in raw cashew nut production is mainly because of the increased area under cashew cultivation by using softwood grafts instead of seedling plantations. At present, the area under cashew plantation is 10.27 lakh ha (2014-15), which was only 5.18 lakh ha in 1985-86. Although, India ranks first in raw cashew nut production but far behind in average raw cashew nut productivity, i.e. 706 kg/ ha (2014-15) against potential productivity of about 2,000 kg/ha. The main factors of low productivity are: large area under cashew plantations especially by State Cashew Corporations and Forest Corporations is seedling in origin, most of the plantations are on degraded sites and under rainfed conditions, poor awareness of latest cashew production technology and non-adoption of site specific recommended package of practices, sometimes severe damage caused by tea mosquito bug (TMB), no proper control measure for cashew stem and root borer, influence of adverse weather conditions etc. Besides these, absence of compact and dwarf high yielding varieties are another limiting factor to realize full potential of cashew nut yield.

The demand of processed cashew kernel is increasing continuously both at National and International level. Thus, it is natural; the global demand of raw cashew nut will also increase proportionately. In India also, even with the present level of processing capacity, there is a need of double production of raw cashew nut. After about 27 years of establishment (1985-86 to 2012-13) of Directorate of Cashew Research, Puttur (erstwhile National Research Centre on Cashew); the compound annual growth rate in area expansion of was 2.36%, increase in production 4.11% and in case of productivity only 1.93%. This clearly indicated that the growth rate of cashew sector was less than other horticultural commodities. The reason for poor growth rate in cashew sector was not only the poor technological advancement but also poor investment and meager involvement of trained scientific manpower in this sector.

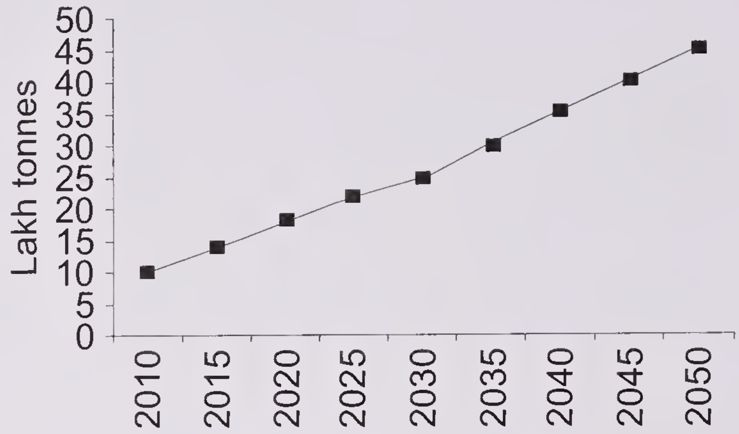

Fig. 1.4 Estimated requirement of raw cashew nut up to 2050

Every year, India is importing about 7-8 lakh tonnes of raw cashew nut from the African countries to meet the requirement of processing industries. Thus, there is an urgent need for achieving quantum jump in raw cashew nut production, which calls for a paradigm shift in our research approaches to harness the potential of modern tools and techniques in technology generation and dissemination. As an estimate, Indian processing industries need about 45 lakh tonnes of raw cashew nut up to 2050 (Fig. 1.4). The present level of raw cashew nut production is about 7.25 lakh tonnes (2013-14) and within 35 years, we have to produce additional 38 lakh tonnes; thus an additional increase in production at the rate of 1.13/year is required. To maintain and sustain the competitive edge and share in the world market, it is necessary to produce adequate quantity of raw nuts to meet the processing capacity established in the country without dependence on import of raw nuts.

Thus, it is concluded that cashew is an important crop both from nutritional security and economic viability points of views but comparatively less attention has been given on research and development of cashew than other commercial horticultural crops. The demand for cashew kernels both in domestic and international market is increasing at faster rate but processing industries are heavily dependent on imported raw nuts due to in-adequate supply of domestic raw nuts. The domestic production of raw cashew nut is about half of the requirement of processing industries. Therefore, there is a need for immediate attention to improve our domestic production by replacing senile and uneconomical cashew plantations, area expansion under newly released high-yielding varieties and adopting scientific crop management practices including plant protection. To address the issue, there should be sufficient trained human resource and financial support as well as better coordination between research and developmental organizations.

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2

The Cashew: A Global Perspective

CASHEW originated in Amazon region of Brazil and thereafter reached the other parts of the world for its attractive fruit. Cashew was introduced to India by thePortuguese in the beginning of 16th century. Initially, it was adopted as a plant for afforestation in coastal degraded lands. Realizing its importance, it has been commercialized as one of the important horticultural crops for production of delicious kernel. The cashew kernel is the main commercial product which contains 47% fat of which 87% are unsaturated fatty acids; 21% protein, 22% carbohydrates, while the remaining 10% constitutes other substances including calcium (Ca), sodium (Na), potassium (K), magnesium (Mg), phosphorus (P), iron (Fe), copper (Cu), zinc (Zn), chlorine (Cl_1), selenium (Si) and vitamins. Cashew nut shell liquid (CNSL) is another important industrial product obtained while processing of raw nut. Cashew apple is also nutritious and can be exploited in preparation of various products. The powder of cashew apple pomace obtained after extracting juice can be utilized for preparation of cookies. Pomace can be used in partial substitution of animal feed.

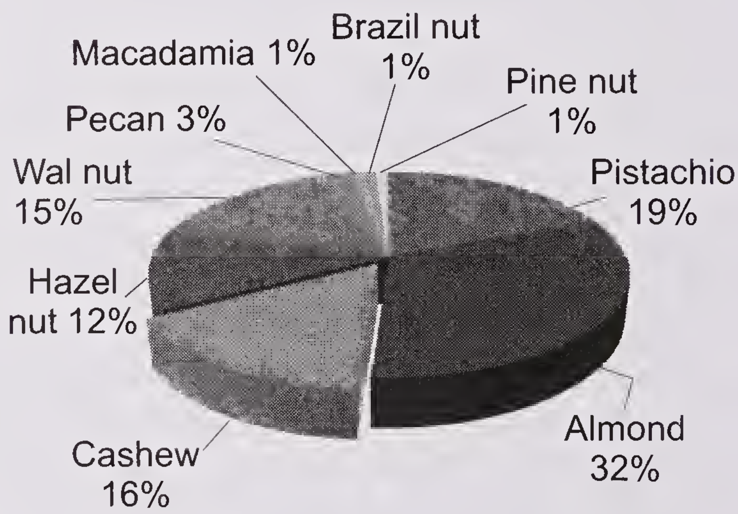

Fig. 2.1. Share of cashew kernel in global tree nut market during 2012.

Among major tree nuts viz. almond (*Prunus amygdalus*), Brazil nut (*Bertholletia excelsa*), cashew (*Anacardium occidentale*), hazelnut (*Corylus avellana*), macadamia nut (*Macadamia integrifolia*), pistachio nut (*Pistacia vera*), pine nut (*Pinus gerardiana*), pecan nut (*Carya illinoinensis*) and walnut (*Juglans regia*) are traded in the world. Cashew stands at third position as far as quantity consumed and second position for its unit value next to walnut. Share of cashew kernels in global nut trade is around 16% (Fig. 2.1). Being a low input-intensive and climate-smart crop, cashew can play an important role in livelihood security of resource-poor farmers, entrepreneurs and local industries. Besides, the economic benefits, growing of cashew has a vital role in stabilizing fragile ecosystem. The demand for cashew kernel is increasing both in domestic and international markets. Therefore, it is important to develop proper strategy so as to fulfill the ever growing demand for cashew kernels.

Research and developmental organizations

There are a large number of organizations involved in cashew research, development, processing and trade. Scientific interventions in production, processing and marketing in cashew was geared up in Brazil through EMBRAPA (Brazilian Enterprise for Agricultural Research), Ceara, Development Agency of the State of Ceará, Department of Agrarian Development, Federation of Agriculture and Livestock of the State of Ceará, Support Service for Micro and Small Enterprises of Ceará, Federal University of Ceará, Union of Industries of the State of Ceará (Sindicaju), Cajucultores Association of the State of Ceará (ASCAJU), Federação of Industries of the State of Ceará (FIEC), Enterprise Technical Assistance and Rural Extension of Ceará (EMATERCE), Department of Science and Technology (SECITECE) and Embrapa Agroindústria Tropical. In Vietnam, Departments for Agriculture and Rural Development (DARD) and Industries (DoI), Agriculture Extension Centre (AEC), the Western Highlands Agroforestry Science and Research Institute (WASI) and Vietnamese Cashew Association (VINACAS) have been supporting cashew production and processing.

The Cocoa Research Institute of Nigeria, Ibadan; The Kenya Agricultural Research Institute, Kenya; Nut Processors Association of Kenya (NutPAK), The Ministry of Agriculture, Kenya; The Africa Cashew Alliance (ACA), Africa; African Cashew initiatives (ACi), Africa; University Eduardo Mondlane, Maputo, Mozambique; Ministry of Agriculture and Rural Development of Mozambique, Maputo; Agricultural Research Institute (ARI) Naliendele, Mtwara, United Republic of Tanzania; Indonesian Agency for Agricultural Research and Development, Indonesia are some of the public and private organizations contributing for the research, development and promotion of cashew.

In India, thrust on systematic research was initiated through *ad-hoc* scheme spearheaded by the Indian Council of Agricultural Research (ICAR) during 1951. The Directorate of Cashew Research (erstwhile National Research Centre on Cashew), Puttur (Karnataka) was established in 1986. Simultaneously, All India Coordinated Research Project (AICRP) located in12 different states also started region-specific research and developmental activities on cashew. Cashew Export Promotion Council of India (CEPCI) was formed under the purview of the Ministry of Commerce and Industry to guide the industry in promoting exports of cashew kernels and allied products during 1955. Besides, Department of Agriculture and Cooperation, Goverment of India started developmental work on cashew with the establishment of Directorate of Cashew and Cocoa Development (DCCD) at Kochi during 1966. State Agricultural Universities, State Forest Corporations and Manufacturers Associations/Industry Associations/Exporters Associations are also involved in its promotion in different ways.

Global scenario of cashew production

Cashew is grown exclusively in developing countries for export and domestic consumption. About 80 to 85% processed cashew kernels are exported to developed countries. Cashew is produced commercially in as many as 32 countries in tropical regions of Asia, Africa and Latin America located below equator. Its total production in the world was 41.53 lakh tonnes during 2012 (Fig. 2.2). which is almost two-fold increases with reference to base year 1961. Although, Mozambique, an East African country, maintained its premier position in early sixties. Asiatic zone comprising India, Indonesia, Philippines, Sri Lanka, Thailand, Vietnam and Malaysia recorded highest production during last three decades, accounting 53% of total global production. Due to intervention of research and development in African countries, cashew production increased by 2.04-fold, i.e. 9.21 - 18.81 lakh tonnes from 2001 to 2012. Brazil is home of cashew, but its production is almost stagnated and contribution of Latin American zone is around 5% only.

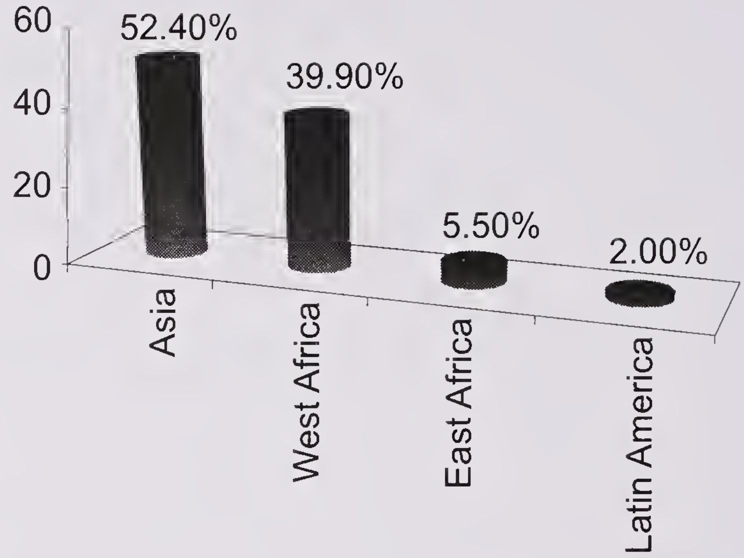

Fig. 2.2. Continent-wise production share of cashew (FAO, 2012)

India ranked first in production of raw cashewnut in the world for several years, but it slipped to the third position during 2012. Vietnam which produced just over 700 tonnes during1961, jumped to first position with the total production of 11.91 lakh tonnes during 2012. Nigeria, one of the West African countries also keeps pace with Vietnam contributing 20% in the global production of cashew. Production in Ivory Coast has grown rapidly in recent years with a share of 11% in the total world production (Fig.2.3).

In India, Maharashtra is largest producer of cashew nuts accounting for 32.07% of the total cashew nuts produced in the country followed by Andhra Pradesh (13.63%) and Odisha (11.64%) during 2013-14. Andhra Pradesh occupies highest area (18.36%) but contributes only 13.63% of the total raw cashew nut production. This is only because of low level of productivity (646 kg/ha). The productivity of

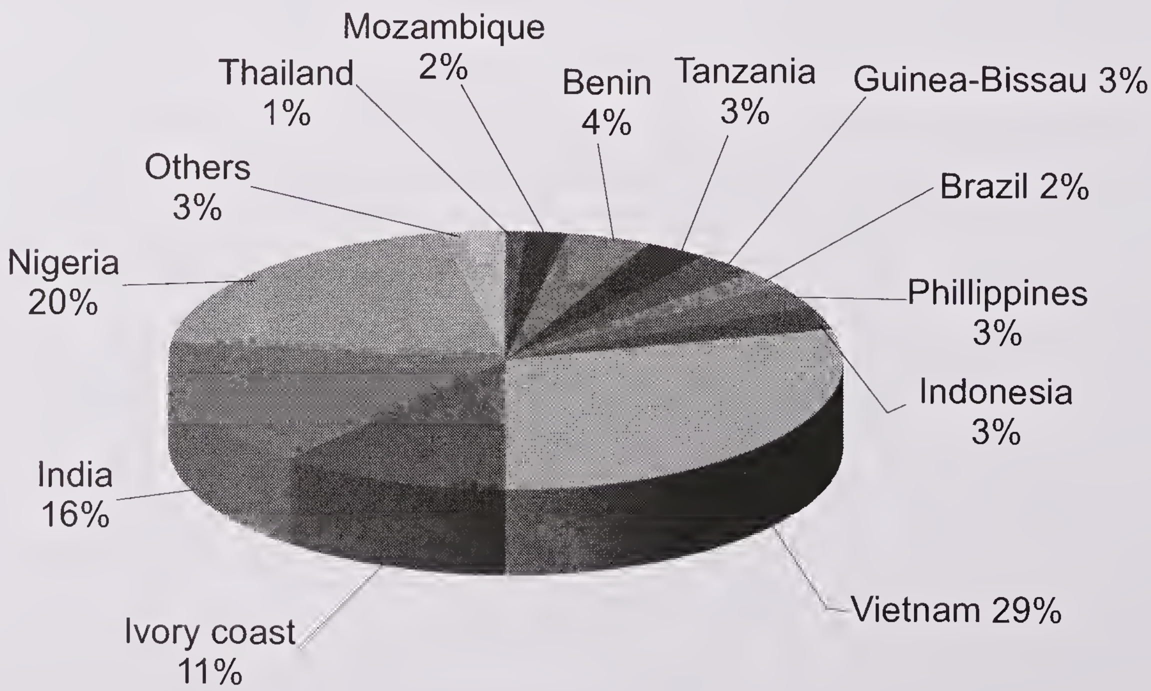

Fig. 2.3. Major cashewnut producing countries in the world (FAO, 2012)

Table 2.1. Quantity of raw cashew nuts imported from African countries (1961-2011)

Country	1961		1971		1981		1991		2001		2011	
	Q	V	Q	V	Q	V	Q	V	Q	V	Q	V
Benin	50	8	NE	NE	NE	NE	2,085	754	33,458	11,140	12,1497	15,0829
Burkina Faso	NE	NE	NE	NE	NE	NE	NE	NE	2,244	721	81,274	55,967
Ivory Coast	NE	NE	NE	NE	541	209	7,415	4,374	85,000	35,295	278,320	263,592
Ghana	NE	NE	NE	NE	NE	NE	NE	NE	419	89	145,013	169,879
Guinea-Bissau	500	40	661	53	2,349	1,645	18,250	14,071	78,597	47,000	139,723	203,750
Guinea	NE	NE	NE	NE	NE	NE	700	700	NE	NE	21,884	27,884
Mozambique	89,583	11,601	53,382	11,788	NE	NE	NE	NE	NE	NE	35,802	46,519
Nigeria	1,000	200	1,000	300	1,000	400	12,600	4,442	4,950	2,200	14,077	16,664
United Republic of Tanzania	41,000	6,560	115,863	20,728	25,145	34,562	19,000	16,700	96,487	63,281	99,425	105,699

Q: Quantity in tonnes and V: value in 1,000 USD (FAO, 2011); NE: No Export

Maharashtra is 1,317 kg/ha, followed by West Bengal (1,096 kg/ha) and Gujarat (1,020 kg/ha). The productivity of cashew nut in non-traditional states like Gujarat, Jharkhand and Chhattishgarh is also good.

Global trade of raw cashewnut

Most of the cashew producing countries in East and West Africa are major suppliers of raw cashew nut to India and are likely to remain as it is in the near future too, amidst strong competition from Vietnam and Brazil. Although, Vietnam and Nigeria pushed India to the third position as far as production is concerned, it stands first in the import of raw cashew nuts in the world. About 8.5 lakh tonnes (MT) of raw cashew nuts, worth of ₹ 5,085 crore, was imported primarily from African countries during 2012-13. The domestic production is not keeping pace with the demand for raw cashew nuts by the processing industries. Inadequate supply of raw cashewnuts to fulfill the continuous operation of cashew processing units has been a burning issue to be resolved. Import of raw nuts, which was around 2.49 lakh tonnes in the beginning of the century (2000-2001), reached an all time high of 7.71 lakh tonnes during 2013-14 (Fig. 2.4). Prices of raw cashew nuts imported into India are highly speculative. Harvesting season and its coincidence with harvesting in India, quantity of production during the season in India, quality assessment in terms of outturn and driage, farm gate price and tax levied at various levels in the exporting country, transit expenses etc. are considered while trading raw cashew nuts. Raw nuts are purchased throughout the year by the Indian processors. Monthly imports are fairly even, but may decline in May and June when the factories are occupied with the local crop. Raw nut suppliers from Tanzania and Ivory Coast export monthly throughout the year; thereby the Indian processors are assisted in not carrying long-term stocks. The export of raw cashew nuts from African countries and their values at decadal intervals are given in Table 2.1.

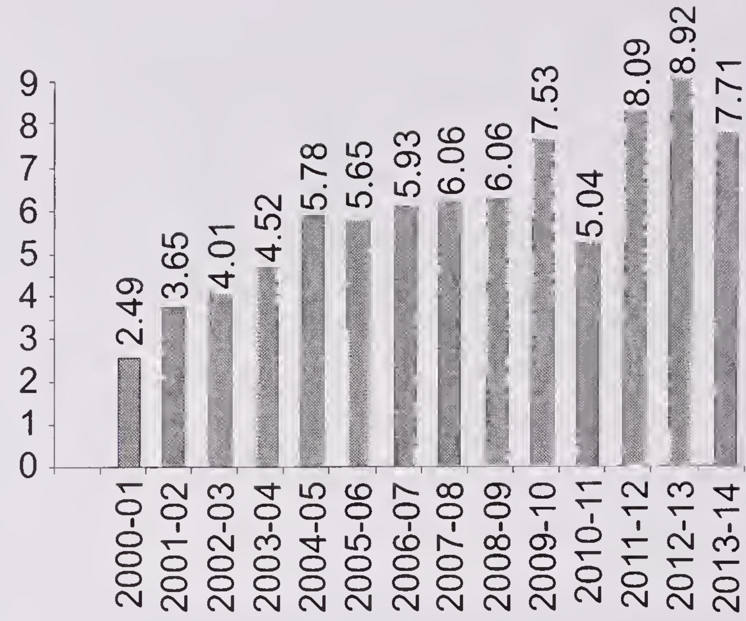

Fig. 2.4. Import of raw cashew nuts in India.

Global trade of cashew kernel

Being a delicious snack food and health benefits, the demand of cashew kernels is increasing continuously. Vietnam, India and Brazil are supplying over 90% of the kernels traded internationally. Among minor exporters, Mozambique, Tanzania and Kenya provide further supplies from East Africa while West African exports are presently derived from Nigeria and Indonesia. Import of cashew kernels by developed countries has grown 7.1% during the last decade, and the principal importing countries of processed cashew nut (90% of the total of world) being the USA, European Union countries, Japan and formerly USSR. USA stands for almost 50% of the total imports of processed cashew kernels and therefore, it dictates international selling prices. Share of cashew kernels in European Union countries is marginal compared to all other kinds of tree nuts import. In Asia, Japanese market is considered to be important, and accounting for only 4-5% of global export market for cashew kernels. Whole kernels without defects or blemishes are required for the snack trade while broken pieces are used in other confectionery, biscuits and bakery products. Mostly plain cashew kernels are traded in the international market and secondary level processing takes place at the importing countries, particularly in USA and Europe for retail sale. There is only a very small international trade in retail packed cashew nuts, mainly coming from India and destined for the ethnic markets in Europe.

India is the first country in the world to export cashew kernels. The Indian cashews are consumed in as many as 60 countries all over the world. The major markets for Indian cashews are the USA, UK, Japan, The Netherlands, Australia, Canada, Germany, Hong Kong, Singapore, New Zealand and Middle East countries. Of the total export earnings from agricultural products in India during 2012-13 is around 7.46% and export share of cashew kernelsis 3.34% (Directorate General of Commercial Intelligence and Statistics-DGCI&S, India). This accounts to 0.25% of total foreign exchange earnings of the country through exports. Consumption of processed cashew kernels has been increasing steadily with the USA as the largest consuming market, followed by the Netherlands. The trade of cashew kernels is almost increasing every year but the domestic consumption has also increased recently. The trade of cashew kernels from India is given in (Table 2.2).

Table 2.2. Cashew trade and its value in India during 2000-2013

Year	Value of kernels ($/kg)	Average value of USD in ₹	Quantity of kernel export ('000 MT)	Value of kernel export (₹ in crore)	Average price of raw cashew nuts (₹)
2000-01	4.80	47.91	89.16	2,049.75	29.50
2001-02	3.78	48.19	97.55	1,776.80	31.22
2002-03	4.17	45.94	104.14	1,933.02	31.95
2003-04	3.98	44.93	100.83	1,804.42	31.60
2004-05	4.83	44.28	126.67	2,709.24	40.83
2005-06	4.84	45.25	114.14	2,514.86	32.92
2006-07	5.14	40.26	118.54	2,455.15	32.73
2007-08	4.35	45.99	114.34	2,288.90	36.24
2008-09	5.75	47.44	109.52	2,988.40	44.68
2009-10	5.21	45.56	108.12	2,905.82	49.27
2010-11	5.85	49.98	105.76	2,819.39	77.00
2011-12	7.00	53.14	130.87	4,383.82	68.13
2012-13	7.46	62.52	100.11	4,046.23	62.29

Production management

Propagation and orchard establishment: Before nineties, cashew was multiplied mainly by seed nuts, thereafter vegetative production was given due emphasis to have true-to-type of planting materials. Of the different methods of vegetative propagation, softwood grafting was found to be the best for mass multiplication of cashew by giving more than 80% success. In this technique, properly dried cashew seed nuts of 6 to 8 g weight are sown in black polybags (20 × 12.5 cm^2 size of 300-gauge thickness) filled with good soil and farmyard manure (FYM)/compost (1:1). After two months, softwood grafting is done by cleft method using 3-5 months old scion shoots of commercial varieties. While grafting two pairs of leaves must be retained on rootstock, tying of graft joint should be done with polythene strip of 100-gauge thickness and covered with inverted poly-tubes. After sprouting of scion (7-10 days), the tubes should be removed. Grafting operation should be done either under partial shade or in shade net house. The time for grafting is from June to February. Moreover, grafting operation in cashew growing-regions is done twice in a year, i.e. (i) sowing of seed nuts in February, grafting in April-June and grafts are ready for sale in July-September, and (ii) sowing of seed nuts in October, grafting in December-February and grafts are ready for sale from May onwards. Production of quality planting material of high-yielding varieties through softwood grafting technique has been a great success story in cashew with tremendous impact in improving cashew productivity.

Ideal time for planting of cashew grafts is usually during monsoon season in most of the cashew growing countries. Therefore, land preparation such as clearing of bushes and other wild growth as well as digging of pits for planting should be completed during pre-monsoon season. In India, a spacing of 7.5 m × 7.5 m or 8 m × 8 m is recommended for cashew (175 and 156 plants/ha). A closer spacing of 4 m × 4 m (625 plants/ha) in the beginning and thinning out in stages and thereby maintaining a spacing of 8 m × 8 m by the tenth year can also be followed.

This enables higher returns during the initial years and as the trees grow in volume, the final thinning is done. However, in ultra-high density planting, at spacing of 3 m × 3 m by accommodating 1,111 plants/ha is recommended. Though, ultra-high density planting system gives 2-3 times more yield but scientific management including development of proper canopy architecture, nutrition, irrigation, pest control etc. are very crucial. High-density planting is also adopted in Vietnam, which acclaimed highest productivity. However, in Brazil, Tanzania and Australia, vigorus varieties of cashew are planted 12-15 m apart.

Varietal wealth

Among various species, *Anacardium occidentale* is the only cultivated species. The variability in Brazilian cashew is viewed mainly from two angles, viz. tall and vigorous types with a tree height of 8 to 15 m, canopy diameter of up to 20 m and yield of 1-180 kg/tree of raw nuts; dwarf types characterized by precocious nature (flowering 16-18 months after planting), short stature of tree with a height up to 4 m, having a homogenous canopy, with a canopy diameter smaller than the common types. Use of different breeding procedures like polycross-method, selection between and within the progenies, inter and intra-specific hybridization has resulted in the development of dwarf cashew clones. In Nigeria, genetic materials introduced from India and Tanzania and Mozambique served as a basis for generation of 25 half-sib genotypes with high-yielding potential. In Mozambique, segregating seed progenies of Brazilian dwarf types served as a basis of crop improvement programme (Prasad *et al.,* 2000). In Australia, Indian and Brazilian accessions are utilized for hybridization programme. In India, more than 50 varieties were developed both from selection and hybridization methods. The varieties developed in different cashew growing countries are given in Table 2.3.

Table 2.3. Major cashew varieties developed in different countries.

Country	Varieties of cashew
Brazil	CP-12,CCP-09, CCP-76 , CCP-1001, BRS-189, BRS-226, BRS-265, BRS-274, BRS- 275, Embrapa-50, Embrapa-51,
Vietnam	PN-1, LG-1,CH-1, MH 5/4, MH 4/5, MH 2/6, MH2/7, EF-04 , EK-24 , BD-01, KP-11, KP-12, DH-66 -14 , DH-67-15, BO-1, TL-2/11, TL-6/3, and TL-11/2
China	GA-63, HL 2-13, HL2-21, FL-30 and CP63-36
Tanzania	AC-4, AZA-2
Mozambique	V.12, AD-IV.1,CP76 11.3 and CP9 XII.8
Sri Lanka	WUCC-05, WUCC-08, WUCC-09, WUCC-13, WUCC-19 and WUCC-21
India	Selection-2, Bhaskara, Ullal-1 to Ullal-4 , UN-50, Anakkayam-1, Madakkathara-1, Madakkathara-2, K-22-1, Kanaka, Dhana, Priyanka, Amrutha, Damodar, Chintamani-1 , Chintamani-2, Goa-1, Goa-2, Vengurla-1 to Vengurla-9, BPP-1 to BPP-6, BPP-8,VRI-1, VRI-2, VRI-3 , VRI (Cw) 5, Bhubaneswar-1, Jagannath , Balabhadra, Jhargram-1 and BidhanJhargram-2.

Canopy management

Development of ideal canopy architecture and to realize potential nut yield is imperative as cashew also respond to pruning. Besides, removal of dead wood and criss-cross branches, leader shoot pruning done in July and August helps in improving the nut yield. This results in production of more lateral shoots and bisexual flowers per panicle. The development of plant canopy architecture starts from training of young cashew plants and should be done in mature trees by pruning of leaders/laterals as per the need. Pruning in cashew trees is highly skill-oriented job and only selective branches should be pruned in order to promote more fruiting laterals. The requirement of pruning largely depends upon variety, plant vigour, planting density, growing conditions, rootstock used, growing purpose etc. So far not much works have been done in this direction. Due consideration should be given about time of pruning, as flushing pattern varies with variety and growing regions. Normally, pruning is done after harvesting of nuts. Based on climatic conditions and varieties, flowering and harvesting seasons vary in different cashew growing countries (Table 2.4).

Table 2.4. Flowering and fruiting season of cashew in different countries

Country	Flowering season	Harvesting season
Australia	August-October	October-January
Brazil	August-November	October-February
India	December-March	February-May
Nigeria	November-December	February-May
Tanzania	August-October	October-December
Vietnam	December-February	February-April

In Brazil, pruning is generally limited to removing sick, dry and poorly growing branches. The transplants should remain upright and lateral shoots should be removed up to 1 m height, leaving three or four of the most robust branches, aiming to obtain plants with good crown architecture. It is recommended to remove the flowers during the first year so that plants grow more vigorously. Removing lower branches should be minimized because fruits are borne at the edges of branches, occupying lower two-thirds of the plant (Oliveira and Bandeira, 2002). In Vietnam, while creating canopy, often buds are pruned on the side at 60 cm from the ground. When cashew tree attains 0.8-1 m height, the top is cut by leaving 3 or 4 buds so as to develop balanced tree canopy. When tree has wide canopy, weak buds near the trunk are eliminated. It is also pertinent that pruned branches must not be over 15% of the total tree branches.

In Australia, early canopy management aims to start branching of trunk about 100 cm above the ground. This allows for access and a 'line of sight' for mechanical harvesting by maintaining the canopy to a high, conical or inverted 'vase' shape. Pruning gives several branches, which in turn give a large number of growing points. It maximizes branching and increases sites for future nut development. In bearing plantations, trees are pruned after the last nuts have been collected and fertilizers are applied. This is commonly in November in hot coastal locations and December in cooler inland and highland locations. Proper pruning also prevents the canopies of adjacent trees from meeting and becoming intertwined along the row and across the row. Assuming a tree spacing of 8 m between rows and 6 m within the row, this spacing should allow for 4-6 years' growth before pruning is needed. During this time, active terminals are produced and farm equipment is able to move easily along the rows. Alternatively, pruning along the top and sides of the cashew row (2-3 m from the tree line) would produce a hedge effect. Height of pruning should be governed by the reach of equipment, particularly for spraying equipment's. A large number of flushing terminals favour insect attack. Injudicious use of nitrogen causes continued flowering and fruiting delays the start of next vegetative growth phase, resulting in delay of pruning and other management operations. High-densities planting (6 m × 6 m or 8 m × 3 m) hasten full light interception and brings forward the need for canopy management to an earlier age. Whereas, wider planting (8 m × 8 m or 10 m × 10 m) delays attainment of full light interception and need for canopy management.

In China, to achieve better fruit-setting, young cashew trees are often trained to provide a better tree form. In mature trees, pruning is carried out to eliminate overcrowding and shading or to remove weak, entangled, dead branches infested with diseases or pests. Non-bearing wood is removed to promote vigorous growth of active branches that bear regularly. Training and pruning of mature trees is regularly carried out to remove excess wood.

Since yield (per tree and per unit area) declines once overlapping of the adjacent canopies occurs. There has to be a compromise between high initial yield at a close spacing (6 m × 6 m; 278 trees/ha) and high yields later in the life of the orchard at a wide spacing (up to 15 m × 15 m; 44 trees/ha). In most locations in Tanzania, the recommended spacing is 12 m× 12 m (59 trees/ha) since this allows intercropping during early years. Where trees grow vigorously, a spacing of 15 m × 15 m is preferred. Although high-density planting (9 m× 9 m) followed by thinning may be appropriate for intensive cultivation, it is not considered to be suitable for small holders.

Integrated nutrient management

The information on integrated nutrient management (INM) in cashew is very meager. In fact, manures and fertilizers account for 20-30% of the total cost of production in cashew. Further, fertilizer-use efficiency is low due to various losses and soil fixation. Moreover, due to extensive root system, its plants can draw nutrients from large volumes of soil, and as a result it can perform reasonably well on poor soils where other crops fail to do so. When cultivating cashew on soils containing all the minerals required, but only available in low quantities per unit of area, the trees may not react strongly to fertilizer applications, and this may have led to the rather general, but wrong opinion in the 1960s, that fertilizing of cashew is uneconomical (Ohler, 1979). Cashew is grown in many soil types of the savanna zones of Nigeria. It is less selective and demanding in terms of soil types and fertility requirements compared to other plantation crops (Ohler, 1979). The vast majority of cashew trees grown in East and West Africa receive no or very little fertilizer. However, they are reasonably well-spaced which allows the extensive root system to absorb nutrients from a large volume of soil and the deep penetrating tap root is able to extract water and nutrients from sub-soil layers not accessible to most plants. Integrated nutrient management (INM) practices involving application of chemical fertilizers, organic manures/green manuring and biofertilizers are essential to maintain and enhance soil quality for sustainable production. Recycling of cashew litter, use of microbial inoculants for mobilizing nutrients from slowly available soil pools, foliar nutrient spray and plant growth promoters can enhance its productivity. More attention needs to be given for recycling of recyclable cashew biomass, *in-situ* compost production, green manuring etc. The inoculation of *Azospirillum* sp. with compost of organically recyclable biomass available in cashew orchard produce significantly higher nut yield and net return than the nutrients applied in inorganic form only. Green leaf manuring with *Glyricidia* and *Sesbania* in cashew results in higher nut yield and improvement in soil nutrient content (Yadukumar *et al.,* 2008). But INM in various cashew cropping systems is warranted to maximize productivity. Inadequate and imbalanced use of inorganic fertilizers with little or no use of organic manures and biofertilizers have made the cashew soils not only deficient in certain nutrients, but also deteriorated the soil health. Under these circumstances, integrated use of organic manures, inorganic fertilizers and biofertilizers assumes great importance for sustainable production and maintaining soil health. The organic manures and biofertilizers not only supply essential plant nutrients, but also improve soil physical, chemical and biological health.

Wahid *et al.* (1993) indicated that cashew trees are surface feeders with 50% of the root activity being confined to the top 15 cm of soil and about 72% of root activity is found within a 2 m radius from the tree trunk. Thus, application of fertilizers within a radius of 2 m from the main stem results in efficient utilization of applied nutrients. During the 1^{st}, 2^{nd}, 3^{rd}, 4^{th} and 5^{th} year of planting $1/5^{th}$, $2/5^{th}$, $3/5^{th}$, $4/5^{th}$ and 5^{th} year onwards full quantity is to be applied. George *et al.* (1984) standardized the methods of fertilizer application to cashew and reported that application of N, P and K fertilizers in two circular trenches (1.5 m and 3 m from the trunk) for sandy soils, a single trench method (25 cm wide and 15 cm deep circular trench at 3 m from the trunk) for sloping ground, and the band method (in a circular band 1.5-3 m from the trunk + soil incorporation) for flat ground are best suited. The root activity of cashew in relation to phenological phases studied by Beena *et al.* (1995) employing 32P soil injection technique reported that 'flushing and early flowering phase (September-December)' is most appropriate time for fertilizer application in cashew. The annual dose should be applied in two split doses. First split dose at the onset of pre-monsoon, while second one during post-monsoon period when soil moisture condition is optimum should be applied. If only one application is given, it should be in the post-monsoon period when enough moisture is available.

Since long back, Indian farmers consider cashew a drought tolerant crop, which can grow in poor soils, with little management. In fact, cashew thrives on a wide variety of soils with a pH range of 5.5-7.5. Soils with pH of more than 8 are not suitable for its commercial cultivation. In India, cashew is mostly grown on laterite, red soils and coastal sands in Andhra Pradesh, Goa, Karnataka, Kerala, Maharashtra, Tamil Nadu, Odisha and West Bengal. To a limited extent, it is also grown on black soils in Tamil Nadu and Andhra Pradesh. The lower status of nutrients in cashew growing belt is the main factor for its low productivity in India. Further, limited or no use of fertilizers and organic manures leading to multiple nutrient deficiencies is other dimension associated with its cultivation. Majority of cashew growing soils in India are lateritic, red and coastal sands which are acidic in nature and poor in fertility. The runoff and soil erosion are very high in steep slopes of west coast. The deficiencies of Mg, Zn, B and Mo are on the rise in cashew growing soils. There is a tremendous positive response to regular application of fertilizers and improved management practices which results in two to three fold increases in nut yield. By and large majority of farmers do not use fertilizers and thus the nutrients being mined by the plants are not replenished.

Major nutrient requirement of cashew plants demands more liberal application of N followed by K, while P is needed in comparatively lesser quantity. Nitrogen and P are most important nutrients during the pre-bearing stage, but at bearing stage, K together with N is important. Application of fertilizers, dosage and time and its schedule under different agroclimatic zones has been standardized. The dose of N 200: P 75: K 100 g/tree/year (Ghosh and Bose, 1986), N 250: P 125: K 125 g/tree/year (Subramanian and Harris, 1995) and N 500: P 100: K 250 g/tree/year (Mahanthesh *et al.,* 2006), is optimum for higher nut yield. Based on the initial fertility status of soil, nutrient dose may vary from location to location. About 10-15 kg farmyard manure (FYM)/plant/year is recommended in addition to primary nutrients (N, P and K). Considering total uptake of nutrients in 30-year-old trees in coastal Karnataka, nutrients to be applied is 2.03 kg N, 0.592 kg P_2O_5 and 0.625kg K_2O/tree, whereas in coastal Kerala, it is 2.03 kg N, 0.669 kg P_2O_5 and 0.75 kg to nil K_2O/tree. In Maharashtra it is 1.081 kg N to nil N, 0.748 to 0.665 kg P_2O_5/tree and 0.96 kg to nil K_2O/tree. In Andhra Pradesh, it is 2.45-2.35 kg N, 0.73-0.714 kg P_2O_5 and 1.143 kg K_2O/tree (Yadukumar, 2001). Studies conducted at DCR, Puttur indicates that application of 500 g N and 125 g each of P and K and 10 kg poultry manure/tree/year under normal planting density (10 m × 5 m; 200 trees/ha) and 250 g N and 50 g each of P and K and 10 kg poultry manure/tree/year under high density planting system (4 m × 4 m; 625 trees/ha) is found superior in terms of higher nut yield for rainfed cashew in Karnataka. In high-density planting system of cashew, fertilizer recommended is reasonable up to 80-100% canopy coverage which is normally achieved during initial 6 - 8 years after planting. Aftercertainstage, reduction in recommended doses of fertilizers per plant may be necessary due to nutrient build-up in soil with the deposit of cashew biomass fall out. It has been estimated that by systematic recycling of all the waste biomass produced by cashew, it is possible to get back 20.7kg N, 10.5 kg P_2O_5 and 30.8 kg K_2O/ha/year (Yadukumar *et al.,* 2003). Quantitative estimation of soil fertility and fertilizer recommendations for cashew was developed by Salam *et al.* (2008) using MS Excel to estimate the fertilizer N, P and K requirement of cashew for different soil fertility regimes, yield levels and tree ages. This model demands three inputs namely available N content in soil (kg/ha), expected yield level (kg/tree) and age of tree for formulating site-specific fertilizer requirement of cashew.

Very little work has been done on foliar feeding of cashew. Foliar sprays of nutrients (urea 2-4%; diammonium phosphate (DAP) 1%, orthophosphoric acid, $ZnSO_4$ 4%, copper 0.3-0.6%) at the emergence of flush, panicle initiation and fruit setting stages ensure better fruit setting and also enhance nut yield in cashew (Ankaiah and Rao, 1987; Sapkal, 2000). Yellow leaf spot in low soil pH (4.5-5.0) could be corrected by foliar spraying of molybdenum (Mo) salts (Subbaiah *et al.*, 1986). In zinc deficient soils, foliar spray of Zn (2 kg $ZnSO_4$+ 1 kg lime in 450 litres of water/ha) showed quick response (Mandal, 1992). Foliar spray of Urea (3%) + H_3PO_4 (0.5%) + K_2SO_4 (1%) at flushing, flowering and nut development stage increased nut yield by 16.1% while $ZnSO_4$ (0.5%) + solubar (0.1%) + Mg SO_4 (0.5%) had increased nut yield by 30.5% under coastal region of south Karnataka.

Organic farming

Majority of the cashew produced in India is organic by default with little use of naturally decomposed cut weed biomass and cashew leaf litter deposited in the orchard. Hence, there is a vast potential of bringing those areas under organic farming practices to take advantage of global demand for organically produced cashew. Cashew can organically be grown in Noth-Eastern-Hill region, which can fetch higher price in the international market. The major constraint in adopting organic farming in cashew is the problem of insect pests, especially tea mosquito bug (TMB) as there are no proper biocontrol strategy has been developed to control this pest. However, for nutrition of cashew, there is a good potential of replenishment of inorganic sources by organic sources through recycling of available biomass. The availability of leaf litter from cashew plantations of 10-40 years old varied from 1.38-5.20 tonne/ha (Guruprasad *et al.*, 2007). About 5.5 t of available cashew biomass waste/ha can be converted into 3.5 t of compost or vermicompost and helps in meeting nutrient requirement to cashew by 50% (Yadukumar and Nandan, 2005). The two years mean value for total dry weight of canopy biomass fall out is 55% as leaves, 27.3% as apples, 5.6% as kernels and 12.1% as shells. The major portion of N, P, K, Ca, and Mg of canopy biomass come from leaves, branches, kernels and apples. The amounts of nutrient elements recycled in canopy fall out may partially meet the nutrient requirements of cashew. Yadukumar and Nandan (2005) determined the nutrient composition of organically recyclable biomass compost with 20% cowdung slurry as N as 0.91-1.5%, available P as 0.34-0.6%, K as 0.39-0.46%. About 15.5–37.7% of total requirements of macronutrients are recycled from canopy biomass fallout of leaves, cashew apples and flowers from six-year-old cashew trees in Australia (Richards, 1993). In decomposed leaf litter, organic carbon content ranged from 0.7-1.61%, total N from 0.18-0.25%, available P_2O_5 from 0.13-0.228% and K_2O from 0.29-0.40% (Kumar and Mahabaleshwar Hegde, 1999). The micronutrient concentrations (Zn, Mn, Cu and Fe) are higher in litter fall compared to the green leaves in cashew (Isaac and Nair, 2002).

Application of biofertilizers enhance soil fertility and productivity by fixing atmosphere N, mobilizing sparingly soluble P and by facilitating the release of nutrients through decomposition of leaf litter. Inoculants of *Azotobacter* and

Azospirillum either sole or in combination improve N nutrition of plants through biological nitrogen fixation and also secretion of some growth-promoting substances which affect the growth, nutrition and microbial activity in the rhizosphere (Zayed, 1999). The phosphate-solubilizing microorganisms (*Pseudomonas* sp.) play an important role in conversion of unavailable inorganic P (Ca-P, Fe-P and Al-P) into available in organic P forms through secretion of organic acids and enzymes. The Arbuscular mycorrhizal fungi (AMF) on the other hand are ubiquitous in soils throughout the world and play an important role in affecting the plant growth through mobilization of nutrients.

Use of plant growth regulators

Foliar spraying of growth regulators, Planofix, Nutron, IAA, IBA, NAA, 2,4-D and ethrel are effective in increasing the total number of flowers, hermaphrodite flowers, sex ratio, fruit and nut yield per panicle, and also improve physicochemical composition of apples and nuts (Ghosh, 1988; Singh *et al.,* 1992). At Directorate of Cashew Research, Puttur, soil drenching with paclobutrazol in cashew variety Ullal-3, showed direct effect on canopy vigour and improved fruiting. The spraying of ethrel @ 50 ppm increased number of fruit setting, fruit retention, nut weight and nut yield in cultivar Bhaskara (Lakshmipathi *et al.*, 2014). The study conducted at Nigeria also suggests that cashew yield could be increased by exogenous foliar application of GA3 at 50-100 ppm at pre-blooming stage (Aliyu *et al.,* 2011).

Water management

No precise data is available on status of irrigated area under cashew but most the cashew plantations are under rainfed conditions in the world. The situation is not different in Indian cashew orchard also. In homesteads, it is advisable to give some supplementary irrigation from January to March (flowering and fruit setting stages). A water application of about 200 litres/tree every fortnight (equivalent to 14 litres/day) had been found to double cashew yield in trials conducted at Directorate of Cashew Research, Puttur (Karnataka). In sandy tracts of East coast, although frequency and quantity of water applied varies, trees are watered during the summer months (Rao, 1998).

In north-eastern Brazil, cashew tree has a period of rapid vegetative growth, followed by a quiescent stage and then a series of pre-floral vegetative flushes. Thereafter, flowering, fruit development and maturation follow. The major period of vegetative growth coincides with rainy season, and the flowering and fruiting phases with dry season (Grundon, 1999). When well supplied with water and nutrients, cashew trees can continue to flower throughout the year (although excess rainfall can prevent nut setting), but actual duration of flowering depends on location. As in south-eastern Vietnam, flowering and fruit setting last for about two-and-a-half months from December to February. Since this is the dry season, irrigation is recommended at this time (Peng *et al.*, 2008). In tropical Australia, flowering continues over a four-month period coinciding with dry season (Grundon, 1999). Water availability can also influence the relative number of male and hermaphrodite flowers produced. For example, in irrigation experiment in the Northern Territory of Australia, irrigated treatment had more male flowers per panicle, in 3 to 7 weeks of flowering phase, than unirrigated control treatment (Schaper *et al.*, 1996).

The development of a nut takes about two months from pollination. In south-eastern Vietnam, harvesting extends over a period of 10 to 12 weeks, from mid-February to end of dry season in April. In the absence of pest and disease problems, poor fruit setting and a high rate of premature fruit abscission can limit nut yield for reasons not yet fully understood, but competition for water and nutrients/ assimilates may play a major role. In north-eastern Brazil, where there are two well-defined seasons, a rainy season (mean annual rainfall is 1,640 mm) and a dry season that lasts from April to December, selection of early-dwarf cashew clones were compared in terms of nut and cashew apple yield over the six years (1990/1991–1995/1996). Initially, tree spacing was 6 m × 3 m (555 trees/ha), but due to mutual shading by the end of the third year, the plant density was reduced to 278 trees/ha.The trees were drip irrigated daily during the dry season with varying quantities of water depending on the year/stage of crop development. It was a sandy soil and good yields were already being harvested in the second year. Over five seasons (1991/1992-1995/1996), average number of nut-in-shell (and pedicels) harvested annually was around 2,50,000/ha; yield of nut-in-shell was about 1,600 kg/ha (sun or oven dried), and that of pedicels was close to 17,000 kg/ha (fresh weight basis).

The results of a long-term (1996–2002) irrigation experiment conducted in the north-east of Brazil were reported by Oliveira *et al.* (2006). The climate predominantly is characterized by a dry season lasting from July to December. The average annual rainfall is about 1,000 mm but is very variable (from 600 to 1,500 mm during seven years of experiment). The experiment compared the responses of three dwarf genotypes (CCP 09, CCP 76 and CCP 1001), grafted on-to seedlings and spaced at 7 m × 7 m to three irrigation regimes, together with an unirrigated control treatment. The soil was described as a deep, sandy red-yellow podzol. Three irrigation frequencies were compared, beginning when the trees were two years old. Trees were irrigated when the cumulative evaporation from a USWB Class A pan reached 10 mm (on average over seven years this equated to daily irrigation), 30 mm (three-day intervals) and 50 mm (five-day intervals). In order to maintain soil water potential above 20 kPa in the top 0–0.5 m of root zone in wettest (10 mm) treatment, adjustments were made each month based on tensiometer readings. All three irrigation treatments received the same total amount of water over a season. For fully developed trees, this totaled 400-500 mm each year. Water (with fertilizer) was applied through a single micro-sprinkler per tree. Unirrigated treatments received the same total amount of fertilizer. The three clones differed in their responses to irrigation. Beginning in the fourth year after planting, irrigation increased yields of 'nut-in-shell' for two of the cultivars (CCP 09 and CCP 76). Over the seven years, this increase averaged +77%, namely from 1,054 kg/ha (unirrigated) to 1,872 kg/ha (mean for all three irrigated treatments). For cultivar CCP 1001, the yields from rainfed and irrigated treatments were statistically similar, 1,627 kg/ha (unirrigated) and 1,848 kg/ha (irrigated). The water productivity (for 'nut-in-shell' and irrigation) averaged over seven years for two responsive cultivars equates to about 2.6 kg/ha/mm (0.26 kg m^{-3}). The yield increase was the result of an increase in number of nuts. The individual nut weight was not affected by the irrigation treatments. There was evidence of alternate bearing, with good years followed by less good years, regardless of the treatment combination.

In northern Australia, Schaper *et al.* (1996) compared the yield responses of cashew (cv. BLA 39-4) to three irrigation regimes over two years (1988 and 1989). The grafts had been planted in 1986, at a 7 m × 7 m spacing, in a deep (>4 m), sandy soil with a low water holding capacity (73 mm/m). For two years after planting, all the trees were irrigated (with under-tree micro-sprinklers) at the rate of 40 mm/week. During 1988, different treatments were introduced, namely irrigated throughout the dry season at 43 mm/week in 1988 and at 64 mm/week in 1989; irrigated weekly from flowering to harvest at the same two rates; and an unirrigated control. Nut-in-shell yields were similar in both years for all three treatments, averaging 4.23 kg/tree, but the components of yield differed. Thus, there were 19% more nuts in unirrigated trees (1,133 nuts/tree) compared with both irrigated treatments (954 nuts $tree^{-1}$)– as a result of having fewer staminate flowers. But irrigation increased individual nut weight from 3.7 to 4.5 g. Irrigation also increased kernel yield (from 1.16 to 1.36 kg/tree), kernel weight (1.04-1.49 g), and kernel recovery (from 27 to 32%). Thus, it is concluded that, despite low yields from these three-year-old trees, irrigation of mature cashew orchards was justified (for greater kernel yield and better quality) in tropical regions of northern Australia, but that it was not necessary to begin irrigation before the trees flowered.

In north Queensland, where the dry season lasts from April to December, there was a highly significant linear relation between nut yield after drying (recorded over three years of the experiment) and water applied (irrigation plus rainfall from January to September: range covered=25–50 m^3). Yield was expressed on a crop surface area basis to allow for trees of different sizes. Extrapolation of the model Y= X106(±18)+5.77(±0.5) X m (n=90; r^2=0.60; where Y=yield of nuts (gm/m^2 canopy surface area and X= water applied in m^3/tree) suggests that 18.4 m^3 of water is required before a tree yields any nuts. Then for every cubic metre of irrigation (or rain) applied above this base level, there is a yield increase of about 6 g/m^2. Kernel recovery averaged about 33% across all treatment combinations (Blaikie *et al.*, 2001). Richards (1993) clearly stated that large commercial yields and good kernel recovery rates require adequate water and nutrient inputs. Irrigation can be restricted to the period beginning with the commencement of flowering to harvesting. Observations made in Australia indicate that the water table should not be closer to the surface than about 1.5 m (Grundon, 1999).

The experiment in north Queensland indicated that the productivity of drip irrigation was marginally (5%) greater than that of sprinklers. Each dripper or pair of drippers wetted an area of soil of about 1 m^2, whereas the sprinkler wetted 28 m^2. In Binh Phuoc province of Vietnam, advice is to apply 100 litres/tree once every 7-10 days during flowering and 200 litre/tree once every 15-20 days during nut setting. The recommendations are based on the results of an irrigation experiment with six-year-old trees (Peng *et al.*, 2008).

Soil and water conservation practices

Cashew is generally planted on degraded lands, where soil erosion, moisture deficit and poor nutrient availability are common phenomena. In India, where cashew is grown on the steep slopes of the west coast region, water stress occurs during February-May despite an annual rainfall of 3,000–3,500 mm (Rejani and Yadukumar, 2010). The period of water stress occurs when its crop is in flowering and fruit setting stages of development. A soil water deficit of up to 300 mm can occur at this time. A number of soil and water conservation techniques were evaluated on a very steep (up to 40%) eroded slope at Puttur (Karnataka) over a seven-year period from planting in 2003 up to 2010. Yield and other growth parameters were recorded for five years (2005/2006 to 2009/2010). The two most effective conservation techniques were a 'modified crescent bund' and 'coconut husk burial' in trenches. These both reduced runoff from 37% of the annual rainfall (mean total 3,011 mm) in the control to 20 and 22%, respectively. The amount of eroded soil was reduced by about 50% from 9.7 tonnes/ha/annum (control) to 4.6 and 4.8 tonnes/ha/annum in the same two conservation treatments. There was also a yield benefit: total yield of 'nut-in–shell' over the five years was increased by about 33%. Now other cashew growing countries also started basin shaping, field bunding, terrace planting, mulching etc.

Intercropping in cashew orchard

A large number of crops can be grown in cashew orchard at pre-bearing and bearing stages based on soil and climatic conditions. In India, cowpea, brinjal, okra, tuber crops and medicinal plants can be grown successfully at pre-bearing stage, while pine apple, elephant foot yam, colocasia, turmeric etc. at bearing stage in cashew orchards. In China, main covercrops include *Calopogonium mucunoides*, *Macrophyllum atropurpureius* cv. Siratro, pasture grasses and intercrops such as peanut, sweet potato and beans. In recent years, cashew is being intercropped in some areas with melons (watermelon and sweet melon) and vegetables. In Sri Lanka, pineapple, papaya, pomegranate and coconut are also used as semi-perennial and perennial intercrops in some areas. The common annuals grown in cashew plantations are legumes (cowpea, blackgram, and greengram), oil crops (sesame and groundnut) and condiments such as hot pepper and onion. Most farmers in Vietnam, who own a larger plot of cashew, often intercrop with different food crops such as beans, maize and cassava. In Nigeria, cocoa, oil palm, rubber or kola are planted in the Southern states, while cereals and pulses are planted beneath the cashew orchards in Northern states (Aliyu and Hammed, 2008). The intercropping of cashew in association with maize, cassava and plantain has proved useful in reducing weed incidence in cashew plots. In Ghana, cowpea, melons, maize, soghum, groundnut, yam, cassava etc. are major crops grown with cashew nut. Whereas in Brazil, native ginger grass (*Paspalum maritimum*) and African guinea grass (*Panicum maximum*) have proven to be successful on cashew plantations. On very small farms, coconut + cashew, cashew +citrus and cashew + banana and coconut inter-planted are also seen.

Pest management

The cashew is affected with a large number of pests including sucking pests, borer, thrips, mites etc. but tea mosquito bug (TMB) and cashew stem and root borer (CSRB) are most common and serious pests. The TMB (*Helopeltis* spp.) is serious pests of many economically important crops. In Southern India, the outbreak of *H. theivora* Wat. was reported around 1920 on tea (Rao, 1970), whereas damage of *H. antonii* was first reported on neem and guava (Rao, 1915) and its damage on other crops viz., cashew (Ayyar, 1932), cocoa and cinchona (Fletcher, 1914), drumstick (Pillai *et al.,* 1979) and ber (Sundararaju, 1996) was recorded subsequently. The record of *H. bradyi* Wat. occurring on cocoa, guava and cashew was brought out by Stonedahl (1991) and Sundararaju (1996). The *Helopeltis* has palaeotropical distribution extending from West Africa to New Guinea and Northern Australia. Out of 41 recognized species, 26 are restricted to Africa and 15 are prevalent in Asia and Pacific region. The *Helopeltis antonii* is only confined to south and east India, Andaman Islands and Sri Lanka, whereas *H. bradyi* is confined to south India, Sri Lanka, Indonesia and Malaysia (Stonedahl, 1991; Sundararaju, 1996) and *H. theivora* in south India, north east India, Sri Lanka and south-east Asia. Among three species of *Helopeltis*, viz. *H. antonii, H. bradyi* and *H. theivora* recorded in India, *H. antonii* is the dominant species (Sundararaju and Bakthavatsalam, 1994).

The population of TMB reaches its peak during flushing, flowering and fruiting season in cashew, i.e. from November to February. Both nymphs and adults suck sap from tender shoots and leaves, floral branches and from developing nuts and apples by making a number of feeding lesions. During outbreak situation, entire flush dries up and the trees present a scorched appearance. This pest has got potential to cause cent per cent loss in yield, though on an average yield loss of about 30%. Varietal screening suggested cashew varieties, viz. Dhana and Bhaskara were moderately susceptible to TMB infestation. The female sex pheromone blend may be useful for TMB control and management in future (Sachin *et al.*, 2008). The insecticides tested against TMB showed that sequential sprays of monocrotophos, λ-cyhalothrin and carbaryl registered the least per cent TMB damage and higher nut yield (Naik and Chakravarthy, 2013). In endemic areas, it is appropriate to spray three times with any of these insecticides during most vulnerable periods of crop coinciding with flushing, flowering and fruiting stages. Although, cashew is an insect pollinated crop, spraying of these insecticides during flowering season does not influence fruit setting.

Besides TMB, widespread incidence of cashew stem and root borers (CSRB) is a major impediment in achieving the potential cashew nut yield. The major species of cashew stem and root borers reported in India are: *Plocaederus ferrugineus* Linn., *P. obesus* Gahan and *Batoceraru fomaculata* De Geer. These lead to death of the infested cashew trees and constitute a core hindrance in maintaining the optimum tree population in all cashew growing tracts in India. The severe incidence of CSRB has been documented from Sri Lanka, Tanzania and China. Occurrence of CSRB in varying levels has been reported by Duffy (1968) from Bangladesh, Burma, Hawaii, Hong Kong, India, Sri Lanka, Taiwan, Thailand and Vietnam. In Nigeria, Asogwa, *et al.* (2008, 2009a) reported that

Plocaederus ferrugineus infested 10.0-35.0% trees resulting in 2.0-4.0% tree annual mortality and from Vietnam (Krishnamurthy, 2007) reported poor tree stand due to infestation by this pest. The emergence period of CSRB as observed by Beeson and Bhatia (1939); Beeson (1941) and Duffy (1968) was April-July and beetles occur quiescent in the cocoon, as early as November. A laboratory rearing technique for the field collected *P. ferrugineus* and *P. obesus* larvae was standardized by Raviprasad and Bhat (1998) on cashew bark.

Several pest management strategies including chemical, mechanical, cultural and biological methods were evaluated against CSRB. Pillai *et al.* (1976) reported that mechanical removal of pest stages of *P. ferrugenius* and maintaining field hygiene reduced the pest incidence. Misra and Basuchoudhari (1985) reported considerable reduction of *P. ferrugineus* infestation through field hygiene. Ayyanna and Ramadevi (1986) reported that, physical removal of CSRB larvae followed by application of BHC 10% (banned now) + 150 g phorate10G applied to soil and swabbing the infested tree trunk using monochrotophos (0.05%) were effective plant protection practices for the management of CSRB. Punnaiah and Deviprasad (1995) reported that infested trees from which CSRB larvae were physically extracted followed by insecticidal treatments, recorded significantly lesser damage. Post extraction prophylaxis (PEP) trials for management of CSRB were conducted in cashew plantations at ICR-DCR, Puttur using chlorpyriphos (0.2%), lindane (0.2%) and monocrotophos (0.2%) and with entomopathogenic fungal spore suspensions of *Metarhizium anisopliae*, which indicated that chlorpyriphos (0.2%) was most effective pesticide in preventing loss of trees due to CSRB. Sundararaju (2002) and Bhat *et al.* (2002) reported effective management of CSRB by adopting IPM like phytosanitation, surveillance, mechanical control followed by post treatment prophylaxis with carbaryl (1.0%). Treatment with mud slurry having carbaryl (0.2%) resulted in lowest mean cumulative percentage of infested trees (6.0) and highest recovery (38.4%) of treated trees after 4 rounds of treatment (Mohapatra, 2004).

Phytosanitation was adopted by uprooting the trees beyond recovery (i.e. >50% bark circumference damage and/or having yellowing of leaf canopy). Trials on post treatment prophylaxis (PTP) indicated that, only trees with initial stages of infestation (<25% bark circumference damage) could recover fully on treatment with insecticide chlorpyriphos (0.2%). Bhat and Raviprasad (1994) reported pathogenecity of three species of entomopathogenic fungi, *Beauveria bassiana*, *B. brogniartii*, and *Metarrhizium anisopliae* against CSRB. The *Beauveria bassiana* induced 90% mortality on direct topical application, while *Beauveria brogniartii* and *Metarhizium anisopliae* induced about 50 and 40% mortality of the CSRB larvae.

Processing of cashewnut

India is major player in processing of raw cashew nuts. The harvested nuts are dried under sun for 2-3 days before processing. If nuts are not dried and stored, it leads to fungal spoilage, resulting in poor quality kernels. Fungi such as *Gonatobotryam*, *Alternaria* sp., *Verticuillium* sp., and many species of *Aspergillus* have been isolated from stored cashewnuts. Varietal variations in colour and size of nuts do exist and weight varies between 5 and 15 g. Maximum permissible moisture content of raw cashew nuts is 8.7-9.1%. The moisture content of whole nut and kernel could be predicted from that of shell with more than 99% accuracy. A higher kernel:shell weight ratio has been shown to be inversely proportional to moisture content. Nuts exposed to higher RH (>75%) lead to mould infection as it picks up moisture from the atmosphere till they attain equilibrium. Gunny bag storage of 80 kg capacity is predominant in all over the world and it has been shown that storage of raw nuts with a moisture content of about 8% for 12 months at ambient temperature ensure processing or biochemical quality.

Cashew nuts have a hard outer shell and a leathery inner coating and both must be removed to obtain the kernels. The outer shell contains a caustic liquid (cashew nut shell liquid) that blisters human skin and spoils the kernel on contact. Removing the shell and skin without breaking or contaminating the kernel is difficult and has been most successfully done manually by skilled workers. Efforts to mechanize the process have generally been unprofitable compared with low-wage manual labour. Value addition through manual processing appears to be high and generates large employment opportunities. Prospects of developing a processing system with balanced approach on manual and mechanized cashew processing appears to be promising. Extraction of white whole kernels which fetches premium price at consumer level is the ultimate aim in cashewnut processing. It is highly difficult to recover cashew kernels in whole form, therefore certain unit operations are essential to be employed, viz. roasting or steaming, shelling, kernel drying, peeling, grading and packaging. Three different methods are followed to condition the raw cashewnuts, viz. drum roasting, oil bath roasting and steam boiling to make it amenable for mechanical or manual opening of shell to extract kernel in whole form. Majority of processing units in India utilizes semi-mechanized sheller, i.e. hand-cum-pedal operated machine to split the shell, whereas automatic shelling machine is deployed in Brazil, Vietnam and certain African countries. Either splitting irrespective of mode of operation, blades designed to suit to contour of nuts either split or twist open shells. Drying of unpeeled kernels in convective mode eases the process of peeling. Steam assisted cashew kernel dryer is latest one ensures higher quantity of white whole kernel recovery. Manual peeling results in appreciable quantity of whole kernels compared to mechanical methods. High performance, energy efficient and low cost peeling machine is of utmost important due to labour shortage.

Cashew, an internationally traded commodity, has different quality specifications followed by various participants of the trade. These quality standards for kernels are as fixed by major producers or as established by major importers. Efforts are on to establish global standards for cashew kernels. However, conventional practices are still followed. Depending on country where it is processed, it is graded according to standards prescribed by either Association of Food Industries (AFI), Bureau of Indian Standards (BIS), Brazilian Cashew Industry (BCI), Cashew Export Promotion Council of India (CEPCI) or United Nations Economic Commission for Europe (UNECE). Flexi or pouch packaging, vita packaging or tin container packaging and Moulded Vacuum Packaging (MVP) are other types of packaging technique widely adopted all over the world for domestic or export market.

Besides cashew kernel, cashew apples are important byproduct of cashew industry. These fruits are not utilized to the fullest extent in cashew growing countries. Research works conducted in several countries has revealed the potential for utilizing cashew apple for production of nutritious and refreshing products. But most often the technology has been confined to laboratories and reports on commercial exploitation of cashew apple is very limited. Cashew apple contains astringent and acrid principles which produce biting sensation on the tongue and throat when eaten in its natural form. Fruits are highly pereshable in nature. These factors together with difficulties experienced in collection of fruits have become barriers towards commercial utilization of nutritious fruit. However, it is now possible to remove astringent principles and then utilize the fruit for conversion in to several edible products. These products include clarified and cloudy cashew apple juice, blended juice, juice concentrate and pulp based products like jam, jelly, marmalade, chutney, candy, pickle etc. Besides, canning of ripe cashew apple in syrup and raw cashew apple in brine ensures long-term storage. Cashew apple residue left after juice extraction accounts for 30-40% of whole fruit. Methoxyl pectin could be recovered from dried cashew apple powder and thereafter it can be used as cattle or pig or poultry feed. Cashew apple residue could be effectively utilized for the production of vermicompost and also for the generation of biogas. Fermented cashew apple juice can be used as a raw material for preparation of wine, vinegar, liquor and alcohol. In Goa (India), Ghana and Brazil are the few cashew growing regions, where cashew apples are utilized exclusively for the preparation of liquor by distillation. Cashew wine is a product of fermentation of hexose sugar of cashew apple juice by intact yeast cells to form ethyl alcohol and carbon dioxide. The Kerala Agricultural University, Thrisur (India) has developed methods for producing four grades of wines such as soft, medium, hard and sweet based on alcohol percentage and sweetness. Bio-ethanol could also be extracted from cashew apples, but its cost effectiveness should be accounted for commercialization.

The pericap of cashewnut consists of a strong vesicant liquid known as cashew nut shell liquid (CNSL). It is often considered as the better and cheaper material for unsaturated phenols. The CNSL has innumerable applications in polymer-based industries such as friction linings, paints and varnishes, laminating resins, rubber compounding resins, cashew cements, polyurethane based polymers, surfactants, epoxy resins, foundry chemicals and intermediates for chemical industry. A number of anticorrosive paint formulations for ship bottoms have been made by the Regional Research Laboratory, Hyderabad and Central Institute of Fisheries Technology, Cochin. Lacquers developed from CSNL could be used for insulation, protective or decorative coatings for furniture, buildings, automobiles, etc. The CSNL or Cardanol derivatives are extensively used in laminating industry for reducing brittleness and improving flexibility of laminates. The use of CNSL in rubber compositions has been found to improve the performance of rubber products especially in relation to vulcanization properties. A CNSL-based adhesive for blending concrete to wooden surface and also substitute for linseed oil in manufacture of foundry core oil developed in India.

Cashewnut processing scenario

India

India is the global leader in cashew related activities; however in future the situation will be different due to increasing international competition. At present, only half of the cashews processed in India are produced domestically, reflecting that production has not kept pace with its growing processing capacity. Due to long history of the sector, India has the strength of highly skilled labour in all stages of manual processing. It is estimated that India's perfected manual processing technique results in only 20% broken, as compared to 50% broken in highly mechanical system. India's low labour costs have enabled it to sustain this method and maintain a quality advantage in the industry. There are 3,750 processing units located in the east and west coast having processing capacity up to 20 lakh tonnes. Depending on the available resources, processing of cashewnuts takes place at home level to highly mechanized processing facility. Kerala and Karnataka have highest share in total quantity processed in our country. On or off-farm cluster based micro level cashew processing has gained momentum in Maharashtra and Tamil Nadu.

The market for cashew byproducts in India has focused on Cashew Nut Shell Liquid (CNSL). Its sale is strongly promoted by CEPCI as a renewable material that can be used to make specialty chemicals and polymers including insulating varnishes and resins. The CNSL-based polymers are resistant to cold, water, microbes and termites. India's largest international buyer of CNSL is the USA, followed by Korea and Japan and the quantities exported ranged from 6,926 tonnes in 2003-04 to 13,575 tonnes in 2011-12 worth of ₹ 7.03 crore to ₹ 59.46 crore, respectively. Utilization of cashew apple is another area of research but due to poor storage life and unpleasant aroma has limited its use. Despite extensive research in public sector that have attempted to diversify farmer incomes by making pickles, jams, jellies, juices, sweets etc. have not gained place in commercial scale. However, alcoholic beverage 'Feni', produced in Goa, is very popular.

Brazil

Though, Brazil has good infrastructure to support cashew industry but currently faces challenges due to competition from countries with lower costs and newer technology. In contrast to other cashew producing countries, most of Brazil's processing is mechanized, which yields fewer whole kernels with darker surface colour. Therefore, it is essential for Brazil to develop increasingly sophisticated technology for mechanization as relatively higher labour costs preclude more labour intensive manual processing. These characteristics limit the access of the Brazilian cashew industry to value-added markets and the low price earned for the final product prevents processors from providing higher remuneration to producers for raw nuts. The competitiveness of mini-mills is also threatened by a tendency to have limited access to information, lower management capacity and less financial records which makes access to credit more difficult. However, as only 2% of the export volume comes from mini-mills, the other 98% are processed by large firms. The domestic market is considered to be an area for potential growth as currently only 20% of Brazilian cashews are consumed domestically and the other 80% are exported. Mini-mill production in particular goes to domestic consumption as these kernels often do not meet international export standards.

Vietnam

Vietnam has made rapid strides in cashew nut processing technology. Till 1994, around 20% of the raw cashewnuts produced was exported to India and other countries for processing. This situation has changed dramatically and at present, processing facilities in Vietnam exceeded the current production and in order to meet the demand at domestic level raw cashewnuts are imported to the tune of 1.0 lakh tonnes. The better economic policies provided a paradigm shift towards a market oriented economy through decentralization, privatization and outward orientation of economic activities, easier access to external markets for trade and a drastic change in the agricultural sector in terms of land and tax policies. Cashew processing facilities are reorganized with locally manufactured machinery. Low price is one of the main advantages of domestically made machines and it could save 40% of its investment cost over imported ones. Besides, addressing the issue of labour shortage, use of cashew machinery confirmed hygiene and safety of cashew products. Export volume of cashew kernels from Vietnam was around 260 tonnes earning forex of 14 millions USD in 1990 but a quantum jump in the export of cashew kernels recorded in 2012, i.e., about 103,000 tonnes with export earnings of 480 million USD. Approximately, 98% of Vietnam's processed cashews nuts are exported and only 2% sold in the domestic market. The primary market for kernels manufactured from Vietnam is the USA (41%), followed by China (20%), the UK and the Netherlands (12%), and Australia (10%). Vietnam's cashew industry has greatly benefited by exporting to China due to proximity and less stringent quality standards. Vietnam's current efforts is on production of CNSL for use in paints and also for export mainly to China. The government is also encouraging processors to utilize cashew apples for production of beverages or bio-ethanol, but currently does not have the technology or market demand to do so.

African countries

Mozambique and Tanzania are major cashew growing countries in East Africa involved in processing. During early 1970's, Mozambique acclaimed the premier position in production and export of processed cashew kernels but now situation is not so good. In a crucial departure from the previously failed approach that was dominated by large scale factories and use of mechanized technology, Mozambique principally makes use of manual shelling technology to achieve higher whole kernel outturn. However, productivity of Mozambique's factory workers is well behind India's and Vietnam's as well as that of other African processing industries such as Tanzania and Ivory Coast. Agro Industries Association plays a vital role in exporting the processed cashew kernels under a brand 'Zamibique'. Monitoring mechanism is in place to regulate and standardize the quality of pooled production for export and it is becoming a powerful tool for generation of individual factory diagnosis. There is less institutional support or capacity to initiate the development of byproducts and factories have not reached high volumes of processing that is necessary to produce CNSL. Mozambique's domestic market is extremely small and industry has been predominantly conceived for export and little or no effort has been done to develop a domestic market for cashews or byproducts. The lack of access to credit facility is major constraint threatening the viability of the industry particularly small- and medium-processors.

Tanzania's cashewnut sector is well-positioned in the international market for raw cashewnuts, exporting 82% of national production due to a combination of seasonality and price but its processing sector still remains underdeveloped, particularly in the presence of strong buyers of raw cashewnuts for the Asian market. Lack of technical and managerial experience of most processors, difficult business environment characterized by over regulation and inappropriate infrastructure, deteriorated machinery and equipment, limited access to financial support, labour cost, services and inputs, lack of technological upgradation as well as lack of coordination among various players in the value chain are the major factors discouraging processing at domestic level.

Production and processing of cashew in West African countries *viz.*, Benin, Burkino Faso, Ivory Coast, Gambia, Ghana, Guinea-Bissau, Mali, Nigeria, Senegal and Togo is quite small given the region's status as the world's second largest producer of raw cashew nuts, contributing 39.8% to the world production. Cashew processing facilities can be divided into three categories,viz. cottage processors, semi-industrial processors and industrial processors. Cottage processors are usually collectives or local associations that manually deshell cashewnuts roasted over an open fire. Plain cashew kernels extracted sold to wholesalers and consumers through traditional markets. Despite their simple technology, these artisan processors dominate the processing sector in this zone largely due to low cost and flexibility. Semi-industrial processors are second most player in cashew processing having operational capacity up to 250 tonnes/annum. Although plain cashew kernels are sold as such, few processors add value through secondary processing targeting high-end consumers to recover their elevated processing costs. Semi-industrial factories exist in Benin, Ivory Coast, Ghana, Guinea-Bissau, Nigeria, Senegal and Togo. Few countries in West Africa now claim industrial capacity cashew processors that target the export market. These factories established in recent years and follow Indian semi-mechanical technology to produce 1,000–15,000 tonnes/annum. Though export-oriented, low grade kernels particularly the broken grades, which can be difficult to commercialize on the export market are supplied domestically for consumption or further processing. Many West African processors remain largely reliant on local consumers due to limited production of specific grade in bulk quantity for export to sustain operations year-round. Morever, West Africa's position as a raw nut exporter may change in the near future, as processing capacity is growing rapidly.

Conclusion

Cashew is a high-value crop, grown in various tropical countries. The demand for cashew kernels and cashew-based products is increasing at a faster rate. Therefore, more input and efforts are needed to fulfill the increasing demand of cashew kernels. The import and export of raw cashewnut and cashew kernels also need proper implementation of quarantine procedures. In the scenario of labour shortage, mechanization of cashew cultivation and automation in processing sector is the need of the hour. There is a need for global forum to intensify the research and development on cashew. Besides production, there is a need to create awareness on health benefits of cashew kernels, to develop quality standards for raw cashewnuts and cashew kernels, and to strengthen accredited national laboratories for certification in order to develop confidence and assure quality at consumers' level. While India has a legacy of leadership in the global cashew industry, it is essential to reassess its comparative advantages in order to remain competitive. India should focus on increasing domestic production and exploit the rising demand for organic products in USA and UK. Overall, India distinguishes itself in cashew sector by maintaining high-quality cashew kernels and large export volume, which needs to be maintained.

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3

Botany, Taxonomy and Genetic Resources

Cashew (*Anacardium occidentale* L.) is an important export oriented crop of tropical region and belongs to the family Anacardiaceae under the order Sapinadales. This family comprises 60 to 74 genera and 400 to 600 species (Barros, 1991). However, Susan (2009) reported approximately 800 species in 82 genera. Members of this family are cultivated throughout the world for their edible fruits, seeds, medicinal compounds, valuable timber, and landscape appeal (Ohler, 1979). Other important species of Anacardiaceae include mango (*Mangifera indica*), pistachio (*Pistacia vera*) and pink peppercorn (*Schinus terebinthifolia*) and products of these species are consumed worldwide. Other distinguished species such as the pantropical *Spondias* fruits, the marula of Africa (*Sclerocarya birrea*), and the neotropical fruits of the genus *Antrocaryon* are considered to be localized cultivation and consumption and are not generally transported to distant markets.

According to Baily (1949), the genus *Anacardium* contains eight tropical American species. Parente (1972) names 10 species but Peixoto (1960) names 20 different species several of which had edible peduncles such as *A. nanum*, St. Halaire, a very early bearing small shrub, *A. subterranium* Liais, a small shrub with its trunk almost completely underground containing water reserves; *A. microcarpum* Ducke, a small tree from sandy savannas, *A. spruceanum* Benth. a large tree and the largest species of the genus *A. gigentium* Hanca which grows

Table 3.1. Species of *Anacardium* described by classic systematic botany (Johnson, 1973)

Species	Country of origin
Anacardium amilcarianum Machado	Brazil
A.brasiliense Barb.Rodr.	Brazil
A.corymbosum Barb.Rodr.	Brazil
A.curatellaefolium St.Hil	Brazil
A.encardium Noronha	Malaysia
A.excelsum Skeels	Brazil
A.giganteum Hancock ex.Engl.	Brazil
A.humile St.Hil	Brazil
A.kuhlmannianum Machado	Brazil
A.mediterranneum Vell.Fl.Flum	Brazil
A.microcarpum Ducke.	Amazon region
A.microsepalum Loesn	Amazon region
A.nanum St.Hil	Brazil
A.negrense Pires & Fro'es	Brazil
A.occidentale Linn.	Brazil
A.othonianum Rizz.	Brazil
A.parvifolium Ducke	Amazon region
A.rhinonocarpus D.C.Prod.	Brazil
A.rondonianum Machado	Brazil
A.spruceanum Benth Ex.Engl.	Brazil
A.tenuifolium Ducke	Amazon region

in Amazon forest. However, 21 species of the genus *Anacardium* were identified through classical taxonomy (Table 3.1) (Jhonson, 1973). Among these species, *Anacardium occidentale* L. is the only cultivated and widely distributed species (Jhonson, 1973; Ohler, 1979; Mitchelle and Mori, 1987). Further, Mitchell and Mori (1987) reported that the fruits of cashew i.e. nut and apple were in use among local people for more than 400 years in Asia and Africa region. Most species of the *Anacardium* genus are found all over Brazil (NOMISMA, 1994). The genus Anacardium is a native to Latin America and has a primary centre of diversity in Amazonia and secondary center in the Planalto of Brazil. Behrens (1998) described the crop as a tropical tree species that originated from South America. The diversity of *Anacardium* is more in the Amazon basin and in the central uplands, the highest degree of diversification of the cultivated species is found in Northeast Brazil. For this reason, Johnson (1973) considered that Ceará state, where the cashew originated and Barros (1995) suggested that the origin and speciation of cashew crop is linked to this region. Now about 98% of cultivated cashew is grown in the Northeast Brazil (Paula Pessoa *et al.,* 1995). Natural occurrences of cashew have been reported from Mexico to Peru and in the West Indies. The crop was introduced into India, the East Indies and Africa by the Portuguese explorer in the 16th century.

Botanical classification

The complete botanical classification of cashew is given below;

Kingdom: Plantae

Sub-kingdom: Tracheobionta

Super division: Spermatophyte

Division: Magnoliophyta

Class: Magnoliopsida

Sub-class: Rosidae

Order: Sapindales

Family: Anacardiaceae

Genus: *Anacardium*

Species: *occidentale*

The cultivated species *Anacardium occidentale* L. is andromonoecious, with male and hermophrodite flowers in the same inflorescence and the phenomenon is almost similar in all the species of the genus *Anacardium* (Damodaran, 1977). Within the species *A. occidentale* also, there is a wide variation in colour, size and shape of the apple, as well as in size and shape of the nuts. The time of flushing, flowering varies among different types. There are also differences in leaf size and leaf shape and numerous other characters. Among the 21 species known, three species viz., *A.pumilum (A.humile), A.othonianum* and *A.microcarpum* have been collected and conserved in National Cashew Field Gene Bank (NCFGB) of Directorate of Cashew Research, Puttur. A brief account of some of these wild species is given in the Table 3.2.

Table 3.2: Salient features of some wild species of cashew (Anonymous, 2015b and c; Pell, 2009)

Wild species/Salient features	Images
Anacardium microcarpum (Miniature cashew)	
A small tree, usually growing to 3-8 meters. Fruits form in large clusters, with well-sized panicles. Overall appearance is much like the cashew apple tree. The fruit is the hard nut, with the bulbous pseudo fruit (the apple) ripening to red and having an acidic sweet flavour. Fresh pseudo fruits are edible and the roasted nuts are edible and quite tasty. Native to scrublands and non flood plain zones of the lower Amazon region of Brazil (Anon., 2013).	
Anacardium othonianum	
The tree grows wild in the central region of Brazil. The adult tree ranges from 2 to 6 m (3 m on average), and produces 200 to 600 fruits every season. The bark is dark and fissured. The leaves (which are reddish when young) are smooth and obovate, measuring about 15 cm × 10 cm, with 4 to 8 mm long stalks. The small pink flowers (4 to 8 mm) are gathered in panicles about 20 cm wide, and are pollinated by bees and wasps. The pear-shaped edible apple is light red when mature, 2 to 3 cm wide and 2 to 4 cm long weighting between 5 and 10 g. The colour of the ripe pseudo fruit peel varies from yellowish to reddish. (Lílian Abadia da Silva *et al.,* 2013). The tea from its bark or leaves is used in the local folk medicine against diarrhoea and as gargle for throat infections. The resin can be used as expectorant. The root is used as a purgative.	
Anacardium giganteum	
Very large tropical tree up to 50 meters. Trunk cylindrical, bark very thick, gray, moderately coarse with vertical fissures, the inner bark pinkish-brown. Hypocarp pyriform, 1.3 cm× 1-5 cm, red. Drupe subreniform, black, 27 mm × 18 mm. The distribution is from the Pacific coast of Colombia and Loreto, Peru south to northern Mato Grosso and east to Surinam and Maranhao, Brazil. A large tree growing in moist forests. It flowers from November to January and in June and August. The flowers of *A. giganteum* change colour after pollination from yellow to white to dark red. The single fertile stamen is only 0.5 mm long in unpollinated bisexual flowers, but it increases to 4.5 - 5 mm long and dehisces after pollination (i.e., in flowers with red corollas). This suggests that self pollination is inhibited by protogyny.	 
The ripe hypocarp is edible and a fine red wine can be prepared from its juice. However, the quality of the ripe hypocarp varies from very sweet and tasty to extremely acidic and usually they are too sour for eating. The seeds are toxic when raw but edible when roasted, and are said to be as delicious as those of the commercial cashew.	

(Contd to page 44.)

(Continued from page 43)

Wild species | Salient features | Images

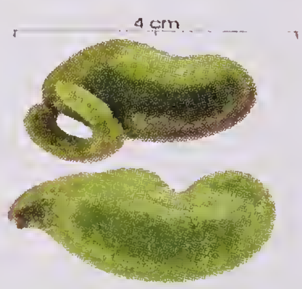
Anacardium humile (Monkey nut)

Monkey nut is an evergreen shrub or small tree, usually growing less than 1.5 m tall with large underground trunk and rigidly ascending braches. The edible fruits and seeds are gathered from the wild for local consumption. Hypocarp obconical to pyriform, 1-3 cm× 1-2 cm, red or yellow when ripe. Drupe subreniform, 1.3 - 2.3 cm × 1.0-1.7 cm, green gray, or dark brown at maturity.

The above ground parts of *A. humile* consist of tight clusters of leaves and terminal or axillay inflorescences. The prostrate form of *A. humile* is well adapted to the frequent and severe fires, seasonally dry environment, poor soils, and the low water table. Flowering occurs primarily between July and October, and peak fruiting takes place in October and November at the beginning of the wet season. *A. humile* is pollinated by bees and butterflies.

Anacardium excelsum

It is a very large evergreen tree with an umbrella-like canopy or a broadly rounded or elongate crown; it generally grows up to 30 m tall with cylindrical trunk, slightly swollen at base, with some specimens reaching heights of 40 m or more. The bole can be free of branches for up to 18 m, diameter up to 3 m and with some basal swellings but no well-developed buttresses. It is a beautiful tree with coarse, rose coloured bark. The leaves are simple, alternate, oval shaped, 15-30 cm long and 5-12 cm broad. The flowers are produced in a panicle up to 35 cm long, each flower is small, pale green to white or creamy white.



Older flowers turn pink and develop a strong clove-like fragrance. The creamy white flowers that give way to a kidney shaped nut. The raw fruit is poisonous; however, the nut may be roasted and eaten. Hypocarp slender, sigmoid, 2-4 cm x 1.5 - 2 cm, green. The true fruit or the drupe is 2-3 cm long and 1.5-2.0 cm broad drupe shaped like a kidney (reniform), glabrous, green at maturity. The flower appear from January to April (May) shortly after the new leaves are flushed and the fruits mature from March to May. *A. excelsum* is pollinated primarily by settling moths.

Anacardium parvifolium

Large trees, 22 to 40 m × 100 cm, Bark smooth. Hypocarp pyriform. 2 cm × 1.4 cm, red. Drupe reniform, 13 × 10 mm. A large tree of moist primary forests growing in flood plains and upland sites. It flowers from May to November and fruits are collected in June.

(Contd to page 45.)

(Continued from page 44)

Wild species	Salient features	Images

Anacardiuim spruceanum

Anacardium spruceanum is an evergreen tree with a sparse crown. It can grow 20 - 35 metres tall. The bole can be 60 - 80 cm in diameter, with a slight swelling at the base. The tree yields a low quality timber and is sometimes harvested from the wild. An ornamental plant, valued especially for the attractive display of white leaves around the inflorescence, it can be used in landscaping in large gardens and parks.

A. spruceanum flowers from April to September and from November to January with peak flowering in July and August. Mature fruits appear at the beginning of the wet season. This species is probably dispersed by bats. The green and white foliage of the outer branches associated with the inflorescences give the tree a magnificent appearance when in flower and therefore it has been recommended as an ornamental tree for tropical climates. Hypocarp obconical or pyriform, 100 mm × 6-15 mm, very juicy, white, red, or yellow, with strong resinous smell. Drupe reniform, 14-15 mm × 13-20 mm, black at maturity.

Anacardium nanum

Sub-shrub, 30 to 150 cm tall, with large underground trunk, 35 to 65 cm diameter. It flowers from May to August and is pollinated by bees and butterflies. Nut is edible.

Anacardium fruticosum

Low spreading tree, 2-3 m tall. It flowers from June to October.
This species is very similar to *A. parvifolium*, differing primarily in being a shrub or low spreading tree 2-3 m tall growing in savannas and bearing relatively large, coriaceous leaves. *A. parvifolium*, on the other hand, is a tall rain forest tree with chartaceous, smaller leaves.

Anacardium microsepalum

Tree bark is smooth with scattered lenticels, the inner bark reddish-brown, forming a resinous exudate when cut. Hypocarp absent. Drupe reniform, 20-30 x 19-26 mm, glabrous, green at maturity, Pedicel not accrescent. A medium-sized to large tree in seasonally inundated forests. Its fruits may be dispersed by water. The seeds of *A. microsepalum* are eaten by fish. The flowers appear from December to June and the fruits are present from December to June. *A. microsepalum* is the only species of the genus without a fleshy hypocarp.

Anacardium corymbosum

Sub-shrub 50 to 150 cm tall, with large underground trunk and rigidly ascending branches. Hypocarp subreniform, 1.5 - 2 cm × 1 - 1.7 cm, dark brown at maturity. Flowering occurs from June through October and fruiting commences in October. The hypocarp is eaten raw by local people in Brazil.

Cytology

The chromosome number of *A. occidentale* as 2n=42 was first reported by Darlington and Janaki Ammal (1945). Further the same chromosome number was corroborated by some researchers in the same species (Hutchinson and Dalziel, 1954; Purseglove, 1968; Aliyu and Awopetu 2007). Aliyu and Awopetu (2007) karyotyped the chromosomes of the cashew populations of Brazilian and Indian origin. The mitotic metaphase chromosome of Brazilian cashew population presented a length of 56.00 μm. Individual chromosome length ranged between 1.00 and 4.50 μm. The chromosome karyotype was very similar to that of Indian population comprising, 6Asm + 1Am + 1Ast + 9Bm+ 2Bsm + 2Cm. It, however, shows that the complement includes, 6 long submetacentric, 1 long metacentric, 1 long subtelocentric, 9 intermediate metacentric, 2 intermediate submetacentric and 2 small metacentric chromosomes with regular mitotic division. The total length of the homologous chromosomes recorded for the Indian cashew population was found to be 51.10 μm, and were designated 1 - 21, according to decreasing lengths. The chromosome compliment gave a karyotypic formulae of 6Asm + 1Am + 4Bsm + 5Bm + 5Cm, while A represent chromosomes >3.00 μm, B = 1.50 - 2.99 μm and C < 1.49 μm. Meanwhile, the chromosome lengths ranged between 1.00 and 4.20 μm for the shortest and the longest respectively. Based on the morphology of the chromosomes, the complement comprises of 6 long submetacentric, 1 long metacentric, 4 intermediate submetacentric, 5 intermediate metacentric and 5 small metacentric chromosomes.

Growth and development

Cashew is an evergreen tropical tree with low branching and medium size canopy (Fig. 3.1). On an average, the plant attains 5- 8 m height and 10-12 m width, however some plants with 15 m height and 20 m width have been observed. The tree bears stout branches and thick, resinous, round and scaly bark. The leaves are alternate, simple, glabrous, oblong, leathery, often notched at the apex; veins prominent, pinnately veined, lateral veins spreading with 10 to 20 pairs. The size of leaf varies from 6 to 24 cm in length and 4 to 15 cm in width (Johnson, 1973; Kumaran *et al.*, 1976). Petioles are short with 1-2 cm length and the leaves are commonly crowded at the ends of branches. The wood of tree is yellow, moderately soft and light and has relative density of 0.5 (Lima, 1954; Tavares, 1959). The sapwood is pale brown when it is dry. The heartwood zone can easily be distinguished by the brown colour. The wood has an even texture with moderately close straight grains (Sebastine, 1955). The root system of complete grown cashew tree consists of a taproot surrounded by a well developed and extensive network of lateral roots, 90% of which lie on the 15 to 32 cm depth of soil layer and possess rootlets. The ratio between lateral and canopy width is close to 2:1 in plants up to six years old.

There are two types of branching in cashew; one is intensive and another extensive (Dasarathi, 1958). The intensive shoot grows to a length of about 25-30 cm and ends in a panicle. Concurrently, three to eight lateral shoots come up below 10-15 cm of the apex and few of these laterals may also bear panicles. This kind of growth pattern is repeated in this type to give bushy appearance to the

Fig. 3.1. A Cashew plant in flowering and fruiting

Fig. 3.2. A flower panicle

Fig. 3.3. Male flower

Fig. 3.4. Hermaphrodite flower

tree. On the other hand in the extensive type, the shoot grows to 20-30 cm length and rests. Thereafter a bud sprouting 5-8 cm below the apex gives rise to further growth. This type of growth process continues for two or three years without giving flowers and results in spreading tree habit. In high yielding trees more than 60% of intensive branches are seen whereas low yielders possess less than 20% of intensive branches.

The pattern of growth of cashew tree alternates with vegetative and reproductive phases. The initiation and duration of these phases vary among varieties as these phases are regulated by both genetic and environmental factors. The cashew plant starts flowering in three to five years. Grafted plants come to flowering in 3 years whereas seedling plants may take 4 to 5 years for flowering. The inflorescence of cashew is called terminal panicle (Fig. 3.2) which bears both male (staminate) (Fig. 3.3) and hermaphrodite (perfect) (Fig. 3.4) flowers in the same panicle. For this reason, cashew is considered as andromonoecious species. The inflorescence may be conical, pyramidal or irregular in shape. Number of panicles per plant, flowers per panicle and distribution of male and hermaphrodite flowers (sex ratio) in each panicle vary significantly. Morada (1941) counted 3 to 11 branches in each panicle, depending on the vigor of the tree, with 40 to 100 individual flowers on each panicle branch or 120 to 1,100 flowers with 90-99% staminate flowers in one panicle. Rao and Hassan (1957) reported that 96% of the flowers are staminate in a panicle; Bigger (1960) observed a ratio of 6:1 staminate to perfect flowers; Damodaran *et al.* (1966) reported perfect flowers from as low as 0.45 to 24.9%. The variations in these traits are observed due to genetic and environmental factors. Flowers are produced in gradual manner and hence each panicle may stay up to three months giving continuous fruits. The duration of flowering phase depends on the genotype and environmental conditions.

Floral Biology: Flowering normally occurs at the end of the wet season, but its timing and duration are strongly influenced by temperature (Wunnachit and Sedgley, 1992). Flowers are produced at the end of the new shoots. Thus, flowers and fruits are borne on the outer extremity of the canopy. Flower bud emergence in cashew initiates by the middle of September and continue until the end of February, the main season being October-November (Damodaran *et al.*, 1965). Nambiar (1977) reported that the flowering season in cashew varies with country depending upon its altitude. The flowering season is from June to November in Tanzania with peak in August-September (Northwood, 1966). In coastal region and transitional zones of Northeastern Brazil (around 6 ÚS and up to 100 m altitude), flowering lasts 4-6 months in the common type (from July/ August to December/January) and 6-8 months (June/July to January/February) in the precocious dwarf type (Barros *et al.,* 1984; Barros, 1988; Freitas, 1994). The flowering period is from December to March with a peak in January-February in Central America (El Salvador) and West Africa. Two flowering periods were reported in Kenya, one from September to November and second from December to January (Agnoloni and Guiliani, 1977).

Even within India, the variation for flowering time was observed across different regions. Based on the season of flowering cashew genotypes are classified as early (Nov-Dec), mid (Dec-Jan) and late (Jan-Feb) flowering types. In the West Coast of India, the peak flowering is in early January and the peak harvest is in early April (Rao, 1956) whereas in the East Coast, the peak flowering is from mid January to mid February and the crop is harvested in the end of April (Dasarathi, 1958). Cashew shows the trend of late flowering and fruiting at higher elevation irrespective of latitude (Nambiar, 1977). For instance, cashew flowering in Northeastern States gets delayed by 2-3 months and flowering is seen during April-June compare to other cashew growing regions of India where the flowering period is November/December to February/March. This is mainly due to reduction in temperature at higher altitudes. Generally flowering occurs in two or three typical phases and that appearing in the intermediate stage is considered as the productive phase. Three distinct phases of flowering are observed in cashew (Pavithran and Ravindranathan, 1974). They are: (*i*) the first male phase with 19 to 100% male flowers, (*ii*) the mixed phase with 0 to 60% male and 0 to 20% hermaphrodite flowers, and (*iii*) the second male phase with 0 to 6.7% male flowers. Many other cashew workers have also found that flowers produced early in a panicle are by and large male. The duration of these flowering phases varies with genotype. The mean duration of flowering observed was 85.2 days in which the duration of first male phase was 2.4 days, mixed phase 69.4 days and second male phase 13 days.

The cashew is chiefly allogamous tree species because of its reproductive system. However, due to coincident flowering of the two kinds of flowers *viz.,* hermaphrodite (bisexual/perfect) and male (staminate) on the same tree and same panicle also favours self-pollination. Self-incompatibility hitherto was not reported among the species of the genus. The perfect flowers are larger than staminate flowers (Damodaran *et al.*, 1965). It was suggested that the staminate flowers are derived from the ancestral hermaphrodite flowers by gradual reduction and loss of function of the gynoecium (Ascenso and Mota, 1972b). The flowers are small, white or light green at the time of opening, later turn to pink. The flowers are pentamerous. The calyx is green and oval with five free sepals. The corolla is linear to lanceolate in shape, white or creamy white at the time of opening with five free petals. The external surface of sepals and petals is pubescent with simple hairs. The androecium consists of one fully developed stamen and 7-9 staminodes. The developed stamen has pink anther. The anther is basifixed, bilobed, dehisces through a slit between the two pollen sacs of each lobe. The staminodes possess short filaments and are hidden in the lower half of the open flower. The developed stamen in the hermaphrodite flower has only short filament and its anther is far below the level of stigma. The pistil is dorsiventral; ovary is superior, reniform and monocarpellate. The style is long and slender, springs from distal margin of the ovary, tapering towards the end with slightly expanded stigma. The ovary is rudimentary in male flowers.

Anthesis takes place between 9 A.M. and 2 P.M. in India and hermaphrodite flowers open mostly between 9 and 11 A.M. though some flowers open beyond this time. Staminate flowers were found to open very early in the morning and continue till about 2 P.M. Over 80% of the perfect flowers open between 10 A.M. and 12 Noon. The peak period of dehiscence of anthers was from 9.30 to 11.30 A.M. and the rate of dehiscence was slightly higher on the sunny side of the tree as compared to that on the shady side. The viability of pollen is usually high and it was 94% in types studied and the stigma becomes receptive one day prior to anthesis and its receptivity stays for two days (Damodaran *et al.*, 1966; Eradasappa *et al.*, 2014). *In vitro* germination of pollen grains up to 50% has been observed on high sucrose medium at Directorate of Cashew Research, Puttur. The majority of male flowers open between 7 and 9 A.M. while majority of bisexual flowers open between 8 A.M. and 12 noon in the West Coast region of India characterized by heavy rainfall and humid climate. Stigma is receptive throughout the day after anthesis of the flower (Rao and Hassan, 1957). The cashew produces scented flowers which attract pollinating insects mainly honey bees (*Apis mellifera*). The pollen grains of cashew are not easily carried by the wind (Paulino, 1992; Freitas, 1994; Freitas and Paxton, 1996). It was reported that only pollens from large stamens of both staminate and perfect flowers are viable and play role in the reproduction. Staminodes (smaller stamens) do not produce viable pollen grains. Reddi (1991) observed in the 20 inflorescences left open to insects bore 89 fruits, whereas those protected with butter paper bags (to exclude insects and wind) or mosquito nets (to exclude insects and allow wind) had no fruits formed. It was also confirmed by the study that cashew pollen grains were sticky and were not released into the atmosphere as no pollen grains were trapped by the air sampler or by the stigmas of flowers left open to the wind. Hence, it was proved that the possibility of the wind acting as a pollinating agent was ruled out in cashew.

Fruiting: The cashew produces abundant flowers but only less than 10% of which are hermaphrodite. Although close to 85% of the perfect flowers are fertilized under standard conditions, only 4-6% of them reach maturity to give fruits, the remaining shed away at different stages of development. The fruit drop in cashew during the early stages of development is attributed to physiological reasons (Nothwood, 1966). Insects attack also plays an important role in immature fruit drop (Pillay and Pillai, 1975). Reddi (1987) reported that cashew plants can permit about 27% of their well pollinated flowers to develop into fruits. But in nature only 10.5% yield is possible because of under-pollination and this was substantiated by stigmatic- pollen load analysis data. About 25-72% of the stigmas were found unpollinated due to limitation of pollinators leading to lower than potential yields. Earlier workers also suggested that pollination in nature is inadequate (Rao, 1974; Kumaran *et al.*, 1976). After pollination, the fruit takes 6 to 8 weeks to develop. The nut develops first and the apple develops during the last fortnight (Figs. 3.5 and 3.6). The nut drop continues for 6 to 8 weeks. Fruit set through bagging of panicles in two varieties of cashew, Bhaskara and Ullal-3 was observed at the Directorate of Cashew Research, Puttur indicating the possibility of self-fertilization to a limited extent.

Fig.3.5. Cluster of immature nuts

Fig. 3.6. Cashew apple with nut

The fruit of cashew is nut, which is a grey coloured, kidney shaped achene (a dry one-seeded indehiscent fruit with the seed distinct from the fruit wall) consisting of epicarp, mesocarp, endocarp and a kernel wrapped by a peel (testa). The nut grows slowly in the initial stages and then accelerates to attain its maximum size by 28 days. In subsequent days, the nut size reduces as it matures and becomes visibly smaller (Damodaran *et al*., 1966). The epicarp is smooth, coriaceous and grey or grayish green and it forms the epidermis. The mesocarp is thickest of three layers, spongy tissue, containing a sticky, acrid and corrosive reddish liquid, the Cashew Nut Shell Liquid (CNSL) which is rich in phenolic compounds. The endocarp is hard and is formed of a compact mass of schlerenchymatous cells. These three layers form the thick shell, i.e., the pericarp which forms 45 to 50% of the nut. The kernel, the edible part of nut is formed by two cotyledons forms 20 to 22% of nut. The kernel is covered by a brown membranous testa (peel), which forms about 5% of the weight of the nut. The peeling is one of the important tasks in the industrial processing of cashew nuts as it is very difficult to remove in as much as 20% of the seeds. The nut size varies from 3 to 13 g and the shelling percentage varies from 15 to 30%. The nuts also vary in shape. The cashew apple is a false fruit and it develops from the hypertrophied pedicel. The apple attains maximum size when nut matures and it is fleshy and juicy and varies in size, weight, shape, texture, colour and taste.

Origin and distribution

Cashew originated in Brazil and the earliest reports about home of cashew are coming from French, Portuguese and Dutch observers (Johnson, 1973). The French naturalist and monk, Thevet was the first to describe, in 1558, a wild plant extremely common in Brazil, the cashew tree and its fruits. He recounted that cashew apple and its juice were consumed and that the nuts were roasted in fire and the kernels were eaten. He provided the first drawing of the cashew showing the local people harvesting cashew fruits and squeezing juice from cashew apples into a large jar (Johnson, 1973). There are indications that local Tupi Indians had used cashew fruits for centuries. They probably played a major role in the dispersion in their temporary migrations towards the coast of north-eastern Brazil where a considerable interspecific variation has been recorded (Ascenso, 1986). The entire cashew fruit with pseudo apple when matures usually floats on the surface of water. This could account in Brazil for coastward dispersal of the species by river draining north and east. Fruit bats might also had been involved in seed movement. Within the Amazon forest fruit bats were the most important agents of seed dispersal of tree species (Johnson, 1973). From its origin in north-eastern Brazil, cashew spread into South and Central America.

The Portuguese discovered cashew in Brazil and spread first to Mozambique (Africa) and later into India between 16th and 17th centuries (De Castro, 1994). According to Agnoloni and Giuliani (1977), it was arrived in Africa during the second half of the 16th century, first on the east coast and then on the west and lastly in the islands. Dispersal of the cashew in East Africa may be due to the elephant, whose fondness for fruits is well known (Johnson, 1973). Attracted by the colour of the false fruit, they swallowed this together with the nut which was too hard to be digested. This was then expelled with their droppings, a natural manure, and trodden far enough into the ground by the animals leaving behind to root and grow, into a seedling first and then a tree. This is how the cashew was spread along the East coast of Africa facing the Indian Ocean. The spread of cashew within the South American continent was gradual and spontaneous.

As for as India is concerned, molecular studies have shown the possibility of its introduction repeatedly over a period of time but at a single location i.e. west coast (Archak *et al.,* 2009). Presently, the cashew plants in wild state as well as in well managed orchards are seen in Maharashtra, Goa, Karnataka and Kerala along the west coast, Tamil Nadu, Andhra Pradesh, Odisha and West Bengal on the east coast. To a limited extent, the crop is also seen growing in Chhattisgarh, Gujarat, Asom, Arunachal Pradesh, Meghalaya, Tripura, Manipur, Nagaland and Andaman and Nicobar Islands (Singh, 1998).

Conservation of genetic resources

Germplasm resources are very essential for crop improvement in cashew as in any other crop. The Directorate of Cashew Research, Puttur, Karnataka is entrusted with the responsibility of germplasm collection, characterization and conservation in the country. The germplasm survey and collection were carried out in cashew growing states namely, Karnataka, Kerala, Maharashtra, Goa, Tamil Nadu, Andhra Pradesh, Odisha and West Bengal. The non-traditional areas such as Garo Hills (Meghalaya), Bastar (Chhattisgarh), Gujarat, Dadra and Nagar Haveli and Andaman and Nicobar Islands were also surveyed for germplasm collection. So far, 539 accessions have been collected and conserved in the National Cashew Field Gene Bank at the Directorate. Similarly, Regional Cashew Gene Banks (RCGBs) have been established at AICRP Centres which are maintaining a total of 1,104 accessions in the field.

The collected scion material of the accession is grafted onto a root stock and each grafted accession is then grown in the field gene bank. Recommended

Compact type | Upright type | Spreading type | Purple type accession

Fig. 3.7: Different tree forms

agronomic practices are adopted and observations are recorded on 3 selected plants in each accession after obtaining 6 annual harvests for 68 characters following 'Cashew Descriptors' (IBPGR, 1986; Table 3.3). For instance, different tree habit types and fruit shapes that are recorded given in Figs. 3.7 and 3.8. So far 478 clonal accessions out of 539 accessions have been evaluated and 444 are conserved in a conservation block by planting 4 plants per accessions at a closer spacing of 4 m× 4m.

The information on first set of 56 accessions planted in 1986 has been published in the 'Catalogue of Minimum Descriptors of Cashew Germplasm Accessions-I', 1997. The second set of 97 accessions planted in 1987 and 1988 have been documented in the "Catalogue of Minimum Descriptors of Cashew Germplasm Accessions-II", 1998. The third set of 102 accessions planted in 1989 and 1990 have been included in the "Catalogue of Minimum Descriptors of Cashew Germplasm Accessions-III, 2000. These are the first efforts made in characterisation of clonal accessions of cashew in the world and so far, 255 accessions have been characterised and catalogued (Swamy *et al.,* 1997, 1999 and 2000). Recently, fourth catalogue containing information on 108 accessions planted during 1991-97 (Nayak *et al.,* 2014) and fifth catalogue containing information on 115 accessions planted during 1198-2003 have been published (Nayak *et al.,* 2015). The germplasm accessions conserved in the field gene bank at Directorate of Cashew Research, Puttur include the diverse types such as high yield, bold nut, semi-tall, compact, Cashew Nut Shell Liquid (CNSL) free, purple pigmented, high shelling percentage, cluster bearing, big apple and early maturity types. Further biochemical profiling of cashew varieties have been accomplished and accession with high mineral composition, neutraceuticals, proteins, starch, lipids, sugars, tannins, phenols and ascorbic acid have been identified. Three wild species namely, *Anacardium pumilum, A. othonianum* and *A. microcarpum* are

Fig. 3.8: Different shapes of cashew apple

Table 3.3. Descriptors used for characterization of cashew germplasm

General characteristics	Plant characteristics	Flowering characteristics	Nut characteristics	Apple characteristics
Accession number	Age of tree	Season of flowering	Colour of mature nut shell	Mature cashew apple colour
Donor name	Tree habit	Inflorescence shape	Nut shape	Cashew apple shape
Donor identification No.	Internodal length of twig	Flower colour	Nut weight	Size of cashew apple - Length
Scientific name	Leaf shape	Colour of boot leaf	Shape of nut base	Size of cashew apple – Width
Type of maintenance	Tree height	Inflorescence size – Length	Suture of nut	Weight of cashew apple
	Tree spread	Inflorescence size – Width	Flanks of nut	Shape of cashew apple base
	Cracks on the trunk bark	Compactness of inflorescence	Stylar scar on nut	Ridges on cashew apple
	Crotch angle of main branches	Type of inflorescence branching	Shape of nut apex	Cashew apple apex
	Ease of peeling bark from trees	Sex ratio	Relative position of suture and apex	Grooves on apex of cashew apple
	Extension growth of twigs	Secondary flowering	Shell thickness	Cavity at apex of cashew apple
	Branching pattern	Flowering duration (days)	Uniformity of shell thickness	Skin of cashew apple
	Twig diameter	Flowering intensity (%)	Cashew nut dimension – Length	Attachment of nut to apple

(Continued to page 54)

(Continued from page 53)

General characteristics	Plant characteristics	Flowering characteristics	Nut characteristics	Apple characteristics
	No. of leaves per twig		Cashew nut dimension – Width	
	Colour of young leaves		Cashew nut dimension - Thickness	
	Colour of mature leaves		Apple to nut ratio	
	Odour of leaves		Shelling percentage	
	Leaf margin		Kernel weight	
	Leaf apex shape		Attachment of peel to kernel	
	Leaf size		Kernel dimension – Length	
	Brittleness of leaf		Kernel dimension – Width	
	Angle of leaf petiole		Kernel dimension – Thickness	
	Leaf cross-section		Cotyledonary grooves	
	Cumulative yield per plant			

also conserved. The collection also has seedling accessions of 23 exotic collections of which nine were collected from Brazil, Nairobi, Mtwara, Lindi, Nacala, Mozambique, Singapore and Australia and 14 from Republic of Panama. The germplasm accessions which are unique and have potential (verified/verifiable) attributes of scientific/commercial value are registered in NBPGR, New Delhi. This includes accessions such as NRC-59 (VTH 196/18) for big apple, bold nut size and high shelling percentage, NRC-111 (Mardol-4) for mid-season flowering, big apple and big nut size, NRC-116 (CNSL Free) for Cashew Nut Shell Liquid (CNSL) free type, NRC-120 (Nairobi) for early season flowering, bold apple and nut size, NRC-121 (Purple genotype) for purple stem and leaves and high shelling percentage, NRC-140 (VTH 155 L) for semi-tall, early season (Nov.-Dec.) and long flowering duration (120 days), NRC 142 (VTH 578/1) and NRC-152 (VTH

713/4) for wild relative with genetic diversity and NRC-201 (Pl.No.1254) for upright and compact habit, semi-tall type.

Genetic architecture of cashew germplasm

It is essential to understand the variability and genetic architecture of germplasm for utilizing them in the crop improvement. Hence, an attempt was made by deploying 13 important quantitative characters of 478 cashew germplasm accessions evaluated and conserved in National Cashew Field Gene Bank of Directorate of Cashew Research, Puttur. Considerable variability was observed for all characters and the highest CV (52.21%) was observed for sex ratio followed by cumulative yield per plant and apple weight. The lowest CV (15.15%) was observed for shelling percentage followed by shell thickness. Frequency distribution patterns (Fig. 3.9) showed highly positively skewed distribution for characters such as nut weight, sex ratio, apple weight and apple to nut ratio. Genetically, it is evident that decreasing alleles are in excess and dominant for these characters. Whereas tree spread, kernel weight and cumulative yield per

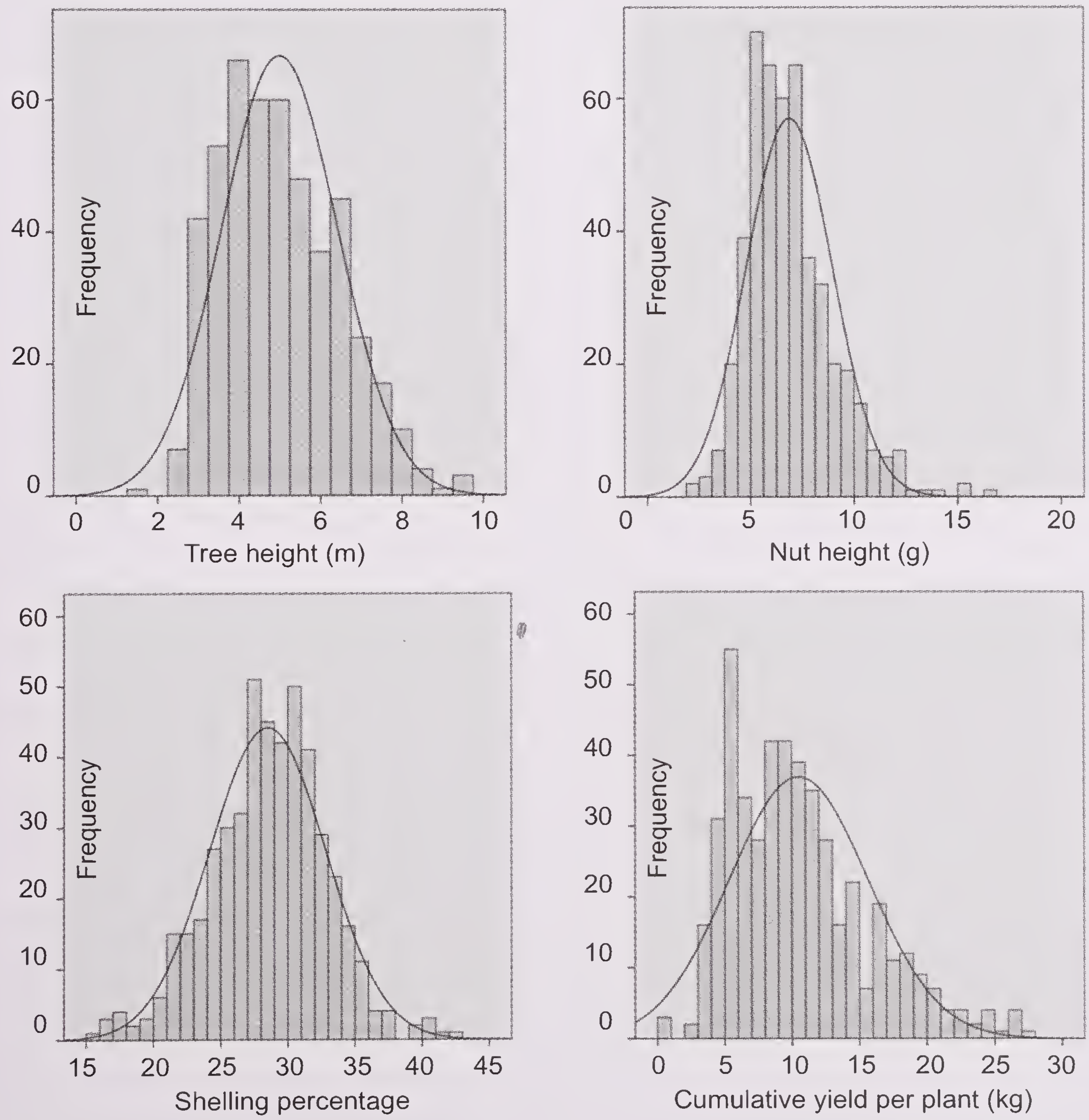


Fig. 3.9: Frequency distribution of some quantitative characters

plant showed moderately positively skewed distribution indicating decreasing alleles are in slight excess and dominant. Flowering intensity showed moderately negatively skewed distribution indicating the presence of increasing alleles in slight excess and their dominant nature. Tree height, shell thickness, flowering duration, shelling percentage and leaf area showed approximately symmetric distribution indicating increasing and decreasing alleles are in equal proportion and the dominance is ambi-directional. However, based on the frequency distribution patterns, it was imperative to collect germplasm with dwarfness, less tree spread, high nut weight, apple weight and high yield.

Significant positive correlations with cumulative yield per plant were observed for tree height, tree spread, sex ratio, flowering duration, apple to nut ratio, shelling percentage and leaf area and significant negative correlation for shell thickness. The germplasm collection represented sufficient number of accessions for both quantitative and qualitative characters in desired direction. Out of 478 accessions, 5 with tree height <2.5 m, 4 accessions with tree spread <3.0 m, 190 accessions with nut weight >7.0 g, 74 accessions with sex ratio >0.13, 29 accessions with weight of cashew apple >100 g, 50 accessions with flowering duration < 60 days, 265 accessions with shelling percentage >28%, 62 accessions with kernel weight >2.5g and 48 accessions with cumulative nut yield per plant >18 kg in 6 years were documented.

Utilization of germplasm

There are 42 improved varieties and hybrids are released so for in the country. Out of 28 cashew varieties and 14 hybrids released in the country, the varieties are *per se* selections made from the germplasm material by different cashew research stations. About 155 germplasm accessions have been effectively utilized for crossing programme at the ICAR-Directorate of Cashew Reserach (DCR), Puttur and several of these were also supplied to other cashew research centres for hybridization programme and other studies. For instance, a total of 75 cashew accessions have been supplied to AICRP on Cashew Centers/ICAR Research Complex for Goa for evaluation and hybridization programme. A total of 107 accessions (65 during 2001 and 42 during 2002 fruiting season) in NCFGB have been utilized as parents under the adhoc research scheme "Network Programme on Hybridization in Cashew" which was in operation during 2000-2003. Leaf samples of 34 varieties and 153 gemrplasm accessions have been supplied to Division of Horticulture, UAS, Bengaluru for DNA Finger Printing of varieties and germplasm under the DST funded project. Leaf samples of 142 accessions have also been supplied to NRC on Plant Biotecnology for DNA Finger Printing, New Delhi.

Presently, the hybridization programme is going on at DCR, Puttur and cashew research stations at Bapatla, Bhubaneswar, Vridhachalam, Madakkatahra and Vengurle. The review of performance of varieties and hybrids indicated that in the States where both selections and hybrids were released for cultivation, the performance of hybrids has been better than the selections. Hybrid vigour can easily be exploited in cashew because of the amenability of this crop for vegetative propagation. It was observed that when tall accessions are crossed with dwarf accessions, the majority of the resulting progenies have tall stature indicating that tall is dominant over dwarf character.

Diversity analysis through molecular markers

Studies done to assess diversity among cashew germplasm accessions revealed that moderate to high genetic diversity exists in germplasm collections when RAPD markers were deployed (Anik *et al.*, 2002) and low diversity has been observed with SSR markers (Sika *et al.*, 2015). The genetic diversity and species relationship in 10 diverse types of cashew including three species (*Anacardium pumilum* St. Hillarie*, A. microcarpum* Ducke*, A. othonianum,* three inter-specific hybrids i.e. V-5 (*A. occidentale*) × *A. pumilum*, *A. pumilum* × V-5 (*A. occidentale*) and *A. orthonianum* × V-5 (*A. occidentale*) and four genotypes of *A.occidentale* was assessed using RAPD, Isozymes and SSR markers. In the cluster analysis three broad groupings were distinguished: In first group *Anacardium pumilum* was found clustering with two of its inter-specific hybrids, in the second group *Anacardium othonianum* clustered with one of its inter-specific hybrid and a dwarf accession Kodippady and while in the third group contained most accessions of *Anacardium occidentale* clustering with *Anacardium microcarpum,* thus indicating close affinity between *A.occidentale* and of wild species *A. microcarpum.* In one of the studies, it was found that among RAPD, ISSR and AFLP markers, AFLP was found to have superior marker efficiency in differentiating germplasm accessions. A total of 172 accessions comprising collections from 9 states of India and exotic sources were fingerprinted using both RAPD and ISSR markers (Thimmappaiah *et al.*, 2009). Based on Shannon's information index and percentage of polymorphic loci, it is evident that high genetic variation was observed in the collections of Karnataka, Kerala and Andhra Pradesh. There was more diversity (96% variation) existed within the groups than between the collections (4% variation) from different states. Among the accessions, NRC-432 and NRC-119 were highly divergent and NRC-235 and NRC-216 were highly similar. The cluster analysis performed to create dendrogram distinguished 17 clusters in all. Although there was no correspondence between the centre of collections and clusters, there were some exceptions as species from Brazil like *A. othonianum* and *A. pumilum* were found to cluster together in the same sub-group and some sub-clusters were in agreement with morphological clusters. From 17 clusters, 63 accessions were identified to form a 'core collection'.

Fingerprinting of cashew varieties

Initially, isozyme markers which are co-dominant were used for characterization of varieties. Isozyme extraction from young cashew leaves was standardized using Arulsekhar and Parfitt buffer. Extraction and staining protocols for 14 enzymes have been standardized. Fingerprinting of 30 varieties of cashew was carried out with Isozyme polymorphism of 10 enzymes. By assaying 10 enzymes, 33 Isozyme bands (loci) were observed (1-4 bands per enzyme) with an average of 3.3 bands per enzyme; of which 23 bands were polymorphic (69.7%) and 10 were monomorphic. Among the different enzymes, Isozymes of Shikimate dehydrogenase were found to be highly informative. Cluster diagram made with

Isozyme markers indicated that Ullal-1 and V1 as most divergent.

Following this, fingerprinting of 40 varieties released in the country was carried out with RAPD, ISSR and SSR markers. Polymorphic markers generated with a combination of 10 primers each of RAPD and ISSR markers and 15 primer pairs of SSR of cashew used in the analysis. Marker analysis was carried individually and by combining all the three markers. Based on the combined markers, Jaccard's coefficient of genetic similarity between the different pairs of varieties varied from 0.54 to 0.81 with an average similarity of 0.68 indicated low diversity existing among the varieties studied. Highest similarity was observed between Goa 11/6 and VRI-3 and lowest similarity was observed between Kanaka and V-2. UPGMA dendrogram grouped 40 varieties in to 8 to 10 clusters at 75% similarity. Among the varieties, Kanaka, Jhargram and V-6 were highly divergent. Varieties clustered together irrespective of their geographic origin indicating no relation between the clusters and the origin of varieties.

Future line of work

- The introduction of dwarf accessions from Brazil and subsequent development of dwarf hybrids needs special attention since dwarf types are very much required for high density planting systems to improve productivity.
- Introduction of *Anacardium gigantium* from Surinam with biggest apple (200 g) will be advantageous, especially in states like Goa where the cashew apple utilization contributes substantially to the economy of the state.
- More comprehensive exploration is required for target specific traits such as resistance to Tea Mosquito Bug and Cashew Stem and Root Borer, high yield, dwarf, bold nut with cluster bearing, tolerance to drought, frost, salt and other problematic soils etc.
- Generation of core collections, utilization of germplasm accessions in hybridization programs, exploitation of unique types such as CNSL free and rich types are some of the areas that need to be attempted. Further, germplasm conservation through *in vitro*/cryopreservation needs attention as conserving in field gene bank requires considerable space and time. However, this requires in first place, the standardization of regeneration protocols for cashew which hitherto has not been successful. Pollen cryopreservation to conserve nuclear genetic diversity also needs to be tried in cashew.

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4

Crop Improvement in Cashew

CASHEW (*Anacardium occidentale* L.) is found throughout the tropical world and in certain sub-tropical areas with favourable climatic conditions. Originated from Brazil, cashew was introduced to India by the Portuguese in the 16th century mainly for soil conservation and afforestationin the coastal region. After its introduction in to southwestern India, cashew probably spread throughout the Indian subcontinent. Cochin (Kerala) served as a dispersal point for South-East Asia as well (Johnson, 1973).Cashew kernel has a high commercial value and the cashew industry provides employment to millions of people apart from sizeable contribution towards income from agri-business sector. Cashew is primarily grown in Asia, Africa and South America. Asiatic zone mainly includes India, Vietnam and Indonesia as the major cashew producing countries followed by Philippines, Malaysia, Thailand and Sri Lanka. African countries producing cashew are Côte d'Ivoire, Nigeria,Tanzania, Mozambique, Kenya, Benin, Guinea-Bissau, Ghana, Senegaland Madagascar. Latin American countries producing cashew consist of Brazil, Columbia, Costa Rica, Honduras and Salvador.

Presently, cashew is cultivated in 32 countries of Latin America, Asia, Africa and Australia, covering an area of about 53.13 lakh ha with a production of 41.52 lakh tonnes of raw nuts with an average productivity of 0.78 tonne/ha (FAO, 2012). Though cashew has originated from Brazil, it gained greater popularity in India, Vietnam and some African countries. In 60's India had a major contribution to the world production along with Mozambique and Tanzania. From 1961 to2013, area under world cashew has increased at a rate of 4.25% Cumulative Average Growth Rate (CAGR). But in 70's Mozambique left the race due to political issues and civil war in the country. In other Asian countries like Indonesia, Malaysia, Cambodia etc. cashew cultivation became popular. Till 80's, raw cashew nut production witnessed slow and steady growth. From 90's, global Raw Cashew Nut (RCN) production has seen a tremendous growth. The huge production increase has been mainly contributed by Vietnam, the newly emerged RCN producer since 1990. From its humble beginning as a crop intended to check soil erosion, cashew has come out as a major foreign exchange earner in most of the countries. During 60's, India, Mozambique, Tanzania, Brazil and Coted' Ivoire were the only producers of RCN. Till mid of 70's, the same trend continued with some new entrants in the market. In 70's, Indonesia and in 80's Vietnam became one among the new entrants of RCN production in the world.

India is the largest producer of raw cashew nut in the world with 1.01 million ha area under cultivation and 0.75 million tonne production in 2013. The area under cashew has been increasing consistently year-after-year. From 1961, cashew cultivation area in India has increased at a CAGR of 3.04%. Though the area under cashew cultivation is increasing, the growth rate of area is declining over the decades. In 60's and 70's, the CAGR was nearly about 4% which declined to 1.44% in 80's. In 90's, the growth rate increased again to 3.54%, but was lower than the previous echelons. In last decade, the area has grown by only 2.88% which was again lower than its previous decade. Vietnam is one of the largest producers of cashew nut in the world and is the world's largest exporter of cashew kernels. During 1990s, Vietnam emerged as an important cashew nut producer within Asia. Cashew is grown in 300,000 ha in Vietnam with an average productivity of 1,000 kg/ha. Through moving plantations from mountains, better seed programme, choosing proper seasons for seeding and harvesting and use of Integrated Pest Management (IPM), Vietnam aims to increase productivity to 1,700 to 2,000 kg/ha. Area and production of cashew nut in Brazil has significantly grown from 1961 onwards at annual rate of 5.35 and 5.45%, respectively up to 2013. With the expansion of area, production has increased steadily over the years. However, from past 10 years (from 2004 onwards), Brazilian cashew production has started declining at a rate of 4.96% due to adverse climatic conditions (mainly continuous drought year and scarcity of farm labour). The area in this period has also grown very slowly at a rate of just 0.97%.

Cashew, one of the major crops of Mozambique, is produced along the entire coastal area. The coastal zone of the provinces Cabo Delgado, Nampula, Zambezia and Inhambane, Gaza and Maputo are the most important areas for production of cashew. After independence in 1975, Mozambique was the world's leading cashew producer, and processed cashew kernels and exported 240,000 tonnes of raw nuts. But sector's performance was tailed off as a result of the civil war (1982-1992). The liberalization policy on exports of unprocessed cashew, led to closing down of a few processing factories due to lack of raw materials. With the return of peace to the country, cashew production has gradually increased again but the Naida cyclone in 1994 destroyed 40% of plantations area. In recent times, Mozambique plans to continue to focus on cashew production, by distributing saplings and combating diseases that affect the cashew trees. Mozambique's cashew production has rebounded substantially in the last 10 years but still the production is far lower than those achieved in 70s. Tanzania is one among the major cashew producing countries in Africa. Major cashew growing area in Tanzania includes Mtwara, Lindi, Ruvuma and Tanga. Among these regions, Mtwara and Lindi regions contributes more than 87% to the national cashew production. Senile plantations are resulting in decrease of cashew nut production in the country. Area under cashew cultivation is decreasing year-on-year as farmers are shifting towards other crops.

The supply of raw nuts produced worldwide does not match with continually increasing demand from the processors. The lower level of productivity is attributed as the chief cause for this huge gap between demand and supply. Crop improvement through development of high-yielding varieties is one the major strategies to address this issue. Development of high yielding varieties needs regular attention as the risk of production is ever increasing under the scenario of climate change which has association with biotic and abiotic factors and in turn poses challenge to productivity of the crop. In this context, the strategies of crop improvement with due importance to location specific problems, processing and export needs high attention.

Centre of diversity

The genus *Anacardium* has two centres of diversity in Brazil itself: one in the Amazon region, in the lowland moist, gallery and dry forests and the savannah like vegetation called 'cerrado'; and other in the central uplands characterized by the cerrado, (Paiva *et al.*, 2009). However, the greatest diversity of the cultivated species, *A. occidentale*, is the "restinga" (sandbank) vegetation, a low dense forest of the sandy soils in the coastal North-East far from the two centres of diversity of the genus (Barros and Crisostomo, 1995). Occurrence of large number of wild species suggests that North-East Brazil is the site of origin for *A. occidentale* L. which is the only species in the genus that attained economic importance (Ascenso, 1986).

Cashew is now distributed over most of the tropical areas of the world, from 27° N in southern Florida, to 28° S in South Africa (Frota and Parente, 1995). *Anacardium* species are naturally distributed from Honduras South to Parana, Brazil and Eastern Paraguay. The genus is found west of the Andes in South America only in Venezuela, Columbia and Ecuador. In the genus *Anacardium*, 10 species have been recognized by Mitchell and Mori (1987) which are: *A. occidentale, A. giganteum, A. humile, A. microsepalum, A. excelsum, A. parvifolium, A. corymbosum, A. spruceanum, A. nanum* and *A. fruticosum.*

The following five distribution patterns of *Anacardium* were also reported by Mitchell and Mori (1987):

(i) *A. excelsum* is isolated taxonomically and geographically from its congeners by the Andes. The uplift of the Andes was probably the driving force in the early differentiation of *A. excelsum* from the rest of the genus.

(ii) *A. giganteum* and *A. spruceanum* have Amazonian-Guyanan distributions.

(iii) *A. occidentale*, which is the most widespread species in the genus, has disjunct populations in the Planalto of Brazil, the 'restingas' of Eastern Brazil, the savannas of the Amazon basin, and the Illanos of Columbia and Venezuela. It should be kept in mind, however, that the natural distribution of this species is obscured by its widespread cultivation in both the old and new world.

(iv) Three closely related species, *Anacardium humile*, *A. nanum* and *A. corymbosum* are restricted to the Planalto of Central Brazil.

(v) Two species of *Anacardium* are narrow endemics. *A. corymbosum*, which is restricted to South-Central Mato Grosso, is an allospecies of *A. nanum* and *A. fruticosum* (a new species), is endemic to the upper Mazaruni river basin in Guyana. It is closely related to the Amazonian *A. parvifolium.*

Twenty-one species of the genus *Anacardium* were identified through classical taxonomy (Barros, 1995). The eastern portion of Amazon river figures prominently in distributions of many plants and animals, many of which are found either exclusively to the North or South of the river. However, in the case of *Anacardium*, all Amazonian species are found on both sides of Amazon river. The reason for this is probably the ease with which bats, large birds, and water (in the case of *A. microsepalum*) carry fruits across water barriers (Mitchell and Mori, 1987).

Genetics/Biometric studies

Cytology of *Anacardium occidentale* L. has not been studied in detail. The chromosome number is reported in the literature range from 2n=24 (Khosla *et al.,* 1973; Goldblatt, 1984), 2n=30 (Machado, 1944), 2n=40, (Simmonds, 1954; Goldblatt, 1984) to 2n=42 (Darlington and Janaki Ammal, 1945; Khosla *et al.,* 1973; Goldblatt, 1984; Purseglove, 1988) for *A. occidentale.* This morphologically polymorphic species also exhibits chromosome polymorphism (Mitchell and Mori, 1987). Such chromosome polymorphism is well known in many domesticated trees (Khosla *et al.,* 1973). Success of any breeding programme depends on the selection procedure adopted. The characters under selection should have high heritability. Practically, no information is available on the genetics of different characters in cashew, though attempts were made to study the genetic variability and also to correlate yield with ratio of perfect flowers, short and synchronized flowering, branching and flowering intensity and fruit per panicle. The yield of nuts from a tree is proportional to the number of fruits set and total number of flowering shoots per unit area (Anon., 1978). Pugalendhi *et al.* (1990) found that yield of nuts from a tree is strongly correlated with flowering shoots per unit area, total canopy area, number of perfect flowers and percentage fruit drop. Manoj *et al.* (1994a) observed that weight of kernel, mean canopy spread, number of nuts/ panicle, girth of tree, leaf area, duration of flowering and height of tree are the important biometric characters which contribute towards nut yield/tree in cashew. According to Morton (1970) trees exhibiting sprawly growth produced only a tangled mass at the base and dead branches. Maximum flowering was seen in trees with erect growing habit. This observation is in agreement with extensive type of branching described by Dasarathi (1958). Rao (1974) found a positive correlation between yield and percentage of perfect flowers and concluded that it was highly desirable to select types with high percentage of perfect flowers for increasing the production of cashew. Damodaran *et al.* (1979) reported positive correlation between the proportion of perfect flowers and gross yield of nuts. Northwood (1966) observed that the trees which produced large number of nuts had small nuts unsuitable for cashew trade. Pugalendhi *et al.* (1990) obtained higher germination percentage from small nuts.

Work done at Cashew Research Station, Ullal (Karnataka) indicted that high-yielding tress were more likely to produce medium-sized nuts (120-130/kg) and hence medium-sized nuts should be preferred in selection. Medium-sized nuts also had higher percentage of germination than either heavy or light nuts (Rao and Hassan, 1956). Albuquerque *et al.* (1960) reported that larger the nuts, larger will be the apples. Swamy *et al.* (1993) obtained strong positive correlation between nut weight and apple weight. Yellow apples are often less astringent, heavier and softer than the red apples (Albuquerque *et al.*, 1960). Albuquerque *et al.* (1960) also reported that heavier and larger the apple, the higher will be the juice content. Variability studies have also been conducted by several workers (Morada, 1941; Rao and Hassan, 1957; Albuquerque *et al.,* 1960; Cordoba, 1967; Northwood, 1967; Morton, 1970; Murthy and Yadava, 1972). Variability observed at present with respect to plant canopy, leaves, flowering period, proportion of male and perfect flowers, percentage of fruit set, size, shape, colour, taste and astringency etc. may be due to the segregation of inherent heterozygosity.

Selection criteria

Seedling stage: Seed and seedling characters having high heritability and high genotypic correlation with yield have been identified in cashew. There were significant correlations between juvenile plant and mature tree characters, especially with yield. The correlations of juvenile plant characters like height of the plant, girth of the trunk, number of primary and secondary branches, leaf length and spread of the canopy with yield are positive and significant. The path analysis revealed that four characters, namely, seed weight, seed length, length from cotyledon to first leaf and mature tree canopy had direct effect on nut yield. There was significant negative correlation between nut yield and days taken for germination. This association suggests that seedlings that are late in germination should be discarded.

Bearing stage: The study conducted at Directorate of Cashew Research, Puttur on correlation and regression analysis of bearing cashew trees showed that number of flowering laterals, fruiting intensity and yield per square meter of canopy are the important yield component characters in cashew. Both fruiting intensity and yield per square meter of canopy had high positive correlation with estimated yield per tree. Regression coefficient of estimated yield per tree on number of flowering laterals and fruiting intensity was on higher side. Since, fruiting intensity and nut yield per square meter of canopy were the most important yield component characters, thus same can be used for evaluating breeding material for improvement of nut yield per tree.

Genetic resources

National Cashew Field Gene Bank (NCFGB) of ICAR-DCR has at present 539 accessions including exotic collections which have been maintained as clonal progenies. Similarly, Regional Cashew Gene Banks (RCGBs) have been established at AICRP Centres which are maintaining a total of 1,104 accessions. The germplasm has been utilized for crop improvement programme. About 155 germplasm accessions have been effectively utilized for crossing programme at the Directorate of Cashew Reserach (DCR), Puttur and several of these were also supplied to other cashew research centres for hybridization programme and other studies.

Breeding objectives

Improving the nut yield is the major objective of breeding in view of lower productivity in cashew. The variability existing in the germplasm suggests that the objectives of breeding are attainable once positive results are already obtained for nut yield and apple quality which are important in Brazil (Barros *et al.*, 2000). Since cashew apple, which yields nearly 10 times that of nut, has tremendous potential to be exploited as value added product, breeding objectives should also consider apple parameters for improvement. Pests and diseases as well as abiotic stresses also affect the yield and must be given priority while formulating breeding programmes. As cashew shell has Cashew Nut Shell Liquid (CNSL), which is a valued product, crop improvement programme can also include attributes related to CNSL yield. In the above context, the breeding objectives can be enlisted as follows.

High yield potential: It is observed that a tree bearing large number of medium-sized nuts can give more yield and such genotypes should be selected for enhancing production. However, as cashew is an export oriented crop, emphasis should also be given to develop variety with bold nuts coupled with high yield which gives kernels of superior grade. This is a great challenge for the cashew breeders even though some achievements are visible. A breeder must aim at developing a variety giving a minimum of 10 kg yield/tree after attaining stabilized bearing i.e., 10 years after planting. However, per plant yield of 20-25 kg at 10 years after planting is not difficult to achieve.

Dwarf and compact canopy types: Required for high density planting system. These types minimize cost of cultivation and give more return per unit area.

Short flowering duration: Short flowering types will reduce the crop loss due to pest and disease infestation, reduce the expenditure for managing the pests and diseases and also reduces the cost of harvesting of nuts.

High sex ratio (hermaphrodite: staminate): Care should be given to select trees with higher extent of mixed phase of flowering with higher percentage of hermaphrodite flowers as parents than trees having distinct male or hermaphrodite phases. This would result in increased proportion of trees having more percentage of bisexual flowers culminating into higher fruit set in the selected progenies.

Resistance/Tolerance to tea mosquito bug: Developing varieties having field tolerance to this pest and mid-season flowering types to escape from attack of this pest should be given importance.

Resistance/Tolerance to cashew stem and root Borer: This is the serious pest as it kills the tree slowly after infestation. Hence, development of varieties resistant to this pest is more important. However, at present, there are no genotypes in germplasm which are tolerant or fairly resistant to CSRB.

Disease resistance: Anthracnose and black mold are the major global fungal diseases which cause huge losses in nut yield and nut and apple quality. Hence efforts should be made to develop varieties resistant to these diseases.

High shelling percentage: For higher recovery of kernels, a variety should have shelling percentage of more than 28% which is the major concern of the processing industries.

Nutrition quality: Need to develop varieties with high nutritive value like rich in kernel protein and minerals and less in sugars.

Breeding for cashew apple: Varieties possessing big size of cashew apple with higher juice content and high TSS need to be developed for cashew apple processing industries.

Breeding for varied CNSL content: Cashew Nut Shell Liquid (CNSL), a byproduct of cashew, is a raw material for various industries like paints and varnishes, resins, industrial and decorative laminates, brake linings and rubber resins. The genotypes having more of CNSL contents are also required to be identified. However, lower CNSL content is not desirable as those plants with less CNSL are more prone for insect attack, rat and porcupine damage to the nuts.

Ideotype attributes

For cashew, where low productivity is the key issue to be addressed, the breeding programme should consider the following attributes to develop an ideal plant type. However, it is very difficult to have all attributes in one genotype but combination of major attributes is essentially desired.

(*i*) Development of dwarf and compact canopy types to fit into high density planting. a) Low horizontal spread, b) Dwarf stature of the plants, c) Short inter-nodal length (<2.5 cm), d) Upright branches (low spread:< 3.0 m).

(ii) Cluster bearing type (> 8-12 nuts/bunch).

(iii) High sex-ratio (hermaphrodite: staminate) with predominance of hermaphrodite flowers (High: >0.13).

(iv) Mid-season flowering to escape to tea mosquito bug (TMB) damage.

(v) More number of flowering/fruiting laterals (>90%) with short harvest duration and synchronous flowering (to complete harvest within 1 – 2 months) to enhance productivity.

(vi) High yield (> 10 kg/tree at age of 9-10 years; minimum of 2 t/ha with a spacing of 7 m × 7 m accommodating 200 plants/ha.).

(vii) Medium to bold nuts (7.5 – 10.0 g/nut).

(viii) High shelling percentage in order to obtain higher recovery of kernels (>28%).

(ix) Kernel weight (> 2g/kernel) and better kernel grade (W 210, W240).

(x) Big size apple (> 75 g/apple) with high juice recovery (> 75%), TSS (>12° Brix) and Vitamin C and low astringency.

(xi) High CNSL types for industrial application.

(xii) Field tolerance to Tolerance to tea mosquito bug and Cashew stem and root borer.

(xiii) Rich in kernel protein and minerals such as Magnesium and Selenium(Bio-prospecting).

Breeding methods

The breeding methods applied for the improvement of a species depends on the reproductive behavior of that species (Allard, 1971). Cashew is a highly cross pollinated crop and hence is highly heterozygous. Cashew has the twin advantages of propagation through seeds and vegetative means. The commonly pursued breeding methods in cashew are plant introduction, hybridization and clonal selection and population improvement. The best identified hybrids can be multiplied by vegetative method called wedge grafting or soft wood grafting technique and thus hybrid vigour heterosis can be easily fixed and exploited in cashew. According to Barros *et al.* (2002) cashew breeding programs typically comprise the following stages: plant introduction, progeny testing, individual selection and hybrid breeding. Much emphasis was given in the past to exploit heterosis in the improvement of cashew since hybrids were found to perform better than selections. Hence, the breeding strategies have been focused on generation and selection of superior hybrids, combined with the vegetative propagation of elite clones. But the genetic base of the crop for some desirable traits still needs to be expanded by targeted introgression of new desirable alleles (Cavalcanti *et al.*, 2000 and 2003). Recently, molecular Marker Assisted Selection is also being employed in cashew breeding programmes to reduce the breeding time. The breeding methods applicable in cashew are detailed below.

Plant introduction: Plant introduction is the easiest way of collecting genetic resources from the country of origin or from the countries or regions where variability already exists. Cashew belongs to Brazil but it has now been introduced to other parts of the world and adapted to environments prevailing in those regions. By this way other countries are exploiting the benefits offered by this crop. Besides, related species and genotypes can also be introduced to enrich diversity, particularly from Brazil, provided it permits to do so under WTO regime.

Individual phenotype selection: The cashew genotype is selected for particular trait of interest based on the phenotype. Here the selection depends on the influence of environmental factors on characters under consideration. In order to reduce the time lag, there is a scope to select the phenotype in the desired environment only. Also there is no control on the male parent and selected plants are pollinated with a random mixture of pollen which ensures cross-pollination with related genotypes. The disadvantage of this methodology is the possibility of loss of genotypes with potentialities not expressed in the environment in which the selection is made because of adverse environmental conditions as well as inadequate evaluation. Parent control occurs only on the female side. This kind of lack of control on environmental effect and male parent effect can be minimized when clonal selection is done through progeny test or hybridization followed by individual selection.

Hybridization: Hybridization can expand the gene pool in relation to genes with different adaptive values, as long as the hybrids are able to produce segregating progeny in future generations (Stebbins, 1974). Evidence of hybrid vigour with an increase of up to 153% in the nut yield as compared to plants derived from outcrossed pollinations were reported by Damodaran (1975). The prevalence of heterosis in hybrids of cashew with respect to nut yield, nut weight and kernel weight were reported by Manoj and George (1993) and Cavalcanti *et al.* (2000). Hybridization work carried out at several cashew research centres in India (Puttur, Vengurla, Bapatla, Madakkathara and Bhubaneswar) showed that hybrid vigour existed for yield and hybrids were found to perform better than selections in cashew.

Floral biology should be properly understood before taking up hybridization. Cashew is an andromonoecious plant having hermaphrodite or bisexual and staminate or male flowers in the same panicle or inflorescence. Cashew is a cross pollinated crop. As cashew pollen grains are sticky and heavy, it is not wind pollinated. The cross-pollination in cashew occurs in nature through insects (entomophily).

The hybridization technique in cashew consists of clipping off all the open flowers in a panicle on female parent tree on the day of pollination, opening of bisexual flower bud, removal of anthers from bisexual flower bud, followed by dusting of pollen from selected male parent on stigmatic surface of emasculated bisexual flower and finally covering the pollinated flower (stigma along with style) with butter paper bag or butter paper roll. At Directorate of Cashew Research (DCR), Puttur, two methods of covering the pollinated flower, namely, butter paper roll (pantographic paper roll, which is prepared using a small piece of butter paper sheet of 2.5 × 1.5 cm in size by rolling it with the help of fingers) and butter paper bag were compared. The initial hybrid fruit setting and mature hybrid nuts obtained at the harvest time were determined. The butter paper roll method resulted in 17.84% fruit set as against 13% setting associated with paper bag method indicating the superiority of paper roll over paper bag in covering the pollinated bisexual flowers (*NRC on Cashew Annual Report; 2003-04*).

Hybrid vigour: It was observed from the hybridisation work carried out at Anakkayam (Kerala) that whenever an exotic parent was involved, the progeny showed better performance than crosses between local types. These results are in agreement with the established concept that hybrid vigour is best manifested in crosses involving parents with greater genetic diversity. Hybridization work carried out at other centres (Vengurla, Bapatla and Vridhachalam) also confirms expression of hybrid vigour in cashew. Comparison of the performance of hybrids with open pollinated and selfed progenies also showed the superiority of the hybrids over others (Nambiar *et al.,* 1990). Manoj and George (1993) reported heterosis for nut yield per tree in 10-year-old F_1 hybrids and the standard heterosis (standard variety-Madakkathara-1) ranged from 11.0 – 33.4%. They have also reported standard heterosis for mean nut weight (11.4 – 54.8%) and weight of kernel (29.8 – 84.7%).

Hybrid evaluation strategies

In a perennial heterozygous crop like cashew, the process of hybrid evaluation is quite long due to juvenile phase (3-4 years) of hybrid seedlings and longer time required to reach stabilized yield (six harvests from third year). At ICAR-DCR, Puttur, the following two strategies were attempted for evaluating hybrid seedlings.

Basic or Original strategy

- Raising hybrid seedlings in nursery
- Field planting in un-replicated trial
- Evaluation of hybrids for 5-6 harvests
- Vegetative propagation of best hybrids
- Field planting the grafts of best hybrids in replicated trial
- Evaluation of clonally propagated hybrids for 6 annual harvests.

This strategy needs lesser land area leading to lesser expense. However, more time is required to develop hybrids. The chances of losing hybrid plants, which are in unreplicated trial, due to the attack of CSRB, is the other disadvantage of this strategy.

Modified strategy

- Planting hybrid seedlings in Trenches for scion production (Trench size: 12 m × 0.6 m × 0.6 m)

- De-topping hybrid seedlings planted in trenches for increasing the scion stick availability
- Grafting the scion sticks from hybrid seedlings on to a common seedling rootstock

The possibility of evaluating hybrids in replicated trial from the beginning itself, which saves time in hybrid evaluation, is the advantage of the modified strategy. The hybrid seedlings up on de-topping produce only solitary shoots and scion sticks will not be mature enough for grafting. This leads to setback in multiplication of hybrid seedlings. Further, inferior hybrids are also carried forward and hence, more expenditure on land, input and man power. At DCR, Puttur, the original strategy was adopted after comparing merits and demerits of both the strategies.

Breeding accomplishments

Indian scenario

In 1951, the Indian Council of Agricultural Research took first attempt by sanctioning an *ad-hoc* scheme for research on cashew at Ullal station (Karnataka) and regional stations at Kottarakkara (Kerala) and Vengurla (Maharashtra). Another station was started at Bapatla (Andhra Pradesh) and Jorhat (Asom) in 1955. Subsequently, in 1962, the Kottarakkara station was terminated when the state government started a research station at Anakkayam in Malappuram District (Kerala). In 1970, the All India Co-ordinated Spices and Cashew nut Improvement Project was sanctioned by the ICAR under which a coordinating centre was established at the Central Plantation Crops Research Institute, Kasargod with participating centres at Anakkayam subsequently shifted at Madakkathara (Kerala), Vridhachalam(Tamil Nadu),Vengurla(Maharashtra) and Bapatla (Andhra Pradesh). The hybridization in cashew was started at Kottarakkara, Kerala(1963) and later continued at Cashew Research Station (CRS), Anakkayam and currently at CRS, Madakkathara. In all, 53 varieties have been released from different research centres and DCR (formerly NRCC). Among them 33 are selections and 20 are hybrids. Twenty-four varieties are having kernels with export grade (W 180 - W 240). The salient features of varieties are given below.

Andhra Pradesh

The Andhra Pradesh Horticultural University (known as formerly acharya NG Ranga Agricultural University) has released the following seven cashew varieties for cultivation in Andhra Pradesh based on trials conducted at Cashew Research Station, Bapatala.

'BPP 1': This is a hybrid (H2/11) developed from the cross between Tree No.1 as female parent and Tree No.273 as male parent and was released in the year 1980. The average yield is 10 kg/tree. The percentage of perfect flowers is about 13 with a fruit set of eight fruits per panicle. Nuts are medium in size with a nut weight of 5g and the shelling percentage of 27.5. Kernel protein percentage is 19.8%. The apple is medium in size and yellow in colour with the juice content of 57%. Kernel grade is W 400. This hybrid is withdrawn from recommendation for cultivation.

'BPP 2': This is also a hybrid (H2/12) with the same parentage as BPP 1, that is, T.No.1 × T.No.273. Released in 1980. The average yield is 11 kg/tree. The nuts are small with a nut weight of 4g and shelling percentage of 25.7. The percentage of bisexual flowers is 8 with the fruit set of 8 to 10/panicle. The protein content of kernels is 21.3%. Juice content in apple is 67%. Kernel grade is W 450. This hybrid is withdrawn from recommendation for cultivation.

'BPP 3': This is a selection from the germplasm collected from Simhachalam in Vishakapatnam district of Andhra Pradesh (3/3 Simhachalam) and the variety was released in 1980. Bisexual flower percentage is 15%. The average yield recorded was 11 kg/tree. The nut weight is 4.8g with shelling percentage of 28.1. Protein content is 19.0%. The apple has juice content of 67%. Kernel grade is W 400. This selection is withdrawn from recommendation for cultivation.

'BPP 4': This is the selection from germplasm accession of 9/8 Epurupalem and released in 1980. This variety has distinct light pink pigmentation in their youngest leaves. The bisexual flower percentage is about 8%. The average yield is 10.5kg/tree with a nut weight of 6g. Shelling percentage is poor (23%). Protein contents of kernels is 18.1%. The apple colour is yellow and shape is conical. Kernel grade is W 400.

'BPP 5': This is the selection from germplasm accession T.No.1. This variety was released in 1980. The bisexual flower percentage is 10%. The nut weight is 5.2g. The mean nut yield is 11kg/tree with shelling percentage of only 24. Protein percentage is also rather low (16.8%). Apple has juice content of 64%. Kernel grade is W 400. This selection is withdrawn from recommendation for cultivation.

'BPP 6': This is also a selection from germplasm collection. Tree no.56 was the source material for this variety released in 1980. The mean bisexual flower percentage is 8% and mean yield of nuts is about 10.5kg/tree. The nut weight is 5.2g and shelling percentage of this variety is also only 24. Protein percentage is 20.3%. Juice content of apple is very high (74%). Kernel grade is W 400.

'BPP 8' (H 2/16): It is a hybrid (H2/16) derived from the cross Tree No.1 x Tree No.39 and released in 1993 for general cultivation in Andhra Pradesh. It has been performing well in Odisha and West Bengal also. This variety is superior to all the other six varieties developed from Bapatla. The variety has mean yield of 14 kg/tree with better nut size (8.2g). Shelling percentage (29%) of this variety is also better than the rest of the varieties released from Bapatla so far. Kernel grade is W 210 (export grade).

Tamil Nadu

The Tamil Nadu Agricultural University released four varieties from its Regional Research Station, Vridhachalam.

VRI-1 (M 10/4): This variety is a selection from germplasm collected from Vazhisodhanipalayam in South Arcot district of Tamil Nadu. It has a medium sized tree having setting of 5 to 7 fruits per panicle. It was released in the year 1981 and the mean yield is 7.2 kg/tree under Vridhachalam conditions. The nut size is small with 5g nut weight and shelling percentage of 28%. The kernel grade is W 320. This variety is withdrawn from recommendation for cultivation.

VRI-2 (M 44/3): This is the only variety released at national level based on the multilocational trial conducted at six coordinating centres. This national variety is a selection from the germplasm (T. No. 1668) collected from Kattupalli village of Minjur block of Changelpattu district of Tamil Nadu and released in 1985. This variety is found to be ‘prepotent’ - meaning that the variety is capable of giving good seedling progenies irrespective of male parents. This variety is found adaptable over wide range of soils and regions. The percentage of bisexual flowers is 10 with a setting of 5-8 fruits per panicle. The average yield is about 7.4 kg/tree. The nut size is small with 5.1g nut weight with shelling percentage of 28.3%. The kernel grade is W 320. The colour of the apple is pinkish yellow. This variety is withdrawn from recommendation for cultivation.

‘VRI-3’ (M 26/2): This is a selection from seedling progeny of a high yielding tree collected from a village Edayanchavadi in South Arcot District of Tamil Nadu and was released in 1991. It has 12.1% perfect flowers. The average yield of this variety is about 10 kg/tree, thus the increase over VRI-2 and VRI-1 being 35 to 39%, respectively. The nut size is medium with 7.2g nut weight and shelling percentage of 29.1%. The kernel grade conforms to W 210 export grade. This variety is picking up fast among farmers of not only of Tamil Nadu but also of other states.

‘VRI (Cw) 5’: It is a hybrid developed from the cross M 26/2 (VRI-3) x M 26/1. This was released in the year 2007. The canopy type is compact and branching habit is spreading. The average yield of this variety is about 13.2 kg/tree. The nut size is medium with 7.2g nut weight and shelling percentage of 30.5%. The kernel grade is W 210. The apple colour is pink with yellow tinge and the shape is round and the apple weight is ranging from 50.0 to 53.5 g. This is recommended for all the cashew growing districts of Tamil Nadu.

Odisha

‘Bhubaneshwar-1’: In IX Biennial Workshop of AICRP on Cashew held in 1989 at Coimbatore, Bhubaneswar-1 for Odisha was recommended for release. It is a selection from seedling progeny of WBDC V (Vengurla 36/3), a collection from Regional Fruit Research Station, Vengurla and released in 1989. Flowering season is from January to March with medium duration of 70 days. It has cluster bearing habit with about 12 fruits per bunch. This variety has average yield of 10 kg/tree with small nut size (4.6g nut weight). The shelling percentage is high (32%) with kernel grade of W 320. It has been found suitable for cultivation in the sandy and laterite soils of the East Coast.

‘Jagannath (BH 6)’: It is a mid-season flowering (Jan-Mar) variety having bold nuts with 8.6 g nut weight. The variety gives an averagenut yield of 2.1 t/ha (10.5 kg/tree) and possesses high shelling percentage (32.5%).

‘Balabhadra (BH 85)’: It is an Early flowering (Dec-Feb) variety having bold nuts with 7.4 g nut weight. The variety gives an average nut yield of 2.0 t/ha (10.0 kg/tree) and possesses high shelling percentage (30.0%).

West Bengal

The variety Jhargram 1 and Bidhan Jhargram 2 were recommended in AICRP Workshop held at Coimbatore (1989) and Kalyani (2013), respectively.

kernel grade is W 210. Apple colour is yellowish orange with cylindrical shape and with average weight of 105 g. Juice content ranges from 68.0 – 72.0%. It is recommended to the state of Goa.

Kerala

Kerala Agricultural University released eight varieties so far under AICRP-cashew programme. BLA 139-1 was released as Anakkayam-1 in 1985 for cultivation in Kerala. In 1987, three selections (BLA 39-4, NDR 2-1 and K-22-1) were released. In 1993 two hybrids (Kanaka and Dhana) and in 1995 one hybrid (Priyanka) were released. In 1999 one more hybrid (Amrutha) was released.

Varieties released by Cashew Research Station, Madakkathara

'BLA 39-4 (Madakkathara-1)': It is a selection from seedling progeny of Tree No. 39 of Bapatla. The variety was released in 1987. The flowering season is from November to January. The mean yield is 13.8 kg/tree. The nuts are medium-sized with 6.2g nut weight. Shelling percentage is 26.8. The kernel weight is 1.6g and kernel quality conforms to W 280. Apple colour is yellow with a weight of 52g. Reducing sugar content is 10.5%.

'NDR 2-1 (Madakkathara-2)': This is a selection from germplasm collection made from Neduvellur in Kerala maintained at CRS, Anakkayam. This variety was also released in 1987. The mean yield is 17 kg/tree. The nuts are bold (7.3 g nut weight) with shelling percentage of 26.2%. Kernel weight is 2g having a count of W 240 export grade. Apple colour is red and with weight of apple 63.3g. Reducing sugar content is 7.8%.

'K-22-1': It is a selection from clonal progeny of Kottarakkara-22 (Layer 23) maintained at CRS, Kottarakkara, and was released in 1987. This variety has a mean yield of 13.2 kg/tree. The nut weight is 6.2g and the shelling percentage is 26.5. The kernel weight is 1.6g with kernel count of W 280. The apple colour is red and weight of apple is 74g. Reducing sugar is 7.2%.

'Kanaka' (H 1598): It is a hybrid of cross BLA 139-1 × H 3 - 13 released in 1993 from CRS, Madakkathara. It is an early variety. Average yield is 19 kg/tree with a mean nut weight of 6.8g. Shelling percentage is 31%. Kernel weight is 2.1g and quality of kernels conform to W 210 export grade. Colour of apple is yellow.

'Dhana' (H 1608): It is a hybrid of cross ALGD-1 × K 30-1 released from CRS, Madakkathara in 1993. It has cluster bearing habit. The mean yield is 17.5 kg/tree with a shelling percentage of 28. Kernel weight is 2.2g conforming to export grade of W 210. Yellow is the apple colour.

'Priyanka' (H 1591): This is a hybrid with parentage of BLA 139-1 × K 30-1 with jumbo nut size developed and released from CRS, Madakkathara in 1995. The yield of nuts is 16.9 kg/tree. The nut weight is 10.8g with kernel weight of 2.87g. Shelling percentage is 26.5. The export grade of kernels conforms to W 180. Colour of apple is yellowish-red. Apple weight is 135g and has 57.4% of juice.

'Amrutha' (H 1597): This is a hybrid with parentage of BLA 139-1 × H 3-13 developed and released from CRS, Madakkathara in 1999. It has yield potential of 18.4 kg/tree with nut weight of 7.2 g. Shelling percentage is 31.6 and with kernel weight of 2.2 g and kernel grade W 210. Colour of apple is yellow and

apple weight is 76.0 g. Apple has 57.4% juice content. It is recommended to Kerala.

'Sulabha': It is a selection released in 1996 with compact canopy and intensive branching. It is bold nut type with 9.8 g nut weight. The tree yields 21.9 kg of nuts with high shelling percentage (29.4%). The kernel weight is 2.88 g and grade is W 210. It bears light orange apples.

'Damodar': It is a hybrid released during 2002 with a parentage of BLA 139-1 × H 3-13. It has yield potential of 13.7 kg/tree with nut weight of 8.2 g. shelling percentage is 27.3. The kernel weight is 2.0 g and grade is W 240. It bears yellow red apples.

'Poornima': It is a hybrid released during 2006 with a parentage of BLA 139-1 × K -30-1. It has yield potential of 14.1 kg/tree with nut weight of 7.8 g. Shelling percentage is 31.0. The kernel weight is 2.6 g and grade is W 210. It bears yellow apples.

'Raghav': It is a hybrid released during 2002 with a parentage of ALGD -1 × K -30-1. It has yield potential of 14.7 kg/tree with nut weight of 9.2 g. Shelling percentage is 26.6. The kernel weight is 2.27 g and grade is W 210. It bears yellow apples.

Varieties released by Cashew Research Station, Anakkayam

'Anakkayam-1' (BLA 139-1): This is a selection from the seedling progeny of Tree No 139 of germplasm collection of Agricultural College, Bapatla, Andhra Pradesh. The variety was released in 1985. The variety has a short flowering duration. The yield is 12 kg/tree. The nut weight is 6g and shelling percentage is 28. Colour of apple is pink. Average apple weight is 67.5g. Reducing sugar content is 10%. Kernel grade is W 280.

'Dharasree': It is a hybrid released in 1996 with a parentage of T 30 × Brazil-18. It has yield potential of 15.0 kg/tree with nut weight of 7.8 g. Shelling percentage is 30.5. The kernel weight is 2.4 g and grade is W 240. It bears yellowish pink apples.

'Akshaya': It is a hybrid released in 1998 with a parentage of H-4-7 × K -30-1. It has yield potential of 11.0 kg/tree with nut weight of 11.0 g. Shelling percentage is 28.4. The kernel weight is 3.12 g and grade is W 180. It bears yellow apples.

'Anagha': It is a hybrid released in 1998 with a parentage of T 20 × K -30-1. It has yield potential of 13.7 kg/tree with nut weight of 10.0 g. Shelling percentage is 29.0. The kernel weight is 2.9 g and grade is W 180. It bears orange red apples.

Karnataka

A total of five varieties have been developed and released by ARS, Ullal (Ullal-1, 2, 3, 4 and UN 50). Directoprate of Cashew Research, Puttur (known as formerly NRC on Cashew) has released three varieties (Selection-1, Selection-2 and Bhaskara). Chintamani-1 and Chintamani-2 were developed and released by ARS, Chintamani, Kolar District of Karnataka for maidan tract of Karnataka.

Varieties released from ARS, UAS, Ullal

'Ullal-1': This is a selection from the germplasm collected from Taliparamba

in Kerala (8/46 Taliparamba) and released by ARS, UAS in 1984. The variety has 2-3% of bisexual flowers. The average yield is 16 kg/tree. The duration of harvest is long (about 110 days). The nut weight is 6.7g with shelling percentage of 30.7%. The colour of apple is yellow. Kernel grade is W210.

'Ullal-2': This is a selection from germplasm collected from Guntur in Andhra Pradesh (3/67 Guntur). This variety was also released in 1984. The variety is a late flowering type (December to March) with very short duration of harvest (85 days). The yield is about 9 kg/tree. The nut size is medium with 6g nut weight and shelling percentage is 30.5. Colour of apple is light red. Kernel grade is W 240. This variety is withdrawn from recommendation for cultivation.

'Ullal-3': It is a selection from 5/37 Manjeri and released in 1993. It is early in flowering (November - January) and fruiting period is very short (50-60 days). The fruiting is from January to March and sometimes starts from last week of December. It is a high-yielding variety with average yield of 14.7 kg/tree. The nut size is medium with nut weight of 7g. The shelling percentage is 30% and the kernel grade conforming to W 210 grade. The colour of apple is red.

'Ullal-4': It is a selection from 2/77 Tuni Andhra and released in 1994 for general cultivation. The average yield is 9.5 kg/tree. The nut size is medium with 7.2g nut weight. Shelling percentage is 31%. Export grade of kernels conforms to W 210 counts/lb. The colour of apple is yellow and apple weight is 75g.

'UN-50': This is a selection from Nileshwar 2/27 (T.No.25) and released in 1995. This is a medium duration variety. The average nut yield is 10.5 kg/tree. The nut weight is 9 g and shelling percentage is 32.8%. The kernels are suitable for export with more than 85% of kernels coming under W 180 export grade. Apple colour is yellow.

Varieties from DCR, Puttur

'NRCC Selection-1': This variety was released in 1989. This is a selection from segregating progeny of germplasm 3/8 Simhachalam (VTH 107/3) originally a collection from Andhra Pradesh. It is a late flowering type (December - February) with a flowering duration of 82 days. The number of fruits per bunch is 5. The yield, on an average, is 10 kg/tree. The nut weight is 7.6g. The shelling percentage is 28.8% and the kernel grade conforms to export grade of W 210. Apple colour is yellow. This variety is withdrawn from recommendation for cultivation.

'NRCC Selection-2': This is a selection from the segregating seedling progeny of 2/9 Dicherla (VTH 40/1) originally a collection made from Andhra Pradesh. This variety was released in 1989. It has a mid-season flowering habit (November - January) with a flowering duration of 74 days. The number of fruits per bunch is 3. The average yield is 9 kg/tree. The nut weight is 9.2g. The shelling percentage is 28.6% and kernel grade conforms to export grade W 210. Colour of apple is orange red.

'Bhaskara': This variety was released during March 2006 for coastal region of Karnataka. This is having mid-season flowering habit (December-March) with a flowering duration of 60 days and has potential to escape from the attack of the tea mosquito bug (TMB) under low to moderate outbreak situation. But the regular insecticidal spray against TMB is essential under severe outbreak situation. The

number of fruits per panicle (bunch) ranged from 4 to 13. The average yield on 13th year was 10.7 kg/tree with highest yield of 19 kg/tree. The nut and kernel weight are 7.4 g and 2.2 g, respectively. The shelling percentage is 30.6 and kernel grade conforms to export grade W240. The apple colour is pinkish orange and juice content is 67.5%. This variety is very popular among the farmers of Dakshina Kannada District of Karnataka and also in neighbouring districts of Karnataka and Kerala.

Varieties from ARS, Chintamani

Plains region is characterized by leveled land with very low rainfall. The soil is deep and red sandy loam in nature. The Kolar region had a coordinating centre at Chintamani and two varieties by name Chintamani-1 and Chintamani-2 were released from this Centre.

Chintamani-1: It is a selection from 8/46 Taliparamba, a germplasm collection from Taliparamba in Kerala and released in 1993 from ARS, Chintamani. This variety is recommended for plain region of Karnataka. Its flowering period is from January to April with 2-4 nuts per panicle. The average yield of this variety is 7.2 kg/tree as against the 2 kg/tree of the local varieties. The nut weight is 6.9g with shelling percentage of 31%. The kernel grade is W 210.

Chintamani-2: It is a seedling selection from ME 4/4 of ARS, Ullal and released in 2007 from ARS, Chintamani. This variety is also recommended for plain region of Karnataka. The canopy type is compact and with intensive branching. Its flowering period is from December to January. The average yield of this variety is 12.4 kg/tree. The nut weight is 7.9g with shelling percentage of 30%. The

State	Recommended varieties
Karnataka	NRCC Sel-2, Bhaskara, Ullal-1, Ullal-3, Ullal-4, UN-50, Vengurla-1 (Uttara Kannada), Vengurla-4 (Uttara Kannada), Vengurla-7 (Uttara Kannada)
Karnataka (Plains region)	Chintamani-1, Chintamani-2 and Dhana (H 1608)
Kerala	BLA-39-4 (Madakkathara-1), NDR-2-1 (Madakkathara-2), K-22-1, Kanaka (H 1598), Dhana (H 1608), Priyanka (H 1591), Amrutha (H 1597), VRI-3
Maharashtra	Vengurla-1, Vengurla-4, Vengurla-6, Vengurla-7
Goa	Goa-1, Goa-2, Vengurla-1, Vengurla-4, Vengurla-6, Vengurla-7
West Bengal	Jhargram-1, Bidan Jhargram-2, BPP-8
Odisha	Bhubaneswar-1, BPP-8, Dhana
Tamil Nadu	VRI-3, VRI (Cw) 5
Andhra Pradesh	BPP-4, BPP-6, BPP-8
Chattisgarh	Indira Kaju-1

kernel weight is 2.35 g. The kernel grade conforms to W 210. The colour of the apple is red purple with average weight of apple of 70g. Juice content is 60%.

A National Group meeting was convened in 1988 to finalize production strategy of different plantation crops. This group suggested cultivation of several varieties of cashew in different states based on the varietal performance in different regions and their availability. Subsequently several cashew varieties have been released for general cultivation in different states. Some varieties developed in one state/ region were found to perform well in other states/regions as well. The state-wise varieties recommended are given on page no. 82

Other cashew growing countries

The varieties developed through crop improvement efforts in different cashew growing countries are: Brazil-CP 12, CCP 06, CCP 09, CCP 76, CCP 1001, BRS 189, BRS 226, BRS 265, BRS 274, BRS 275, Embrapa 50, Embrapa 51; Vietnam-PN 1, LG1,CH1, MH 5/4, MH4/5, MH2/7, MH2/6, EF-04, EK-24, BD01, KP11, KP12, DH 66 -14, DH 67-15, BO 1, TL2/11, TL6/3, and TL11/2; China- GA-63, HL2-13, HL2-21, FL-30 and CP63-36; Tanzania- AC 4, AZA 2; Mozambique-V.12, AD-IV.1, CP76 11.3 and CP9 XII.8 and Sri Lanka-WUCC 05, WUCC 08, WUCC 09, WUCC 13, WUCC 19 and WUCC 21.

The variability in Brazilian cashew is viewed mainly from two angles, viz., tall and vigorous types with a tree height of 8-15 m, canopy diameter of up to 20 m and yield ranging from 1-180kg/tree of raw nuts; dwarf types characterized by precocious nature (flowering between 16-18 months after planting), short stature of tree with a height up to 4 m, having a homogenous canopy, with a stem diameter and canopy diameter smaller than the common types. Use of different breeding procedures like poly cross method, selection between and within the progenies, inter and intra specific hybridization has resulted in the development of dwarf cashew clones (Paiva *et.al.*, 2009).

In Nigeria, genetic material introduced from India, Tanzania and Mozambique served as a basis for generation of 25 half sib genotypes with high yielding potential. In Mozambique, segregating seed progenies of Brazilian dwarf types served as a basis of crop improvement programme (Prasad *et al.,* 2000). In Australia, Indian and Brazilian accessions were utilized for hybridization programme.

Breeding for special characters

(a) Breeding for bold nuts

Bolder cashew kernels fetch premium price in the international markets. Hence, emphasis is being given to develop new improved cashew varieties with bold nut size and high yield potential. More than 70 bold nut types having a mean nut weight of 12-21 g have been collected by Regional Fruit Research Station, Vengurla (Maharashtra). Some of these bold nut types have been used in the hybridization with existing high yielding varieties like Vengurla-2 and Vengurla-5. Some of the hybrids, viz., H-610, H-613 had given high yield and bold nut size (10 g) (Gunjate and Deshpande, 1994). Large scale hybridization was carried out under an ICAR *ad-hoc* scheme 'Network programme on Hybridization in Cashew' Among the hybrid seedlings under evaluation at DCR, Puttur, hybrids namely H-43, H-66, H-68 (cross combinations of NRCC Selection-2 × Bhutnath-II), H-125 and H-126 (cross combinations of NRCC Selection-2 × Bhedasi) have been identified as promising and found to be consistently performing good for both annual and cumulative yield. Upon testing under replicated trial, the hybrids, namely H-125 and H-126 were found promising with a special character of jumbo nut (nut weight of 11-12g) with kernel grade better than W150.

(b) Breeding for dwarfness

Currently, the concept of high density planting using dwarf genotypes with compact canopy is gaining more acceptances in cashew cultivation. In Brazil, dwarf root stock seedlings have been used for several years. More recently, research workers were able to succeed by using seedlings from *Anacardium microcarpum* Ducke and *A. Pumilum*, the slow growing species. These two types of root stocks, more markedly the latter, exert a dwarfing effect and induce earlier bearing upon the grafted trees. No symptoms of root stock–scion incompatibility have been observed so far (Ascenso, 1986). The spreading nature of the tree is not desired for commercial orchards as it does not allow high density plantings (Chacko *et al.*1990). Therefore, trees with more erect growth are currently being selected in Australia. Efforts are also on at Directorate of Cashew Research, Puttur to develop dwarf and compact hybrids with high yield and better nut characters. These hybrids developed by hybridizing recommended popular varieties with dwarf types from germplasm block as donors showed the signs of precocity and reduced growth habit.

(c) Breeding for drought tolerance

Cashew is predominantly grown in rainfed conditions on marginal soils and hence often experiences drought/stress. Plants adaptation to such situations by increasing efficiency of water use for biomass production is an important physiological trait. Any attempt to improve water use efficiency (WUE) primarily depends on the existence of sufficient genetic variability and availability of a convenient technique for its rapid determination. Genetic variability in WUE was determined by both Gravimetry and Gas Exchange approaches in 10 cashew clones. Carbon Isotope Discrimination (CID) ($D^{13}C$) could be a potential tool in quantifying the variability in WUE. Plants discriminate against the heavy isotope of carbon $D^{13}C$ during photosynthesis. This carbon isotope discrimination (CID) ($D^{13}C$) has been well established as a measure of WUE in several crop plants. A strong association between $D^{13}C$ and WUE in cashew suggests that CID techniques can be employed as a powerful approach to assess the genetic variability in cashew also. Breeding for WUE will succeed only when selection for high WUE accompanies higher growth rates (Udaya Kumar *et al.,* 2000). Not much work has been done on this aspect of cashew so far. However, cashew varieties namely, VRI-2, VRI-3, BPP-1, BPP-2, BPP-8 and Dhana were reported to be drought tolerant (Anon, 1997). Therefore, screening of high yielding types in drought prone areas for yield may be taken up.

(d) Breeding for pest resistance/tolerance

Tea mosquito bug, stem and root borer and thrips are the major pests of cashew for which resistant/tolerant types need to be developed. Laboratory screening of 27 accessions at DCR to tea mosquito tolerance has indicated that two accessions/types, namely G 11/6(released and popularly known as "Bhaskara) and VTH 153/1, are relatively tolerant than the susceptible check and some of the test accessions (Nagaraja *et al.,* 1990). Uthaiah *et al.* (1994) reported low infestation of tea mosquito on type 9/72 at Ullal, Karnataka as compared to the susceptible types 2/48 and 145. The hybrids were also generated from cross combinations involving popular and recommended varieties with wild species like *Anacardium microcarpum* and *A. orthonianum* to look for tolerance to pests of cashew. These inter specific hybrids are under field evaluation at DCR, Puttur.

(e) Breeding for quality parameters of cashew kernels

At present no emphasis is placed on the quality of cashew kernel. But with increasing competition from African countries in the international market, it is essential to breed varieties with superior quality. Data collected so far from defatted kernel flour indicated that there is considerable variability for protein ranging from 32-44 per cent, lysine 35-75 mg/mg protein, vitamin-C 144-274 mg/100g and kernel sugar 10-19 per cent. It is desirable to identify the varieties with the protein level of over 35 per cent, lysine level of over 50 mg/mg protein and sugar content of not more than 14 percent (Bhagavan, 1986).

(f) Mutation breeding

Occurrence of natural mutants and bud sports in woody trees like cashew is very rare. Induction of mutation with chemical or irradiation has not been practised regularly. However, this tool appears to be very potent from the work initiated at Regional Fruit Research Station, Vengurle, in 1985. The irradiation of cashew bud sticks with one, two and three Kr gamma (γ) rays at the Bhaba Atomic Research Centre, Bombay and soft wood grafting led to mortality of all the bud sticks subjected to 3 Kr dose. Whereas those subjected to 1 and 2 Kr dose led to 100% sprouting and variation in phenotypic characters (Anon., 1985). The variations included changes in leaf shape, leaf thickness and leaf venation. When these plants were examined subsequently, many were observed to revert to original characters in subsequent growth. At Cashew Research Station, Madakkathara (Kerala), dwarfism was observed in seedlings produced from the nuts irradiated at 40 Kr to 60 Kr using Cobalt 60. The LD50 value for cashew nut is between 40-50 Kr. The dwarf seedlings have been planted in the field and are being observed. Beyond 60 Kr, the seed nuts did not germinate (Abdul Salam *et al.,* 1992).

(g) Distant hybridization

The National Cashew Field Gene Bank at the Directorate of Cashew Research, Puttur conserves 539 germplasm accessions including three wild species *Anacardium microcarpum, A. othonianum* and *A. pumilum.* An attempt of interspecific hybridization with four varieties (Ullal-1,Ullal-3, Vengurla -4 and Bhaskara) of cultivated cashew (*Anacardium occidentale* L.) was made during

2010 involving two wild species viz, *Anacardium microcarpum* and *Anacardium othonianum* with the objective of introgressing characters related to biotic and abiotic stress tolerance. The average seed set of all the successful cross combinations put together was 53%. The average seed set was 51% when *A. microcarpum* was used either as male or female parent, while, it was 55% when *A. othonianum* was used as male parent. However, highest success of 71% seed set was observed in the cross Ullal-3 × *A. microcarpum* and the lowest success of 25% seed set was observed in the cross Vengurla-4 × *A. microcarpum*. The varied success could be attributed to extent of cross compatibility between different combinations involving wild species of cashew.

The frequency distribution of girth, height, spread (in both directions) showed approximately symmetrical distribution. The number of flowering laterals in East, West, North and South directions showed highly positively skewed distribution indicating the absence of individuals having higher number of flowering laterals. However, non-flowering laterals in East, West and South directions showed approximately symmetric distribution and in North direction it showed moderately positively skewed distribution. The yield of interspecific progenies (N=189) ranged from 0 - 0.83 kg/tree in the fourth year after planting with a mean yield of 0.34 kg/tree. The frequency distribution pattern of yield per tree revealed that it was approximately symmetrically distributed (Skewness = 0.23). It can be observed that yield in interspecific progenies in very low due to introgression of wild alleles. Making one or two further backcrosses may help in improving the yield levels along with tolerance to biotic and abiotic stress in these progenies (Adiga *et al.*, 2015)

Future strategies

Hitherto, crop improvement in cashew was aimed at higher nut yield with high- shelling percentage. Recently, efforts are under progress to breed bold nut types, dwarf types to suit high density orchard as well as to introgress desirable genes from wild species of *Anacardium* to the recommended varieties by hybridizing with them. In order to reorient the crop improvement programme to cater the present and future needs of cashew industry, the following strategies seem to be appropriate.

- Broadening of genetic base to aid in crop improvement programme to address the challenges anticipated in the future.
- Conservation, evaluation and screening of germplasm for biotic and abiotic stresses in view of changing climatic scenario.
- Polyclonal breeding for natural gene pyramiding followed by development of new hybrids.
- Molecular marker assisted selection/molecular breeding to speed up the process of evolving desired varieties.
- Development of genotypes with high productivity (minimum 2 tonnes/ha) even under conditions of lower soil fertility and varied climate.
- Rootstock breeding to address issues related to tree vigour (dwarfing), adaptability to lower soil fertility status, biotic and abiotic stresses.
- Breeding for resistance/tolerance to major insect pests like Cashew Stem

and Root Borer, Tea Mosquito Bug and other minor pests.

- Breeding for resistance/tolerance to diseases like anthracnose, powdery mildew, panicle drying, gummosis etc.
- Breeding for cashew apple with higher size, shelf life, juice content, TSS, vitamin C, antioxidants etc to address issues related to secondary agriculture.
- Breeding for varied Cashew Nut Shell Liquid (CNSL) content. The varieties can be exploited for higher recovery of CNSL which has varied industrial use.

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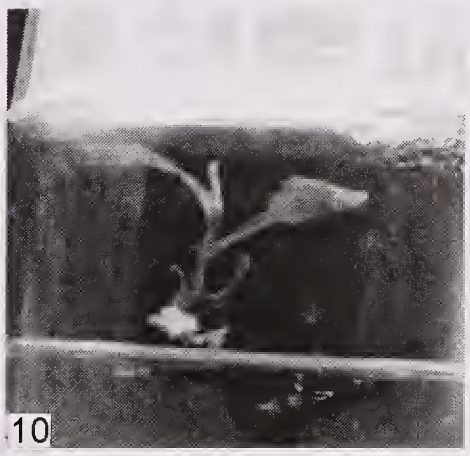
bud proliferation in cotyledonary nodes cultured on Murashige and Skoog (1962) (MS) medium containing BAP (10 mg/l) and sequentially transferring cultures to media with reduced BAP and containing addents like coconut water, maltose, L-arginine and or DL-valine. Similarly, proliferation of axillary shoot buds in cotyledonary nodes cultured along with cotyledons on MS medium containing 2.25mg/l BAP and 0.2mg/l IBA was observed. By repeated culture on same medium, the shoot bud proliferation increased (40-60 shoot buds) within a span of 3-4 months. Cotyledonary nodes without cotyledons also showed limited shoot bud proliferation (4-8 buds/explants) (Thimmappaiah, 1997). Apart from cotyledonary nodes, nodal cuttings and shoot tips were also found capable of axillary shoot bud proliferation (Lievens *et al.*, 1989; Nair and Mohanakumaran, 1993; Das *et al.*, 1996). Age and cultural conditions influenced the rate of multiplication in nodal cultures (Sardinha *et al.,* 1993). Nodal explants showed maximum bud break on hormone free MS medium and hormones like BAP and NAA had no significant effect (Thimmappaiah, 1997). Gemas and Bessa (2006) observed combination of maltose and fructose (83 mM) influencing the yield of well-developed shoots. Lievens *et al.* (1989) observed overlay of BAP in liquid phase over the semi-solid cytokinin medium to help in axillary shoot bud formation. Das *et al.* (1996) reported better shoot formation in media containing all the three cytokinins (BAP, kinetin, zeatin). Microshoots derived from cotyledonary nodes showed better rooting than nodal shoots (Aliyu and Awopetu, 2005). D'Silva and D'Souza (1992) used a combination of 2.9 μM IAA and 4.9 μM IBA to root shoots *in vitro*. Das *et al.* (1996) used pulse treatment with IBA and *Agrobacterium rhizogenes* for rooting of micro-shoots. Similarly, others had used auxins like NAA (Leva and Falcone, 1990) and IBA (Lievens *et al.*, 1989; Mantell *et al.*, 1997) for rooting in cashew.

A reproducible regeneration protocol from shoot explants was standardized at Directorate of Cashew Research (DCR), Puttur. Media requirement for initiation, multiplication, shoot bud elongation, rooting, potting and hardening processes were standardized (Thimmappaiah and Shirly, 1999; Thimmappaiah *et al.*, 2007). Nodal explants excised from one month old *in vitro* raised seedlings (Fig. 5.1) were initiated into culture on three- fourth strength MS salt hormone free medium and their culture subsequently after 4-6 weeks on TDZ medium or direct culturing of shoot explants immediately after excision on MS medium containing thidiazuron (TDZ) alone (0.05 – 2 mg/l) or TDZ (0.1 mg/l) in combination with BA (0.6, 1.0 mg/l) and IBA or NAA (0.05 – 0.5 mg/l each) showed shoot-bud proliferation (Fig. 5.2) ranging from 1-13 buds/explant with an average multiplication rate of 1:4. The shoot buds induced were elongated either on hormone free half MS medium or Raj Bhanasli medium (RBM) (Raj Bhanasli, 1990) supplemented with 500 mg/l glutamine and activated charcoal (0.2%). The elongated shoots (+2 cm) were rooted under both *in vitro* and *ex vitro* methods. Under *in vitro* condition, 50-80% of micro-shoots rooted on half MS medium containing NAA (5 mg/l) or NAA + IBA (2.5 mg/l each) (Fig. 5.3). The rooting took 10- 40 days with 1-6 roots formed per shoot. Liquid medium proved better than solid medium and woody plant medium (WPM) was better than MS medium for rooting. *Ex vitro* rooting of micro-shoots (12.5%) was achieved by slow dip in 250 ppm of NAA/IAA for 48 hours in dark. Hardening of rooted shoots carried out under *in vitro*



Figs 5.1–5.10: **1.** *In vitro* germination of seedlings; **2.** Axillary shootbud proliferration; **3.** *In vitro* rooting of microshoots; **4.** Hardened micropropagated plants; **5.** Micropropagated plant in field; **6.** Micrograft of cashew; **7.** Induction of somatic embryogenesis from nucellus; **8.** Differention of somatic embryos in nucellus callus(histological section); **9.** Somatic embryos in different stages of germination; **10.** Shoot development in somatic embryo.

and *ex vitro* conditions (Fig. 5.4) resulted in 60-100% survival of plantlets under laboratory condition. Transfer of hardened plants to ordinary pot mix in green house and their maintenance for 3-4 months under partial shade, diffused light and drip irrigation resulted in complete survival of plants.

Evaluation of micropropagated plants: Two sets of micropropagated plants (29 +40) planted during 1997 and 1999 respectively were evaluated in field. The first set had 29 micropropagated plants with variable number of plants in four varieties. The second set had 20 micropropagated plants of two varieties namely H4-7 and VRI-2 which were planted along with their grafts. The survival of micropropagated plants in field was total and there was no mortality in field

(Fig 5.5). Evaluation of one-year-old of micropropagated plant and grafted plant of same variety for root biomass (sectorial excavation) revealed that the tissue cultured plant had root biomass four times that of grafted plant. Micropropagated plants had strong lateral root system while grafted plants had prominent taproot system during the initial stage of planting. The flowering and fruiting behaviour of micropropagated plants was on par with that of grafted plants, however there was significant difference for growth characters particularly for plant height and yield.

Regeneration from adult tree: Micropropagation from adult tree source has been met with limited success. At ICAR-DCR, Puttur, shoot explants from field grown trees (14-year-old) and young cashew grafts (1 and 2- year-old) have been established *in vitro* on a modified MS medium. Culture establishment depended on season and type of explants. Shoot explants excised from young grafts performed better than explants cultured from field-grown trees. Boggetti *et al,* (1999) too had observed effect of ageing on the response by culturing shoots from different age groups. Response decreased with increase in age of the stock plants. Contamination was a major problem and it was high during rainy season coupled with poor bud break. In contrast, the contamination was low and bud break was better during summer. Nodal cuttings regenerated better than shoot-tips with bud break of 39.6 and 20.9%, respectively. Explants excised from grafts obtained by repeated grafting and shoots explants from pruned branches had higher percent of bud break. Hormonal sprays and other treatments to stock plants prior to collection had no effect on explant response (Thimmappaiah and Shirly, 2000). Sucrose and glucose concentrations had significant influence on the explant response, while gelling agents had no significant effect on bud break (Thimmappaiah *et al.*, 2002a). Long shoots cultured after 4 to 6 months in culture showed axillary shoot bud proliferation (1-11 shoot buds/explant) on MS medium containing TDZ or in combination TDZ with BAP (~ 3 shoot buds/explant). However, elongation of shoot buds was poor and only limited elongation (30%) occurred on hormone free liquid medium. So far no satisfactory rooting was achieved with shoots regenerated from mature tree source indicating the recalcitrance of this species for micropropagation. Similarly, recalcitrance to tissue culture has been observed in other woody species (Benson, 2000; Krishna and Singh, 2007).

Contamination and browning of cultures: Contamination and browning of cultures/media is a constraint in micropropagation. Microbial contamination due to fungi and bacteria is common and serious during establishment of *in vitro* cultures from adult tree source. The source of contamination may be from exogenous and endogenous sources. D'Silva and D'Souza (1993) observed reduction in contamination by fungus when explants were agitated in 200 mg/l bavistin (carbendazim) for five hours on a rotary shaker and also by incorporating of bavistin in the medium. However, aggressive treatment with fungicide was found to reduce or delay bud break. On the other hand, shoot explants excised from seedlings raised from *in vitro* source showed low contamination. Germination of mature seeds was carried out on plain agar medium after softening the seeds in sterile distilled water and removing the pericarp. This had less contamination while germination of seeds with pericarp intact showed very high degree of contamination (D'Souza *et al.*, 1996). At DCR also aseptic seedlings were raised by germinating mature seeds on simple absorbent cotton presoaked with sterile distilled water. The seeds were first softened in 50-100% HCl and sterilization done in 0.1% mercuric chloride or 50% sodium hypochlorite (4% available Cl_2) and incubating seedlings in dark. The seedlings were ready for culturing within 15-day of germination. *In vitro* seedlings were also raised by germinating mature embryos with part of the cotyledons on MS medium containing NAA (Hegde *et al.*, 1991). Contamination in explants of mature tree origin was controlled in our laboratory by establishing them first as young grafts in green house and maintaining hygienically with periodic fungicidal sprays.

Browning of explants is a serious bottleneck in micropropagation of cashew due to the presence of high concentration of phenols and leaching of these exudates into the media causing darkening of media and necrosis in explants (D'Silva and D'Souza, 1993). Pretreatment of explants in ascorbic acid (0.28 mM) for 1h reduced browning (D'Souza *et al.*, 1996). Nodal explants from young grafts presoaked in 0.1% polyvinylpyrolidone had shown better establishment on media containing activated charcoal (AC). Similarly, others had found incorporation of AC in the medium to overcome browning (Das *et al.*, 1996; Mantell *et al.*, 1997). Even incubation of cultures initially in dark was found useful.

Micrografting: It was adopted in cashew mainly to rejuvenate mature tree and overcome slow growth of cultures of mature tree origin. Micrografts also serve as means for germplasm exchange. Ramanayake and Kovoor (1999) reported micrografting in cashew using shoot tip or axillary shoots of seedling origin as scion and *in vitro* raised seedlings as rootstock. Mantell *et al.* (1997) described a modified side grafting procedure in cashew. At DCR also a micrografting technique was standardized using *in vitro* shoot- cultures established from grafts as scion and decapitated *in vitro* raised seedlings as root stock (Fig. 5.6). The scion was given a pre-treatment soak in sterile distilled water or DIECA to prevent phenolic exudation from cutting injury. Both hypocotyls and epicotyls grafting were successful with a grafting success of 80-100% (Thimmappiah *et al.*, 2002b). Size of scion and method of grafting had significant effect on graft success. Scions longer than 0.5 cm and side grafts were more successful than others. The micrografts were hardened and field planted along with normal grafts for evaluation.

Somatic embryogenesis and organogenesis: Though several explants (leaf, cotyledon, internode, and nucellus) were tried for induction of embryogenesis, only immature cotyledonary segments and nucellar tissue were found useful for induction of embryogenesis. Embryoid structures were induced from callus of immature cotyledonary segments (Hegde *et al.*, 1994; Nair and Mohanakumaran, 1993; Sy *et al.*, 1991; Thimmappiah, 1997; Cardoza and D'Souza, 2000 and Gogate and Nadgauda, 2003) however, their frequency was low and the somatic embryos failed to germinate properly. Similarly, nucellar tissue excised from developing nuts (3-4 weeks old) were induced to form calli and from these calli somatic embryoids differentiated at a low frequency. Ananthakrishnan *et al.* (1999) observed formation of somatic embryos in nucellar callus cultured on MS liquid medium containing 2, 4-D, but the development of somatic embryos did not go beyond the torpedo stage. Gogte and Nadgauda (2000) observed somatic embryogenesis in nucellar callus induced on semi-solid medium containing 2, 4-D and gibberelic acid. Similarly, Gagate and Nadagauda (2003) reported somatic embryogenesis from immature zygotic embryos cultured on MS medium containing 2, 4-D, BAP and GA_3 embryogenesis was also observed in immature embryos and nucellar tissue (Cardoza and D'Souza, 2000, 2002). At DCR, bisected ovules (nucellar tissue) from 2 to 3 weeks old immature nuts of 15 elite varieties were initiated on MS and SH medium containing various plant growth regulators (2, 4-D, NAA, BAP, picloram, spermine). Callus was induced in all media and varieties. Variety had significant effect on callus induction. Kanaka variety had shown highest callus induction and growth. Induction of somatic embryogenesis was observed when nucellar calli was sub- cultured on RBM medium with reduced level of 2, 4-D and containing kinetin or spermine and or hormone free medium (Shirly and Thimmappaiah, 2005) (Figs. 5.7 and 5.8). Induction of embryogenesis was observed in 5.5-41.8% of the cultures, highest being in Kanaka. Somatic embryos of Kanaka and BPP-6 was matured on half MS containing abscisic acid (20 μM) and successful germination of somatic embryos was achieved on RBM medium containing NAA, GA_3, amino acid supplements and glucose (Figs. 5.9 and 5.10).

Cotyledonary segments from mature seeds cultured on different media showed direct adventitious shoot regeneration (caulogenesis) without the intervening callus (Philip, 1984; Hegde *et al.*, 1991). Similarly, Bessa and Sardinha (1994) observed adventitious shoot formation from the callus induced at the base of micro-cuttings was sub-cultured repeatedly at monthly intervals on MS medium containing Morel's vitamins. Callus of immature cotyledon induced on TDZ medium and sub-cultured on either RBM medium or MS medium containing zeatin (1 mg/litre) resulted in low frequency adventitious shoot formation. Further differentiation of plantlets took place on half- MS medium containing 0.2% AC (Thimmappiah, 1997). In another experiment, immature cotyledonary segments of VRI-3 variety when cultured on 14 combinations of media (MS) with different plant growth regulators an adventitious shoot formation was observed on media containing BAP (10 μM) with NAA/IAA (5 μM). Anathakrishnan *et al.* (2002) reported adventitious shoot formation from the proximal end of cotyledonary segments of mature embryos cultured on MS medium containing 22.2 μM of BAP and 3% sucrose. Isolated shoots were rooted separately on half MS medium containing IBA. Regeneration through organogenesis is not preferred path way for micropropagation due to the possibility of creating somaclonal variation in this method. However, somaclonal variation that may arise may be used to the advantage of creating variation and make selections for use in breeding.

Embryo rescue: Culture of embryos in early stage of fruit development could be used to regenerate plants especially of unviable hybrids arising out of post-fertilization barriers after pollination in hybridization programme. Das *et al.* (1999) cultured embryos as small as 1-2 mm but radical emergence (99.7%) and seedling development (95.5%) was observed in embryos of 11-14 mm size cultured on MS basal medium containing BAP and GA_3 at 2 mg/l each. The survival of plants was 90% and was successfully transferred to field. Aliyu and Awopetu (2005) also cultured embryos from F_1 hybrid immature nuts harvested at 2, 4, 6 and 8 weeks after pollination on MS medium containing 1 μM each of NAA, BAP and GA_3 and observed better germination with embryos excised from 6- week-old nuts. Growth regulator and media composition were critical at the early stage and observed autonomy of growth regulator with increased in age of the embryos. Successfully germinated seedlings were ready for transfer between 90 and 112 days of inoculation. In DCR laboratory also embryo germination was achieved by culturing embryos from 3- week-old immature nuts of 5 varieties on a semi-solid modified B-5 medium containing 0.5mg/l of NAA and GA_3 (5mg/l).

Molecular markers in cashew

Although cashew is an important economical nut crop, its genetic structure and functions (genomics) is yet to be studied to have any improvement in this crop. Improvement of this crop requires the usage of biotechnological tools like molecular markers which have potential applications in this crop. Unlike phenotypic markers, these markers are more stable and not unduly affected by the environment. There are several molecular markers available like isozymes (protein markers), RAPD, RFLPs or AFLPs, SSR (DNA markers) with their own advantages as well as disadvantages which can be used usefully in cashew. These markers can be an aid in better management of germplasm resources, developing genetic maps, tagging or linking of genes with important economic traits which can be used in marker-assisted breeding programme.

Molecular profiling of germplasm: Among the DNA markers, RAPD markers were used first to characterize 20 Tanzanian cashew accessions and observed a high degree of DNA similarity between these accessions (Mneney *et al.*, 1997, 2001). Subsequently other markers were used to characterize germplasm in India. Dhanaraj *et al.* (2002) at University of Agricultural Sciences, Bengaluru analyzed 90 cashew germplasm accessions at Directorate of Cashew Research (DCR), Puttur with 7 RAPD primers and observed moderate genetic diversity and also identified a 'core collection' from these accessions. Similarly, Archak *et al.*, (2002) at NRC on Plant Biotechnology, New Delhi analyzed diversity in 19 cashew accessions collected from DCR, Puttur using RAPD, ISSR and AFLP markers. Among the markers tried AFLP was found to have superior marker efficiency.

Molecular characterization of germplasm maintained at National Cashew Field Gene Bank (NCFGB), DCR, Puttur, was also undertaken (Thimmappaiah *et al.*, 2009a). A total of 172 accessions comprising collections from 9 states of India and exotic sources were fingerprinted using both RAPD and ISSR markers. Polymorphic markers generated with selected 9 RAPD and 10 ISSR primers were subjected to analysis alone and in combination. RAPD analysis carried out with nine primers generated 46 bands, of which 40 were polymorphic (86.9%) with an average of 4.4 polymorphic bands per primer. In ISSR analysis, with 10 primers, 61 amplified bands were generated, of which 56 were polymorphic (91.8%) with an average of 5.6 polymorphic bands per primer. For deriving better genetic relationship, the data of both markers were combined and from a total of 107 bands, 96 (89.7%) bands were found polymorphic with an average of 5 polymorphic bands per primer. The genetic similarity of 0.38 to 0.87 observed between different pair of accessions and average similarity of 0.5 indicated moderate diversity existing among the accessions. Shannon's information index and percentage of polymorphic loci indicated high genetic variation in the

Fig. 5. 11: Cluster of 172 germplasm of cashew-based on combined markers (RAPD + ISSR)

collections of Karnataka followed by Kerala and Andhra Pradesh. There was more diversity (96% variation) within the groups than between the collections (4% variation) from different states (Thimmappaiah *et al.*, 2012). Among the accessions NRC-432 and NRC-119 were highly divergent and NRC-235 and NRC-216 were highly similar. The cluster analysis performed to create dendrogram distinguished 17 clusters in all (Fig. 5.11). Although there was no correspondence between the centre of collections and clusters, there were some exceptions as species from Brazil like *Anacardium othonianum* and *A. pumilum* were found to cluster together in the same sub-group and some sub-clusters were in agreement with morphological clusters (Swamy *et al.*, 2002). From 17 clusters, 63 accessions were identified to form a 'core collection'.

Similarly, genetic diversity and species relationship in 10 diverse types of cashew including three species (*Anacardium pumilum* St. Hillarie, *A. microcarpum* Ducke, *A. othonianum,* three inter-specific hybrids, i.e., V-5 (*A. occidentale*) × *A. pumilum*, *A. pumilum* × V-5 (*A. occidentale*) and *A. othonianum* × V-5 (*A. occidentale*) and four genotypes of *A. occidentale* was assessed using RAPD, Isozymes and SSR markers (Thimmappaiah *et al.*, 2009 b). Polymorphic markers generated with 11 RAPD primers, 6 primer pairs of SSR and isozymes of 6 enzyme systems were used in the analysis (Figs. 5.12 and 5.13). The combined marker analysis revealed 81.5% polymorphism and genetic similarity varying from 0.39-0.77 with an average similarity of 0.55 indicating moderate diversity. In the cluster analysis three broad groupings were distinguished: In first group *Anacardium pumilum* was found clustering with two of its inter-specific hybrids, in the second group *A. orthonianum* clustered with one of its inter-specific hybrid and a dwarf accession Kodippady and while in the third group contained most accessions of *A. occidentale* clustering with *A. microcarpum* thus indicating close affinity between *A. occidentale* and of wild species *A. microcarpum.*

Croxford *et al.* (2005) at University of Reading (United Kingdom) reported development of SSR markers in cashew and used an automated, high throughput system to isolate cashew microsatellites from a non-enriched genomic library blotted onto membranes at high density screening. Sixty-five sequences contained

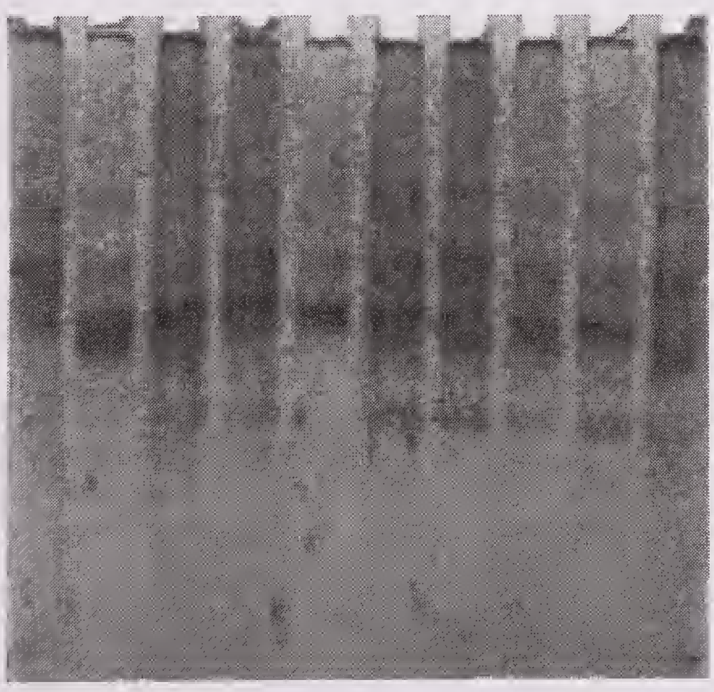


Fig. 5. 12: Aspartateamino transferase (AAT)

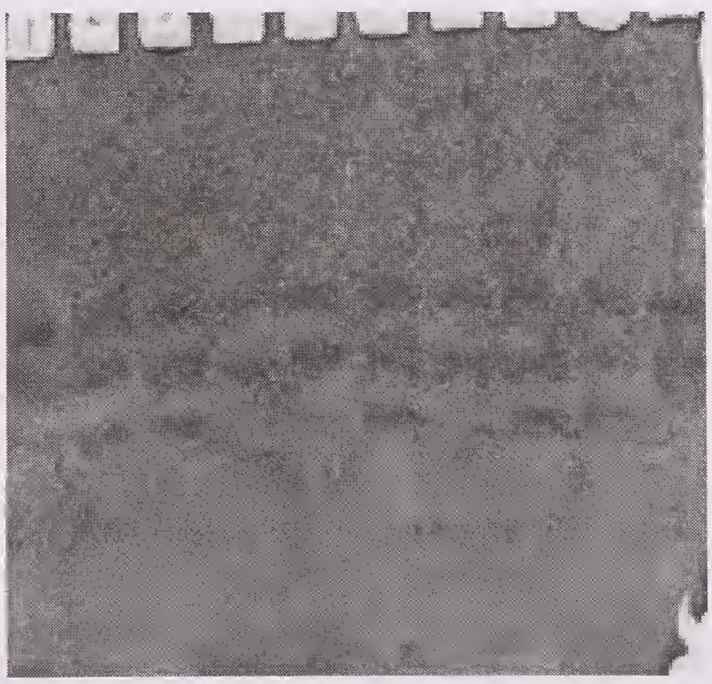


Fig. 5. 13: Acid phosphotase

a microsatellite array, of which 21 were found to be polymorphic when screened with a population of 49 cashew genotypes. Among these, 12 were suitable for multiplex analysis. Of these, 10 were amplified in 3 related species (*Ancardium microcarpum, A. pumilum* and *A. nanum*) of cashew.

Syed *et al.* (2005) reported Ty1-copia retrotransposon based Sequence Specific Amplification Polymorphism (SSAP) molecular marker system. The efficiency of SSAP and AFLP technologies were compared and observed higher proportion of polymorphic markers in SSAP as compared to AFLP. This marker may find application in QTL mapping and marker assisted selection.

Aliyu and Awopetu (2007) used protein-isoenzyme electrophoretic analysis in three Nigerian population of cashew (59 accessions). The accessions grouped into six clusters on the dendrogram of Ward's method of squared Euclidean distance, indicating 'moderate' diversity among Nigerian cashew collections. Clustering pattern reflected the eco-geographical origin of the accessions. Closer genetic affinity was observed between Indian and Local clonal populations.

Maranan and Mendiore (2008) subjected 16 accessions of cashew to isozyme analysis involving seven enzymes such as alkaline phosphatase (*ALP-1* and *ALP-2*), acid phosphatase (*ACP-1* and *ACP-2*), esterase (*EST-1* and *EST-2*), shikimate dehydrogenase (*SKDH-1* and *SKDH-2*), isocitrate dehydrogenase (*IDH-1* and *IDH-2*), phosphoglucomutase (*PGM-1* and *PGM-2*) and 6-phosphogluconate dehydrogenase (PGD-1 and PGD-2). Twelve loci were monomorphic and only two loci were polymorphic (ACP-2 and EST-2). There were three clusters indicating the genetic similarity among the accessions within a cluster and these three clusters belonged to accessions from Zambales, Palawan and Los Baños provinces.

Desai (2008) used RAPD and differentiated 57 genotypes of cashew into two broad groups. The first group comprised of 35 and other comprised of 22 genotypes which in turn grouped the genotypes into eight and three sub-clusters. It was inferred that the comparative analysis of clustering pattern based on morphometric and molecular diversity data reflected rather a partial consensus.

Archak *et al.* (2009) attempted to construct historical events related to cashew introduction by investigating the level of genetic variation and genetic structure of cashew populations collected from different geographical regions of India. A total of 91 individuals from four populations were analyzed using AFLP markers and morphometric data. AFLP analysis based on 354 polymorphic loci revealed Indian cashew to have low but relatively substantial genetic diversity for an introduced species (HE=0.262 and IS=0.404). Twenty-seven qualitative and quantitative traits also revealed the existence of considerable morphometric variation. Bayesian cluster analysis based on AFLP data did not indicate the existence of definite population differentiation. The results supported the possibility of cashew having been introduced into India repeatedly over a period of time but at a single location (west coast).

Carvalho *et al.* (2012) studied the genetic variability and importance of bushy cashew for future programs of improvement and conservation of the species of cashew. Genetic variability of 122 accessions of *A. humile* from 11 cities (origin) from the Cerrado of the states of Goiás and Mato Grosso in Brazil was quantified through RAPD markers. The study showed the genetic distance of material from different provinces and highlighted the importance of these origins in the enrichment of the germplasm bank of the species.

Fingerprinting of cashew

Markers were also employed for fingerprinting of varieties and elite lines in cashew. Archak *et al.*, (2003) analyzed diversity in 24 selections and 11 hybrids of cashew using a combination of both RAPD and ISSR markers and observed narrow range of similarity values (low diversity) among the major cashew breeding centres and also between selections and hybrids. Similarly, Samal *et al.* (2003) analyzed genetic relationship in 20 varieties of cashew using RAPD markers and observed no coincidence in the similarities on comparison of morphological with molecular data.

Fingerprinting of 40 varieties released in the country was carried out in DCR laboratory with RAPD, ISSR and SSR markers. Polymorphic markers generated with a combination of 10 primers each of RAPD (Fig. 5.14) and ISSR markers and 15 primer pairs of SSR of cashew were used in the analysis. Marker analysis was carried out individually and by combining all the three markers. Based on the combined markers, Jaccard's coefficient of genetic similarity between different pairs of varieties varied from 0.52 to 0.81 with an average similarity of 0.68 indicated low diversity existing among the varieties studied. Highest similarity was observed between Goa 11/6 and VRI-3 and lowest similarity (52%) was observed between Kanaka and V-2. UPGMA dendrogram (Fig. 5. 15) grouped 40 varieties in to 8 to 10 clusters at 75% similarity. Among the varieties, Kanaka,

Fig. 5. 14: RAPD profile (OPP-10) of 40 varieties of cashew

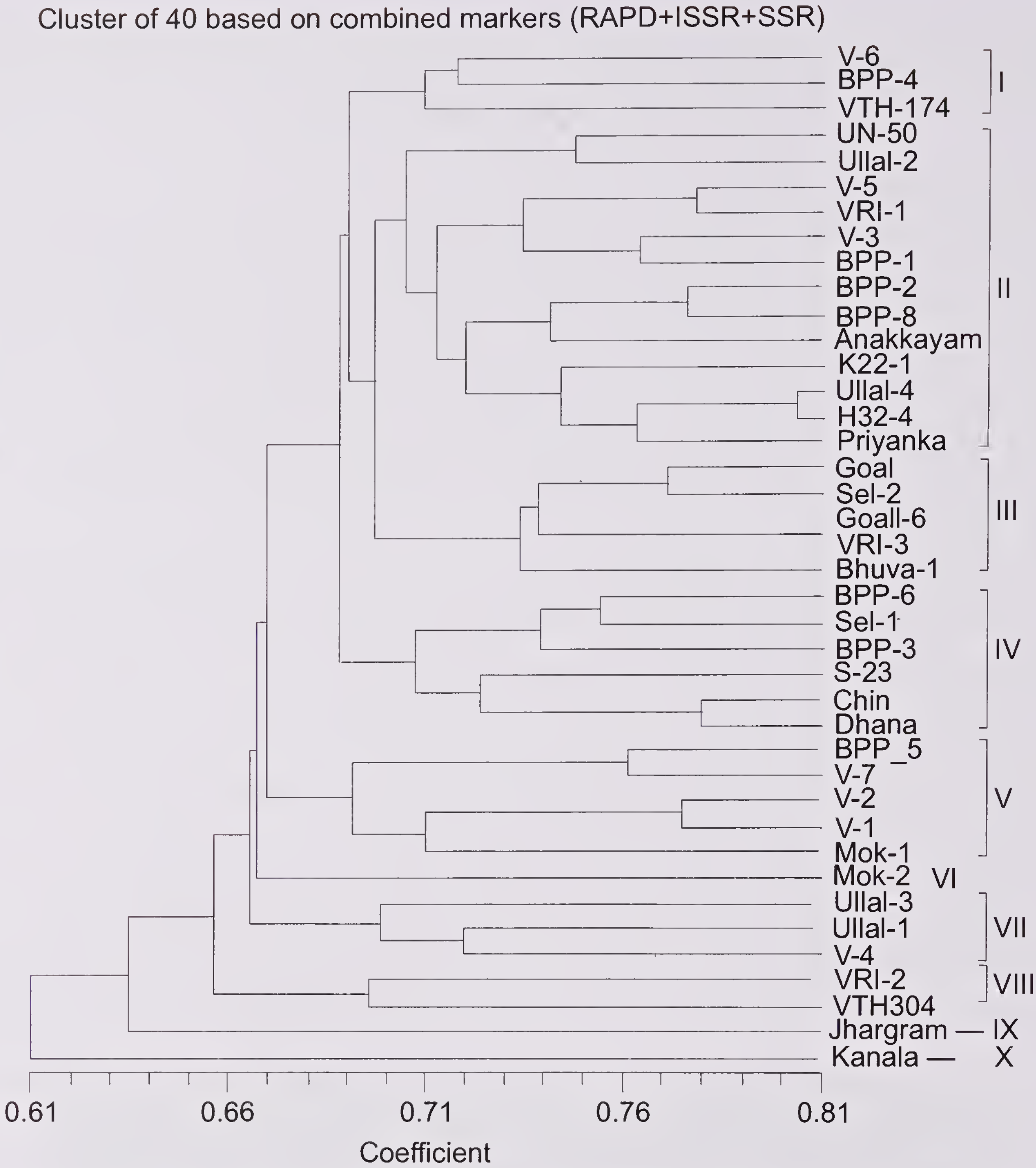


Fig 5.15: Dendrogram of 40 varieties of cashew based on RAPD, ISSR and SSR markers

Jhargram and V-6 were highly divergent. Varieties clustered together irrespective of their geographic origin indicating no relation between the clusters and the origin of varieties.

Apart from DNA markers, Isozyme markers which are codominant were used for characterization of varieties. At DCR, Isozyme extraction from young cashew leaves was standardized using Arulsekhar and Parfitt (1986) buffer. Extraction and staining protocols for 14 enzymes have been standardized so far. Fingerprinting of 30 varieties of cashew was carried out with Isozyme polymorphism of 10 enzymes (Figs. 5.13, 5.14). By assaying 10 enzymes, 33 Isozyme bands (loci) were observed (1-4 bands per enzyme) with an average of 3.3 bands per enzyme; of which 23 bands were polymorphic (69.7%) and 10 were monomorphic. The Polymorphic Information Content (PIC) varied from 0.104 to 0.399 and Marker Index (MI) from 0.104 to 1.596. Among the different enzymes, Isozymes of Shikimate dehydrogenase were found to be highly informative. Cluster diagram made with Isozyme markers indicated that Ullal-1 and V1 as most divergent. Groupings based on Isozyme and RAPD were neither identical nor with any marker type.

Linkage maps, tagging of genes and QTLs identification: The first genetic map in cashew was developed by Cavalcanti and Wilkinson (2007) utilizing a mapping population of F_1 progeny (85 individuals) and generated two linkage genetic maps comprising of 205 genetic markers (194 AFLP and 11 SSR markers). The female map (CP 1001) contained 122 markers assembled in 19 linkage groups while male map (CP 96) comprised of 120 markers assembled in 23 linkage groups. The total map distance of the female map is 1,050.7 cM representing around 68% genome coverage, whereas the male map spans 944.7 cM (64% coverage). The average map distance between markers is 8.6 cM in the female map and 7.9 cM in the male map. Homologies were identified between 13 linkage groups (64%) of the female map and 14 linkage groups (61%) of the male group based on 46 common markers.

Although markers have been used for diversity analysis and also in mapping and their utility in tagging and marker assisted selection studies are few. Neto *et al.* (1995) showed the utility of RAPD markers in distinguishing dwarf seedlings in cashew. Among the six primers tried, OPB-15 alone was sufficient to identify the dwarf seedlings raised from four clones.

Table 5.1 DNA bulks made in F_2 with phenotypic selection criteria

Sl. No.	Phenotypic characters	Criteria	No. of plants selected
1	Apple weight (g)	Low (<40g)	11
		High (>115g)	11
2	Apple dimension (L × B × T)(cm^3)	Low (<20)	11
		High (>50)	11
3	Brix (%)	Low (<9%)	11
		High (>17%)	12
4	Nut weight (g)	Low (<5.5g)	13
		High >(9.0g)	16
5	Plant girth (cm)	Low (<30cm)	10
		High (>65cm)	14
6	Plant height (cm)	Low <450cm)	17
		High (>750cm)	15
7	Thickness of primary branches (cm)	Low (<20cm)	11
		High (>40cm)	11
8	No. of fruiting laterals/m^2	Low (<2)	10
		High (>12)	11
9	No. of leaves/laterals	Low (<4.5)	12
		High (>11.0)	11
10	Leaf area (M^2)	Low (<75)	10
		High (>158)	10
11	Fruit set/panicle	Low (<2.8)	10
		High (>5.5)	10

An attempt was made to identify molecular markers (RAPD/ISSR/SSR) linked to some important economic characters like nut weight, apple weight, juice quality, dwarfing, compact canopy and characters of high yielding efficiency and to validate the markers identified in the population at the Directorate of Cashew Research, Puttur. A mapping population (F_2) of 251 plants of a cross VRI-2 (small nut, high yield) × VTH 711/4 (bold nut, Brazilian) raised in 2001 were phenotyped in their 7-8 years of orchard life for various morphological, flowering, fruit and yield characters. F_2 plants were selected for constituting bulks based on their high and low phenotypic values for some important phenotypic traits. Similarly, phenotypic data on 177 germplasm accessions were collated and sorted based on their phenotypic values.

Initially parental survey for polymorphism was carried out with 258 RAPD, 31 ISSR and 21 SSR primer pairs and detected polymorphism in 86 RAPD, 13 ISSR and 5 SSR primer pairs, respectively. DNA bulks were constituted for 11 phenotypic traits in F_2 (Table 5.1) and 6 traits in germplasm (Table 5.2). Bulked segregant analysis (BSA) (Michelmore *et al.*, 1991) was carried out using the polymorphic primers identified through parental survey and identified several polymorphic markers between the bulks. Though several markers were found polymorphic between the bulks in F_2 but none could be confirmed within the individuals constituting the bulks. However, BSA carried out in germplasm on bulks of nut weight and plant stature could identify four RAPD markers which could be validated even with individuals constituting the bulks (Shobha and Thimmappaiah, 2011). Three markers (UBC 184_{450}, UBC 185_{275}, OPN 14_{775}) were identified for nut weight and one marker was identified for plant height (dwarfing) (Table 5.3) (Figs. 5.16, 5.17). These markers were validated with additional individuals and population. Marker bands were eluted, cloned and sequenced to develop 'SCAR' markers in cashew. The SCAR sequences were submitted to Gene Bank of NCBI website and obtained ID numbers. Association analysis using 40 RAPD and 56 ISSR markers were carried out by regress these markers on 14 phenotypic traits studied in germplasm. A single marker association with several traits and several markers influencing a single trait were also observed (Shobha *et al.* 2013).

Table 5.2. DNA bulks constituted in germplasm with selection criteria

Characters	Phenotype	Range value	No. of individual accessions/ plants in bulk
Plant height (M)	Low (< 2.8)	1.5–2.8	9
	High (> 7.3)	7.3–8.17	9
Weight of apple (g)	Low (< 36.7)	10–36.7	10
	High (> 104.9)	104.9–142.0	10
Flowering duration (d)	Low (< 54)	42–54	10
	High (> 115)	115–150	10
Nut weight (g)	Low (< 4.3)	2–4.3	9
	High (> 12.0)	12–16.8	9
Shelling percentage (%)	Low (< 20)	5.3–20	10
	High (> 35.5)	35.5–41.0	9
Cumulative yield/tree (kg)	Low (< 3.85)	0.4–3.85	9
	High (> 12.5)	12.5–16.91	9

Identification QTLs was also attempted in cashew. Santos *et al.*, (2009) reported

Table 5.3. RAPD Markers identified and their segregation in individuals of bulks

Character	RAPD band/marker	High phenotype		Low phenotype	
		Present	Absent	Present	Absent
Nut weight	UBC 184_{450}	6	2	1	9
	UBC 185_{275}	0	9	5	5
	OPN 14_{775}	**2**	**6**	**7**	**2**
Plant height	UBC 185_{275}	**0**	**9**	**6**	**3**

30 QTLs to be associated with cashew apple character in a cross of CCP 1001 × CP 96 having 66 F_1 plants. They found that lowest number of QTLs (two) was detected for red colour intensity of cashew apple and the highest (seven) for cashew apple weight. The QTLs explained between 3.15 and 21.33% of the total phenotypic variation.

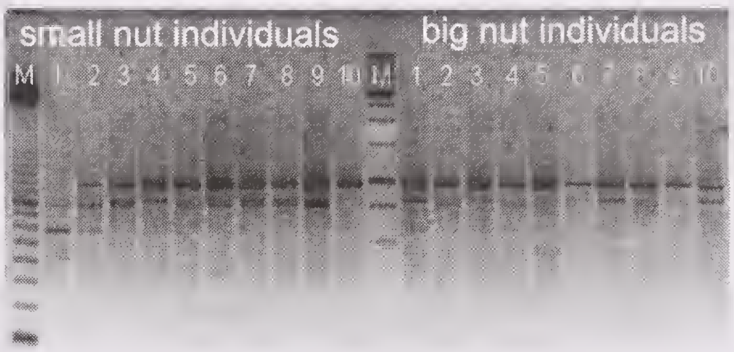


Fig 5.16: Identification of putative marker (RAPD-OPN14) for nut size in cashew

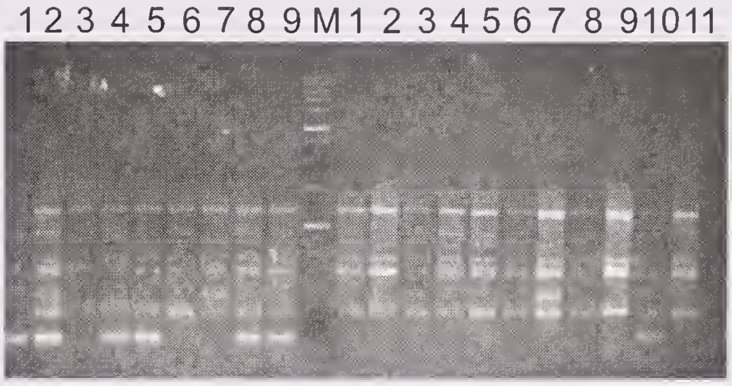


Fig 5.17: Marker for low plant height ($UBC185_{450}$)

Later Santos *et al.* (2011) analyzed the physicochemical characteristics such as oligomeric phenolics, total soluble solids, total titrable acidity and vitamin C contents of cashew apple in the mapped cashew population and observed high phenotypic variation for all these characters in the segregating F_1 generation. Eighteen QTL associated with cashew quality were identified: three for oligomeric phenolics, five for total soluble solids, six for total acidity and four for vitamin C. QTL are promising for marker-assisted selection since they have the greatest phenotypic effects and contribution to phenotypic variation.

Cavalcanti *et al.* (2012) identified QTL for yield-related traits such as nut weight, male and hermaphrodite flowers. The traits were evaluated in 71 F_1 genotypes of the cross CCP 1001 × CP 96. The methods of interval mapping and multiple QTL mapping were applied to identify QTL and 11 QTL were detected: three for nut weight, four for male flowers and four for hermaphrodite flowers. The QTL accounted for 3.79 to 12.98% of the total phenotypic variance and had phenotypic effects of -31.81 to 34.25%. They concluded that potential for marker-assisted selection of the QTL for hermaphrodite flowers i.e. hf-2f and hf-3m is immense as they have phenotypic effects and percentage of phenotypic variation higher than of the others.

Gene cloning and transgenic technology

Gene cloning studies in cashew is scarce, however the recombinant cashew 2S albumin was amplified from a cDNA library by means of PCR, sequenced, and expressed in *Escherichia coli* (Wang *et al.*, 2002). The allergin (Ana o 3) identified was belonging to the vicilin and legumin families of seed storage proteins (Robotham *et al.*, 2005). The 2S albumin gene was amplified from the cashew cDNA library by means of PCR with a degenerate forward primer and a lock-dock reverse primer. The resulting 585-bp PCR product (GenBank ID AY081853) encodes a 138-amino-acid protein designated Ana o 3.

In cashew cultivation damage due to insect pests is a serious problem and pest attack is known to reduce the yield drastically. Tea mosquito bug (TMB) (*Helopeltis* *antonii*) and cashew stem and root borer (CSRB) (*Plocaederus ferrugineus, P. obesus*) are the prominent pests attacking cashew causing considerable damage. Often insecticide sprays are resorted to control these pests which results in severe pesticide load on environment and there has been debate on the use of some of the insecticides to control this pest and their effect on human beings dwelling in that plantation area. TMB can be controlled by insecticide spray while for controlling CSRB only prophylactic measures are available and no host resistance has been reported so far for these two pests. Under these circumstances, use of biotechnological tools (transformation) to impart resistance in this crop for these pests is necessary. Some of the gene constructs available like BT genes and protein inhibitor genes are the candidature genes to be tried in cashew by incorporation through *Agrobacterium* or by other means.

Cardoza *et al.* (2002) used plasmid pB1426 harboured with GUS-npt II fusion protein driven by a double CaMV 35S promoter linked to a translational enhancer alfalfa mosaic virus with a NOS terminator. The plasmid was cloned in *Escherichia coli* and plasmid DNA was purified and precipitated onto a gold particle. The DNA coated particle was bombarded at 900 psi and 1,100 psi pressure onto the embryogenic callus induced from nucellar tissue of cashew. GUS assay was carried out and blue spots were seen on the callus tissue bombarded with pB1426 after 48 hr confirming transient 'Gus' expression. It was found that 900 psi give more transient expression than 1,100 psi.

Nivas *et al.* (2007) attempted transformation in cashew by using *Agrobacterium tumefasciens* strain EHA-105 with plasmid pBIN m-gfp5-ER and npt II (kanamycin resistance) was used for the selection. Successful transformation was confirmed with PCR amplification of transformed *in vitro* cashew plants using GFP specific primers. The fluorescent glowing of the leaves of the *in vitro* grown cashew plants at 365 nm confirmed the expression of the gene in transformed plants. Wounding of young seedlings at the cotyledonary node region, an inclusion of acetosyringone in the cocultivation medium resulted in transformation.

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6

Soil and Climate

T.R. Rupa and R. Rejani

IN India, cashew (*Anacardium occidentale* L.) is a neglected horticultural crop among the farmers and usually grown on marginal soils and also on wasteland mostly unsuitable for other economic crops. Bulk of the cashew growing soils in India is lateritic, red and coastal sands which are acidic in nature and poor in soil fertility. The runoff and soil erosion are very high in steep slopes. On other hand, nutrient mining has occurred in many cashew growing soils due to lack of affordable fertilizer/organic sources and where fewer or no biomass residues/leaf litters are returned to the soils. The deficiencies of nitrogen, phosphorus, potassium, magnesium, zinc, boron and molybdenum are on the rise in cashew growing soils. Low or unbalanced fertilization leads to depletion of soil nutrients and degradation due to lower soil organic matter contents with reduced nut yields, and indirectly reduced soil structure which promotes soil erosion. Soil and water conservation activities are an essential part of the cashew production technology followed in sloppy areas where the fertile top soil and surface runoff have to be conserved. Integrated nutrient management practices involving combined application of chemical fertilizers, organic manures/green manuring and biofertilizers which constitute an efficient nutrient management strategy in cashew are crucial to enhance soil fertility for sustainable production. Cashew is a tropical nut crop and it is grown between 28° North and 28° South latitude. In India, it is grown in pow altitude areas of coastal belt with a mean rainfall of 1,500 to 2,000 mm are excellent for cashew. The maximum temperature ranging from 28°C to 32°C, minimum winter temperature of 19°C and relative humidity of 70-80% are good for proper growth and development of cashew. Bright sunshine (>9h/day) with moderate dry weather is good for flowering. Cashew is usually grown as a rainfed crop in ecologically sensitive areas such as coastal belts, hilly areas and areas with high rainfall and humidity, and hence its performance mainly depends on climate. The flowering, fruiting, insect pest incidence in cashew crop, yield and quality of cashew nut and kernels are more vulnerable attributes for climate change.

Soil requirement

Cashew, being a hardy plant, is grown on a diverse range of soils, from the sandy seacoast to laterite hill slopes, pure sandy soils to sandy loam, laterite soil, deep loam and red latosols. It is cultivated on laterite, red and coastal sands in the states of Kerala, Maharashtra, Goa, Karnataka, Tamil Nadu, Andhra Pradesh, Odisha and West Bengal. Whereas, in maidan tracts like Hassan and Tiptur of Karnataka, where the soil type is red sandy loam or red loam or black mixed red clay it can be grown. It is also grown on black soils in Tamil Nadu and Andhra Pradesh to a limited extent. Although it is grown in almost all types of soils, it performs better in well drained, brown forest soils, red sandy loam and light coastal soil with a high water holding capacity and rich in organic matter. Crop suitability studies using ARC-GIS showed that cashew is distributed along loamy red and lateritic soil, mixed red, and black soil, coastal, and deltaic alluvium derived soil (Fig. 6.1). Cashew productivity is higher in loamy to clayey mixed red and black soils as compared to other soil types. The site suitability map for cashew revealed that Maharashtra, Goa, Kerala, West Bengal and Odisha are highly suitable, while Andhra Pradesh, Tamil Nadu, Karnataka, north-eastern hills regions and Gujarat are moderately suitable. Jharkhand, Andaman and Nicobar Islands and Bastar

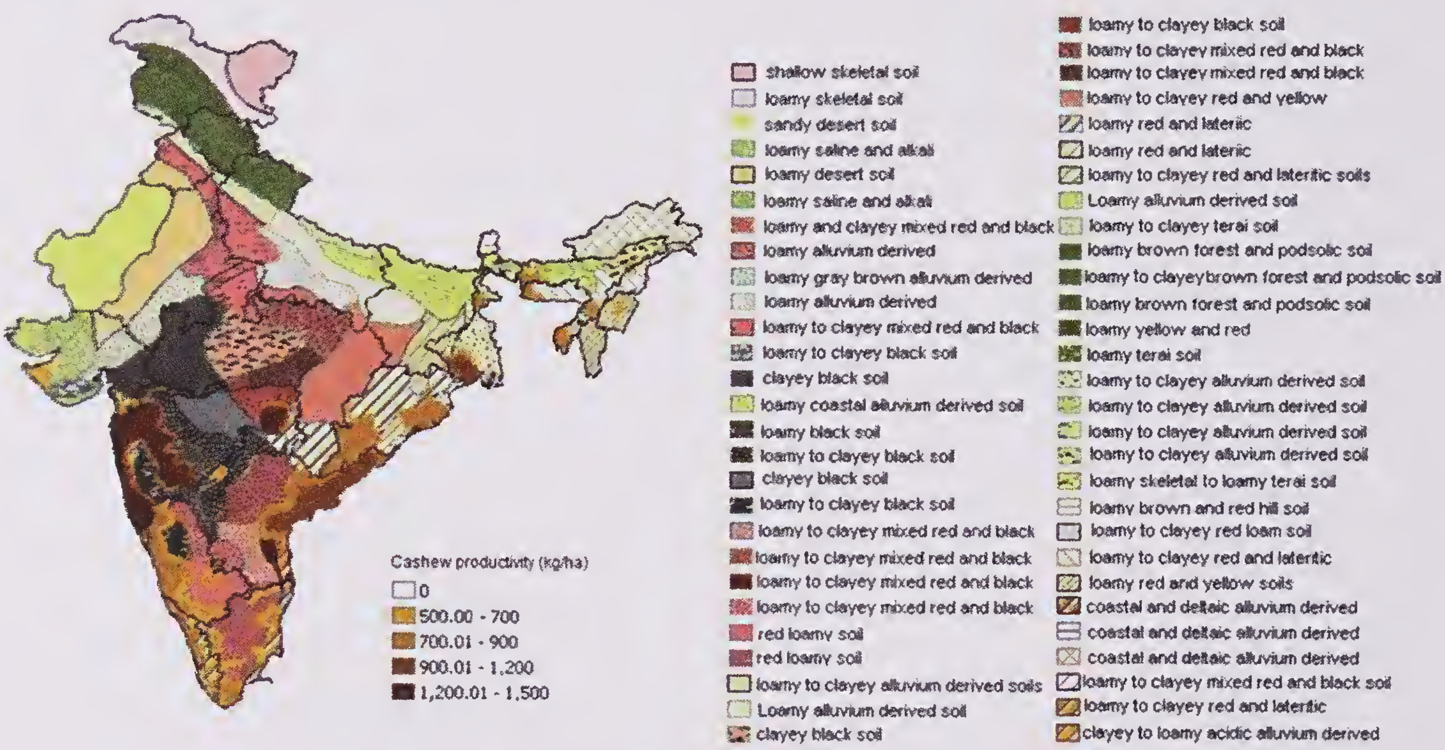

Fig.6.1. Cashew area and productivity (kg/ha) overlay with soil types

region of Chhattisgarh are also moderately suitable for cashew cultivation, Fig. 6.2, (Rejani *et al.,* 2013).

Cashew prefers slightly acid soil of pH 4.5 to 6.5, with low Ca content. Soil pH of >8.0 and poor drained soils are unsuitable for cashew cultivation (Guruprasad *et al.,* 2007). According to FAO (1994), the optimum pH range for cashew is between 4.5 and 6.5. Sandy loam texture having a depth of >180 cm, permeability 20-50 mm/h, salinity <1 dS/m, pH 6.1-7.3, available water holding capacity >18 cm and slope 3% are considered as best suitable land for cashew, Table 6.1, (Mishra 1984). The growth and performance of trees in the coastal soil is generally good suggesting

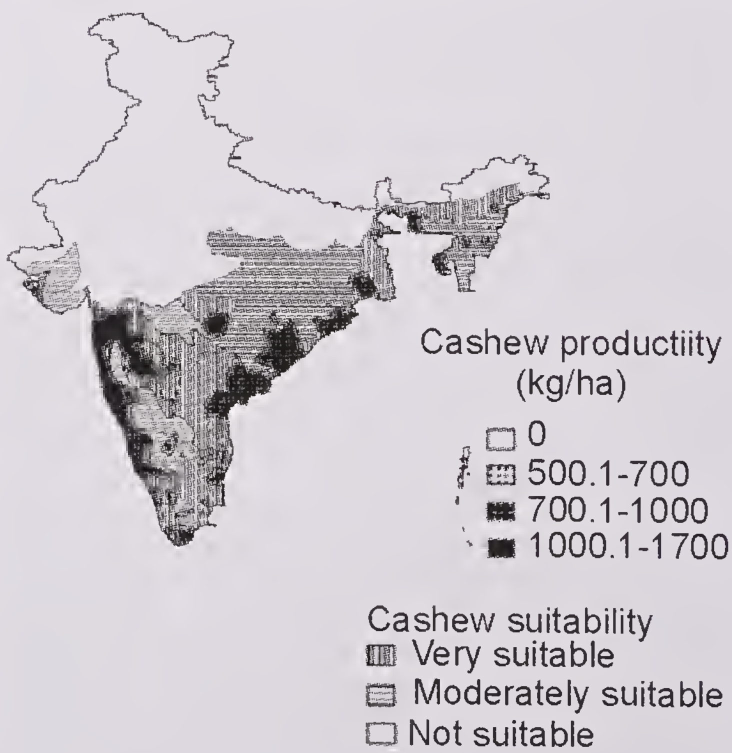

Fig. 6.2 Site suitability map for cashew

Table 6.1. Land suitability classification for cashew

Soil parameters	Land suitability classes				
	Class I	Class II	Class III	Class IV	Class V
	Very suitable	Well suitable	Moderately suitable	Poorly suitable	Unsuitable
Texture (Surface soil)	Sandy loam	Fine sand	Sand	Coarse sand	Sandy clay
Texture (Subsoil)	Fine loamy	Coarse loamy	Coarse silty	Fine silty	Fine
Soil depth (cm)	>180	90-180	45-90	22.2-45	<22.5
Permeability (mm/h)	20-50	5-20	50-130	1.0-5	<1.3
Salinity (EC 1:2 soil: water) (dS m^{-1})	<1	1-1.5	1.5-2.0	2.0-3.0	>3.0
Soil reaction pH (1:2 soil:water)	6.1-7.3	5.6-6.0	5.1-5.5	4.5-5.0	<4.5
Available water holding capacity to a depth of 180 cm (in cm)	>18	14-18	9-14	3-9	<3
Slope (%)	<3	3-5	5-15	15-25	>25
Erosion	Slight	Moderate (sheet)	Moderate (sheet and rill)	Severe (sheet and fully)	Very severe (gully and ravine)

tolerance of the crop to soil salinity. However, laboratory trials indicated that cashew has only a little tolerance for soil salinity and also that difference in tolerance exists amongst cashew trees (Rocchetti, 1970). Electrical conductivity of irrigation water 1.48 dS/m is a threshold tolerance for precocious cashew during the initial growth (Carneiro *et al.,* 2002). Productivity of cashew was medium in eroded laterite soil and low in coastal sandy, saline/alkali and waterlogged soils. Soil salinity higher than 2% was unsuitable for the growth of cashew (Venugopal and Khader, 1991). Heavy textured soils, compacted subsoils, hard pans and similar conditions impede root penetration and on such soils, cashew doesn't perform well. Cashew is very sensitive to waterlogging and hence heavy clay soils with poor drainage conditions may not be suitable for its cultivation.

Soil constraints and management approaches

Plantation crops like cashew, tea, rubber, coffee, etc. grow well on red and laterite soils, they have large agricultural importance. Red and lateritic soils are generally acidic and have low cation exchange capacity, low to moderate base saturation. Due to intensive leaching and presence of high amounts of Fe and Al oxides, the soils show deficiency of nutrients, such as N, P and K causing nutrient imbalances. Laterite soils are deeply weathered soils and the depth of weathering may extend up to several meters. With pronounced leaching, the soils lose bases

(Ca, Mg, Na and K) and silica with relative accumulation of sesquioxides and the soils develop acidic reaction. The clay fraction of red soils is not exclusively kaolinitic and may contain illite or occasionally montmorillonite, whereas, laterite is predominantly kaolinitic. Soil acidity and kaolinitic nature of the clay mineral causes fixation of water soluble phosphorus but allows the use of rock phosphate as a good source of P to cashew crop. Magnesium assumes significance for cashew in coarse textured soils. Zinc deficiency is widespread in all soils under cashew cultivation. Deficiencies of Mg, Zn, B and Mo are more likely common in acid soils. Some disease causing agents (especially fungi) thrive well in acid soils. Incidence of disease is, therefore, increased. A large population of beneficial microorganisms suffers badly due to high concentration of hydrogen ions which results in decreased soil fertility.

Majority of the cashew farmers do not apply fertilizers/manures and thus the nutrients being mined by the plants are not replenished. Inadequate and imbalanced use of inorganic fertilizers with little or no use of organic manures and biofertilizers have made the cashew soils not only deficient in certain nutrients, but also deteriorated the soil health. Cashew requires regular fertilizer application to ensure early and high yields in new/young plantations, and regular high yields from mature plantations. Integrated nutrient management practices involving conjoint application of chemical fertilizers, organic manures/green manuring and biofertilizers, recycling of cashew litter, use of microbial inoculants for mobilizing micronutrients from slowly available soil pools are some of the strategies to manage nutrient constraints and enhance soil quality for sustainable production.

Low soil pH is countered by applying liming materials such as agricultural lime (calcium carbonate), dolomite (magnesium carbonate plus calcium carbonate), or other materials that have a liming effect on the soil. Liming materials improves the availability of some plant nutrients, promotes desirable biological activity and improves the structure of cashew growing acid soils. Liming also prevents soil erosion in cashew grown in steep slopes because liming of soil supports good plant growth. Lime also brings about a more rapid decomposition of organic manure, both native and added, as a result of improved microbial activity. Since cashew crop has a greater degree of tolerance for acidity within the range of pH 4.5 to 6.0, research efforts to get higher production of cashew in acid soils have not been made.

The majority of the cashew plantations in India are established on degraded slopes with poor fertility, where soil and water erosion is a common phenomenon. Soil and water conservation technology is an essential part of the cashew cultivation practice followed in sloppy areas where the top soil and surface runoff have to be conserved. A mean rainfall of around 67 to 415 mm is received during fruiting season of cashew (February-May). The water deficit is highest during March-May (112-183 mm) (Yadukumar *et al.,* 2009). Cashew starts flowering after monsoon and soon after fruit set till maturity (January to May), there is a deficit of water. To mitigate this problem, making terraces around the plant and opening of catch pits are very useful. Before the onset of south west monsoon (May-June), terraces of 1.5 m radius should be made during the second year of planting and this should be widened up to 2 m during the third year. Terraces are prepared by removing soil from the elevated portion of slope and spreading on the lower side which forms a flat basin of 1.5 to 2 m radius depending upon the age of the plant. Terraces may be crescent with inwardly sloping, so that the top soil which is washed off from the upper side due to rain water is deposited in the basin of the plant. The basin area of cashew plants can be mulched either with green leaves, dry leaves or weeds soon after planting.

A catch pit (200 cm long × 30 cm wide × 45 cm deep) across the slope at the peripheral end of the terrace is made for withholding water during pre-monsoon and post-monsoon in sloppy areas. A small channel connecting catch pit sideways/ water ways is made to drain out excess water during rainy season. Among the various *in situ* soil and water conservation measures tried, modified crescent bunds made at 2 m radius having a crescent shaped bund of 6 m length, 1 m width and 0.5 m height on the upstream of the plant (so that a trench of 6 m length and 50-75 cm deep will be formed while making the bund) or staggered trenches with coconut husk burial were found superior. A considerable amount of nutrient leaching and soil erosion is common in the eastern states of Nigeria as cashew was planted in the 15th century mainly to control erosion around Nsukka, Oghe, Udi areas due to their slopy nature. Terraces made by removing the soil from the elevated portion above the tree trunks to create basins of 1.5 to 2 m and contour drains constructed were effective to collect rain water above the tree-line and prevent soil wash from the slopes. In low rainfall areas (northern states), mulching around the base of trees with grasses or slashed weeds help in the control of weeds, retention of water and modulation of soil temperature, especially in dry season (Asogwa *et al.,* 2008).

Cashew is usually planted in areas which are totally dry and unsuitable for cultivating any other crop and the availability of moisture is very low. Under such situations mulching is very useful as it prevents weed growth, reduces evaporation during summer and regulates the soil temperature, improves the soil fertility and also prevents soil erosion. Mulching protects the soil against the direct impact of raindrops and lowers the potential for soil erosion and surface crust formation, besides reducing evaporation losses, checks weed infestation and increases water infiltration rate. Mulching is especially useful to rainfed cashew when severe drought stress occurs at fruiting and nut formation stages. The basin area of cashew plants can be mulched either with green leaves, dry leaves and weeds soon after planting. Black polythene mulch was helpful to conserve soil moisture (Nawale *et al.,* 1985). Using coconut coir pith as a soil mulch in cashew plantations resulted in 14.15% more water retention and suppression of weeds to an extent of 73.52% (Kumar *et al.,* 1989).

Among major inputs, manures and fertilizers account for 20-30% of the total cost of production. Nitrogen (N) is the mineral nutrient that cashew requires in the greatest amount. It has more influence on tree growth, production and quality of cashew than any other nutrient. Phosphorus (P) is the second most limiting nutrient after N in the nutrition of cashew. It plays an indispensable role for many life processes such as photosynthesis, synthesis and breakdown of carbohydrates, and the transfer of energy within the plant. Potassium (K) is the second largest nutrient next to N required by cashew. Potassium is necessary for several basic physiological functions like the formation of sugars and starch, synthesis of proteins, normal cell division and growth, and neutralization of organic acids. It helps to reduce the influence of adverse weather conditions like drought, cold and flooding.

Nitrogen and P were most important nutrients during the pre-bearing stage, but at the bearing stage, K together with N is also important. The response of cashew to applied N is tremendous and the same is observed universally. Increase in cashew yield due to N application was reported by several workers (Lefebvre, 1973; Reddy *et al.,* 1982; Rao *et al.,* 1984; Veeraraghavan *et al.,* 1985; Ghosh, 1988; Mathew, 1990). Ghosh (1990) reported that number of nuts/plant and nut weight was the highest at 600 g N/tree/year. However, Latha *et al.* (1994) obtained response to N up to 1,000 g/tree. Urea is the most commonly used nitrogenous fertilizer in India. However, in Nigeria urea and sulphate of ammonia are generally used. Falade (1984) reported that sulphate of ammonia was superior to urea particularly when medium or high doses of N were applied to cashew. Phosphorus deficiency is common in cashew growing acid soils in which the mineral fraction is dominated by kaolinite and sesquioxides. Conflicting reports were observed regarding the response of cashew to P fertilizer. Rao *et al.* (1984) observed no response to P application in sandy loam soils. Similarly, Veeraraghavan *et al.* (1985) found no effect of P on cashew in laterite soils of Madakkathara. It was observed that the main effect of P to increase the yield was limited to a dose of 25 kg/ha, but when applied with N fertilizer, P application increased yield up to a dose of 75 kg/ha (Sawke *et al.,* 1985). However, Kumar (1985) reported positive influence of P on nut yield. Richards (1993) reported that soil P is a major limiting nutrient in P deficient soils of Australia. According to him, P application increased nut number and nut yield. Of phosphatic fertilizers for use on acid soils in India, the slow release and more efficient ground Mussoorie (rock) phosphate is popular. Application of K increased the cashewnut production particularly in the presence of N (Lefebvre, 1973). Significant positive effects of K on growth and yield of cashew were reported by Ghosh (1988 and 1990). But Veeraraghavan *et al.* (1985) could not observe positive effect of K application in cashew. Kumar (1985) obtained linear response for K up to 150 g K_2O/tree. Phosphorus and K application at higher level improved the nut yield (Sawke, 1980). Increased nut weight and nut yield due to application of higher levels of N, P and K was reported by Ghosh and Bose (1986), Harishu Kumar and Sreedharan (1986), Ghosh (1990) and Kumar *et al.* (1995).

It is crucial that level of micronutrients in soil and plant should be optimum for growth and development since the micronutrient need is site specific. This calls for location specific management of micronutrients in cashew so that these do not become toxic to plant. To minimize wide spread deficiency of micronutrients, it would be the best option to incorporate them into macronutrient fertilizer sources which facilitates to apply small quantity of micronutrient fertilizers over a large field area in an uniform manner. In spray applications, micronutrients may also be mixed with plant protection chemicals besides macronutrients to reduce the cost of application. Foliar feeding is often the most effective and economical way to correct micronutrient deficiencies in horticultural crops. Foliar application of nutrients normally reduces the loss through adsorption, leaching and other processes associated with soil application. Deficiencies of Fe, Mn, Zn, Cu, B and Mo can be corrected by foliar sprays of 0.5-1% ferrous sulphate, 0.5-1% manganese sulphate, 0.5% zinc sulphate, 0.1% copper sulphate, 0.1% solubor and 0.1% Mo salts respectively to cashew at the emergence of the flush, panicle initiation and fruit set stages.

Fertilizers dosage, time and its schedule under different agro-climatic zones has been standardized (Veeraraghavan *et al.,* 1985; Harishu Kumar and Sreedharan, 1986; Grundon, 2001; Salam *et al.,* 2008; Yadukumar *et al.,* 2009). Integrated use of organic manures, inorganic fertilizers and biofertilizers assumes great importance for sustainable cashew production and maintaining soil health. The organic manures and biofertilizers not only supply essential plant nutrients, but also improve the soil physical, chemical and biological health. Inoculants of *Azotobacter* and *Azospirillum* either sole or in combination have been shown to improve N nutrition of plants through biological N_2 fixation and also secretion of some growth promoting substances which affect the growth, nutrition and microbial activity in the rhizosphere (Zayed, 1999). The phosphate solubilizing microorganisms *(Pseudomonas)* play an important role in conversion of unavailable forms of P into available forms through secretion of organic acids and enzymes. Arbuscularmycorrhizal fungi (AMF), on the other hand are ubiquitous in soils throughout the world and play an important role in affecting the plant growth through mobilization of nutrients. Green manuring maintains and improves soil structure by addition of organic matter, minimize P and K fixation in soils, produces humus, which enhances the utilization of fertilizer nutrients by plants and helps in reducing leaching losses by enhancing water retention ability of soil. Growing green manuring crops like glyricidia, sesbania, sunhemp and cover crops between two rows of cashew resulted in the nutrient addition of 186 kg N, 23.6 kg P_2O_5 and 126.2 kg K_2O through glyricidia and 141 kg N, 17.9 kg P_2O_5 and 162.3 kg K_2O/ha through sesbania (Yadukumar *et al.,* 2008).

Climatic requirement

Cashew, a tropical nut crop can be found growing between 28° North and 28° South latitude. In India, it is an economically important crop between 15° South and 15° North. Cashew thrives at temperatures up to 40° C. Damage to young trees or flowers occurs below the minimum temperature of 7° C and above the maximum of 45° C. Only prolonged cool temperatures will damage mature trees; cashew can survive temperatures of about 0° C for a short time (Ohler, 1979). Low altitude areas with a mean rainfall of 1,500 to 2,000 mm is excellent for cashew. Environments with maximum temperature ranging from 28 to 32 °C, minimum winter temperature around 19 °C and 70 to 80% relative humidity are fine for better output. Frost is detrimental to the crop. Mandal (1992) attempted to rate cashew growing environments as very good, good, fair and poor based on variation in altitude, rainfall, proximity to sea, maximum and minimum temperature, humidity and occurrence of frost. The ratings and the range of these parameters are indicated in Table 6.2.

Suitability studies for cashew using GIS showed that cashew grows at an

Table 6.2 Environmental rating for growing cashew

Parameter	Very Good		Good	Fair	Poor
	Class I	Class II	Class III	Class IV	Class V
Altitude (m)	20	20-120	120-450	450-750	
Rainfall (mm/year)	1500-2000		1300-1500	1100-1300	900-1100
Proximity to sea (km)	<80	80-160	160-240	240-320	
Maximum temperature (°C)	28-32	32-33	33-34	34-35	
Minimum temperature (°C)	19	18-19	17-18		15-17
Humidity (%)	70-80	65-70	60-65		50-60
Occurrence of frost	None	None	Very rare	Once in 5 Years	

elevation ranging from 0 to 1,000 m above mean sea level (MSL). However, the productivity is the highest up to the altitude of 750m above MSL. The average annual rainfall distribution in cashew areas ranged from low rainfall (300-600 mm in Gujarat) to high rainfall (2,700-3,000 mm in west coast and NEH region) but the productivity is highest in regions with a mean annual rainfall distribution of 600-1,500mm. The mean annual temperature ranged from 20°C to even more than 27.5°C and the productivity of cashew is higher in regions where the mean annual temperature ranged from 22.5 to 27.5°C. The productivity of cashew is higher in regions where the minimum temperature ranges from 10 to 22°C and is lower in regions where the minimum temperature drops below 10°C (Fig. 6.3 to 6.6) (Rejani *et al.,* 2013).

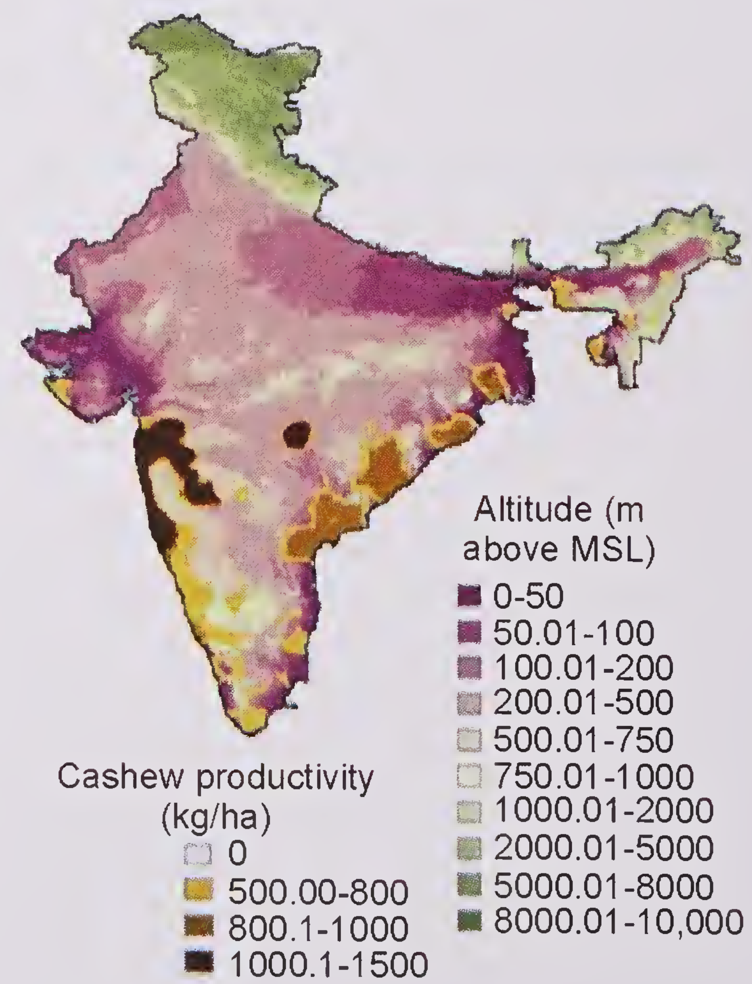

Fig.6.3. Cashew area and productivity (kg/ha) overlay with altitude (m above MSL)

The rainfed cashew crop is highly sensitive to change in climate and weather, especially during reproductive phase. High temperature (>34.4°C) and low relative humidity (RH) (<20%) during afternoon cause drying of flowers. The maximum temperature, humidity and rainfall are the major climatic factors that influence the productivity

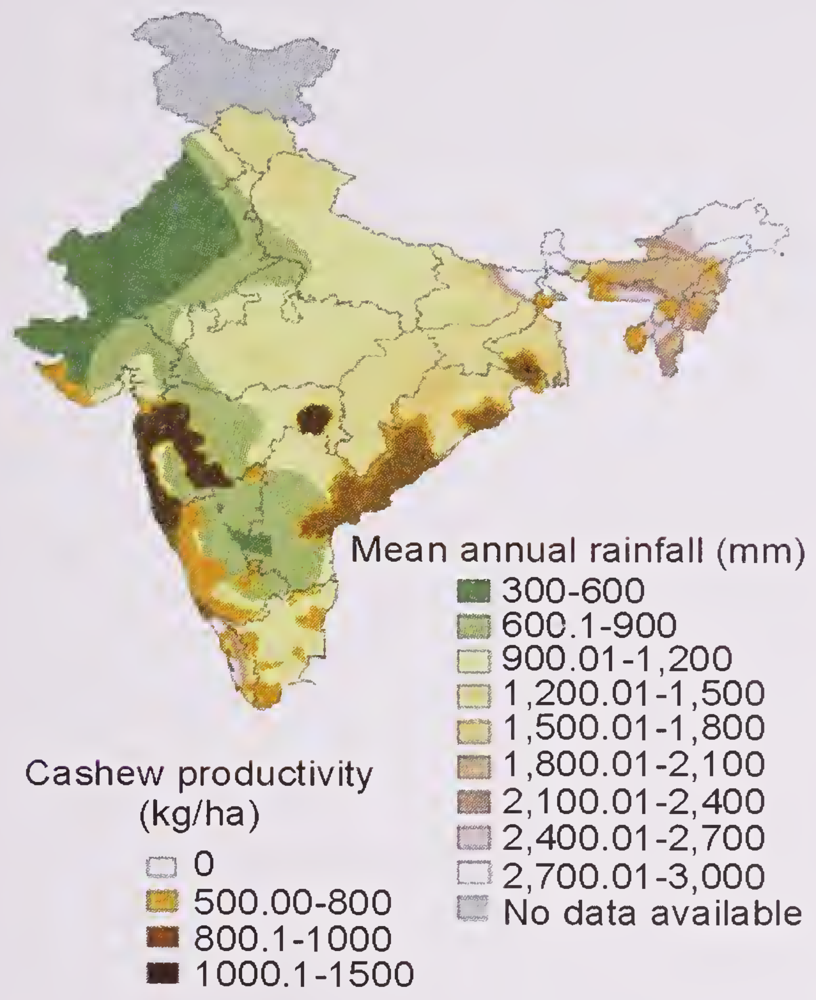

Fig. 6.4. Cashew area and productivity (kg/ha) overlay with mean annual rainfall (mm)

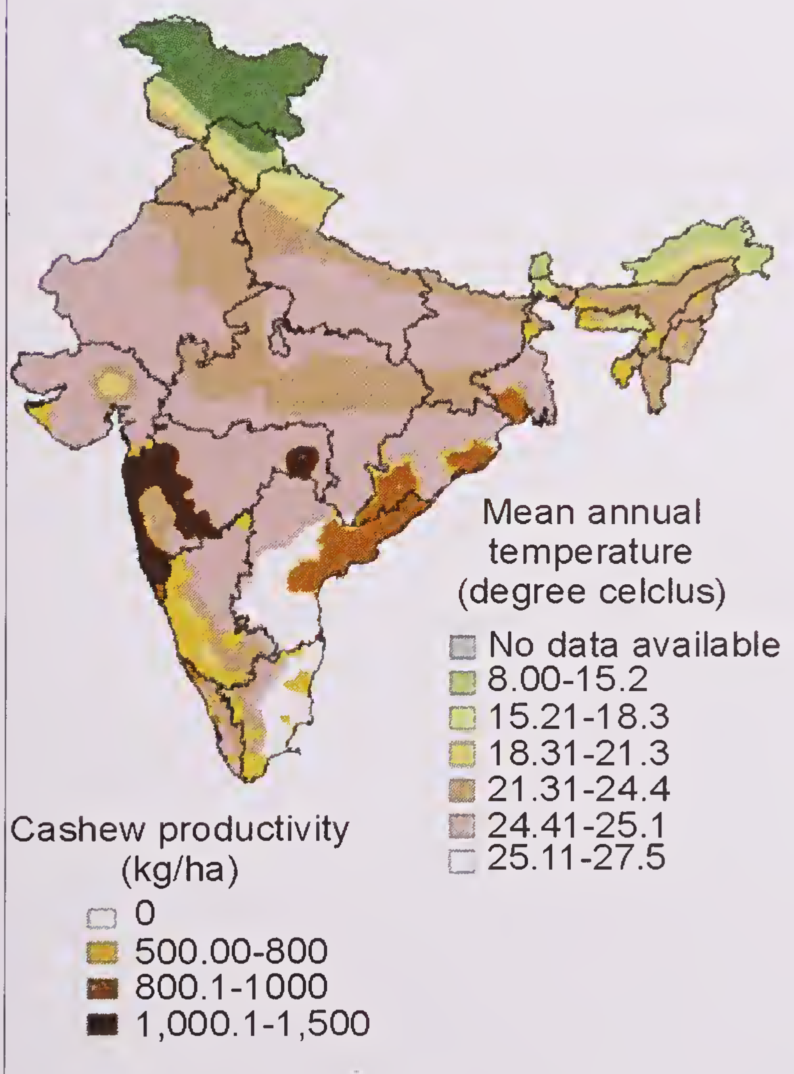

Fig. 6.5. Cashew area and productivity (kg/ha) overlay with mean annual temperature (°C)

of cashew. According to Prasada Rao and Gopakumar (1994), the growth and production of cashew is highly dependent on latitude, altitude, temperature, rainfall, RH, sunshine, wind and soil moisture content. The RH during pre-flowering stage is the main factor which explains the yield variation in cashew plantations (Haldankar *et al.,* 2003). According to Prasada Rao *et al.* (2010), the maximum temperature plays a crucial role on nut size and kernel weight of cashew during the nut development stage. The humidity of suitable region ranged from 60 to 80%. High relative humidity adversely affects the nut quality. The unusual rains between November and December inordinately delay reproductive phase of the late flowering varieties. Unseasonal rainfall and heavy dew during flowering and fruiting intensify the incidence of pests and diseases as well as deterioration of nut quality. The flowering, fruiting, insect pest incidence, yield and quality of cashew are more vulnerable attributes for climate change. The sea water level rise due to the melting of glaciers as a result of increase in temperature may also pose problem for cashew cultivation since large proportion of cashew plantations exist in Eastern and Western Coastal regions of India.

Though cashew can tolerate wide range of temperature but the optimum monthly temperature is between 24°C and 28°C. In major cashew growing regions, the mean daily maximum temperature

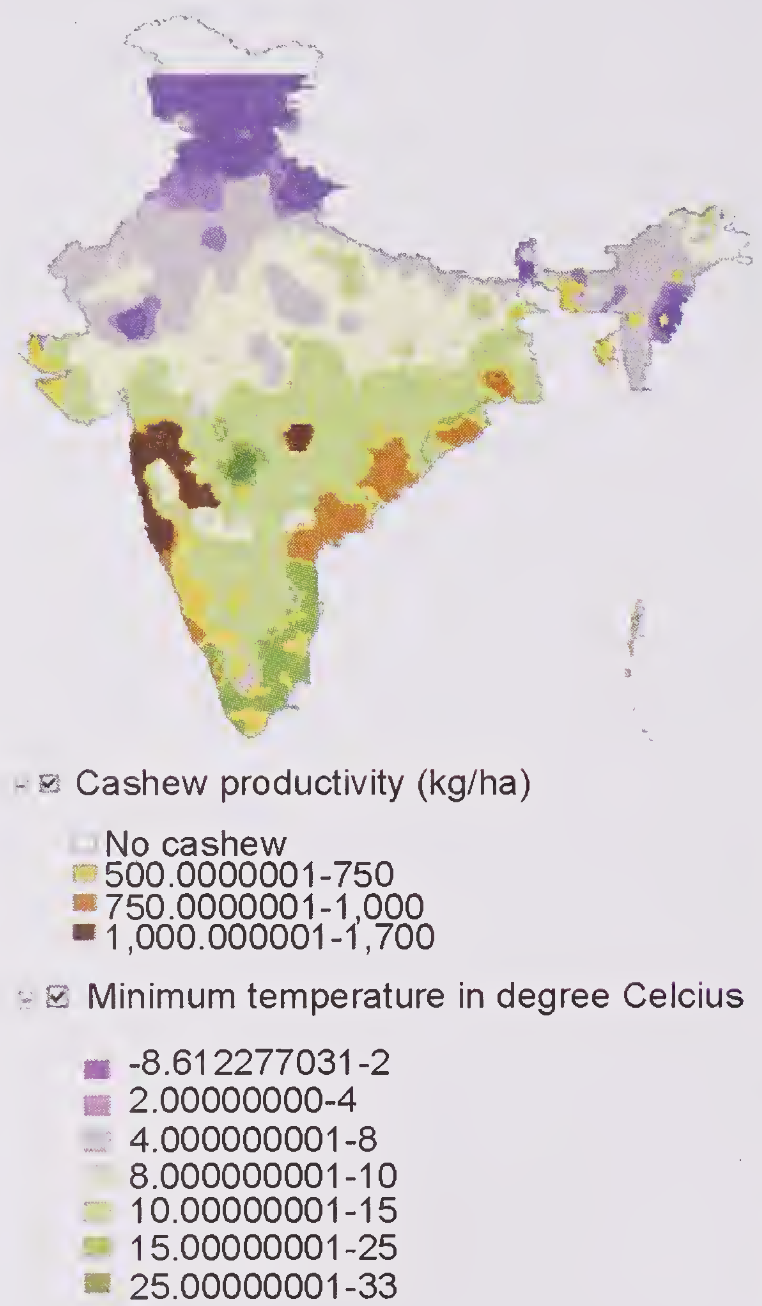

Fig. 6.6. Cashew area and productivity overlay with decrease in minimum temperature (-2 °C)

vary between 25°C and 35°C and the mean daily minimum temperature vary between 15°C and 25°C. The productivity of cashew is higher in regions where the mean annual temperature ranged from 22.5 to 27.5°C and the minimum temperature ranges from 10° to 22°C. The productivity is lower in regions where the minimum temperature drops below 10°C. Cashew grows in the semi-arid regions like northern Mozambique where a daily maximum temperature exceeds 40°C and in Asom, cashew survives up to 7 °C. It has been reported that cashew cultivation is not economical in regions where annual temperature falls below 20°C for prolonged periods.

Flowering time depends on the latitude. In Brazil and Tanzania, peak flowering is between August and September. The highest flowering occurs in October in Mozambique, while in Philippines it is March. In the west coast of India, flowering is from October to March while in the east coast of India, flowering is delayed by about 2-3 months. However, the crop is ready for harvest in summer, both in the north and south of the equator. For flowering, cashew requires mild winter, that is low minimum surface air temperature ranging between 16 °C and 20 °C coupled with more dew nights. Several factors such as genotype, meteorological parameters, exposure to sunlight, latitude, altitude, crop management practices, the incidence of pests and diseases etc, play a crucial role in flowering and fruiting pattern in cashew. Year to year variation in flowering phase of a variety is common even under uniform cultural and management practices, signifying the role of climatic variables on flowering behaviour of cashew. Although no data are available on the effect of daylength, cashew might be expected to display equatorial behaviour in this respect, viz., equal day and night lengths being most favourable. It has been reported that flowering of cashew is more influenced by the occurrence of rainy and dry seasons than by length of daylight. In regions with two dry seasons cashew may flower twice. If there is no marked dry season cashew may flower throughout the year, whereas in regions with a well-defined dry season flowering occurs only once, at the beginning of the dry season (Ohler, 1979).

Cashew, a tropical tree, bears more fruits on the peripheral branches, which receive complete sunlight. It is highly sensitive to light and produces less foliage, flowers and fruits on the shaded branches than on braches exposed to sunlight. Cashew shows a tendency to grow more towards south in response to sunlight in the Northern Hemisphere. It is more evident in higher latitudes towards north in exploration of sunlight. The branches of cashew in south produced maximum number of fruits, followed by west and east while the lowest towards north. Cashew responds well to sunlight, indicating that it has a predominant phototropism character. To complete its reproductive phase and to give a full yield, it must have required sunshine uniformly distributed over its entire foliage. Cashew requires a bright sunshine (>9 h/day) with moderate dry weather for flowering. In Togo the optimum sunshine is held to be 2,464 h/year with 1,285 h in the flowering/fruit set period (November-March) which is only found in the north and centre of the country. In Brazil the optimum sunshine lies between 1,500 and 2,000 h/year, while the precise sunshine for Venezuela is considered to be an average of 2,000 to 2,400 h/year. Cashew genotypes vary distinctly in their heat units (day °C) requirement. Early variety (Anakkayam-1) requires only 1,953 heat units for reproductive phase, while late variety (Madakkathara-2) requires 2,483 heat units. Continuous rains without critical dry spells and late winter rains delay the bud break in cashew. A dry spell of 7 days is usually necessary 30 days prior to the bud break. Late and extended winter rains reduce the number of bright sunshine hours invariably which results in delaying of bud break and better availability of soil moisture during flowering (December and January), (Prasada Rao *et al.*, 2001).

Cashew can survive under very high and low rainfall conditions. Although cashew can tolerate drought conditions but for proper vegetative development and regular fruit-setting, the average annual rainfall of 1,300 to 2,500 mm is considered to be suitable. The average annual rainfall distribution in cashew areas ranged from low rainfall (300-600 mm in Gujarat) to high rainfall (2,700-3,000 mm in west coast and NEH region) but the productivity is highest in regions with a mean annual rainfall distribution of 600 to 1,500 mm. Cashew needs a clearly defined dry season of at least 4 to 5 months. A dry spell from January to May with occasional light summer rains ensures better cashew production. A well distributed rainfall during growing and pre-flowering phase (September to November) favours higher productivity (Venugopal and Khader, 1991). A well distributed North-East monsoon rainfall of about 500 mm from September to December and about 100 mm between February and April are ideal for better crop production. The rains during March-April may be more beneficial in particular to late season varieties. Cashew can tolerate drought conditions without much adverse impact on its productivity as compared to other tree crops (Veeraraghvan and Pushpalatha, 1990). Any unusual rains during November and December inordinately delay the reproductive phase of late-season varieties (Rao, 1994, 2001). Light rains during flowering do not affect the production but heavy rains during flowering affects the yield. Year to year variation in time of flowering of a variety is common even under uniform cultural and management practices. It signifies the influence of weather factors on flowering behavior of cashew.

Cloudy conditions, high RH and heavy dewfall are favourable for outbreak of insect pests and diseases. Cashew is infested by a number of insect pests hence limiting the production considerably. The occurrence of an important sucking insect pest, tea mosquito bug (TMB) (*Helopeltis antonii* Signoret) during the cropping season is one of the main reasons for reduction of cashew nut yield. The incidence and severity of the pest is highly dependent on climate and weather factors. The pest population commences from October and depending on the location and climatic conditions, it continues till the end of the cropping season. Although the pest population exists in cashew orchards at varying levels during the whole year, the increase of population synchronizes with the flushing and flowering period. It reaches a peak during the early to mid blossom period (December to February). The minimum temperature plays a vital role in the incidence of pest population and is negatively correlated with the TMB pest incidence (Godse *et al.,* 2005). The favourable minimum temperature for TMB incidence ranges between 13-18 °C. Low temperature (12 °C) is antagonistic for pest build up. Based on the information available on cashew production in relation to weather, soil and yield potential, an attempt has been made to demarcate agroclimatic zones for cashew across the west and east coasts of India by Prasada Rao (2002). Cashew productivity can be improved towards north across both the coasts of west and east while it may decline towards inland plateau of Peninsular India. The northeast region may not be favorable due to occurrence of frequent cold waves during fruiting season.

Apart from the damage caused by the infestation of TMB, infection of the panicles by the fungal pathogens, viz. *Colletotrichum gleosporoides* and *Gleosporium mangiferae* cause drying up of young shoots, inflorescence and immature nuts in cashew. The characteristic symptom is the drying of floral branches. The symptoms appear as minute water soaked lesions on the main rachis and secondary rachis. The incidence is very severe when cloudy weather prevails. The incidence of this disease is being reported from different new locations in which it was not prevalent earlier. High relative humidity in forenoon during December - February both in 1997 and 1998 and the minimum temperature of 18-20°C were favourable for sporulation of fungi. A significant increase in dewfall was one of the most important factors which favoured the growth, sporulation and spread of fungi. Cloudiness leading to low bright sunshine hours (2 h/day) followed by dewfall triggered the growth, sporulation and spread of fungal pathogens causing inflorescence blight during 1998-99 in Kannur and Kasaragod districts (Prasada Rao, 2002).

Future thrusts

- Need to generate detailed information on soil scenario of cashew growing regions in India and to develop nutrient diagnostic norms in cashew growing soils.
- Research work needs to be strengthened on nutrient constraints in cashew growing soils and their remedial measures.
- Development of climate resilient agro-techniques in order to suit unfavourable abiotic stresses.

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7

Production Technology

THERE are several trees provide a tempting variety of edible nuts. The nutrient content of tree nuts makes them a good dietary choice, while their potential in relation to disease reduction shows promise. Eating a variety of tree nuts is a good approach to support and protect health. Edible tree nuts contain important compounds that protect against the disease process. With a host of bioactive nutrients and protective fats, tree nuts make an ideal food. Tree nuts could be said to be nutritionally dense morsels that come in compact packages. Tree nuts are so nutritious; in fact, they are considered an ideal food. Common edible tree nuts include almonds, Brazil nuts, cashews, chestnuts, hazelnuts (filberts), hickory nuts, macadamia nuts, pecans, pine nuts (*Pinon pignolias*), pistachios, shea nuts and walnuts. Cashewnut is one of the most widely consumed edible tree nuts in the world and ranks third among the edible tree nuts of the world. Botanically, cashew is an average size evergreen tree belonging to the Anacardiaceae family of the genus: *Anacardium*. The scientific name of cashew is *Anacardium occidentale* L. Cashew is widely cultivated throughout the tropics for its nuts and is a native of tropical American country: Brazil. It was one of the first fruit trees from the New World to be widely distributed throughout the tropics by the early Portuguese and Spanish adventurers (Purseglove, 1988).

India is the first country that nourished this crop and made it a commodity of international trade and acclaim. Cashew tree bears numerous, edible, pear shaped false fruits or pseudo fruits or "accessory fruits" called "cashew apples." A small bean shaped, grey color "true fruit" is firmly adhering to lower end of these apples appearing like a clapper in the bell. This true fruit is actually a drupe, featuring hard outer shell (cashew nut shell) enclosing a single edible seed. The nut consists of shell and the seed consists of cashew kernel and the testa. The outer shell is green and leathery and turns an orange red when mature. The inner shell is hard, similar to other nut shells, and contains the edible kernel. The oil enclosed in the nut's shell (cashew nut shell liquid-CNSL) (anacardic acid) is toxic and can burn the skin. It is used in producing plastics and as a lubricant and insecticide (*Anon*, 2012a). It is therefore, the outer shell which is roasted in the processing unit and then, the edible kernel is extracted.

Cashew kernel measures about 2.5 cm in length and 1.25 cm in diameter with kidney or bean shape, and smooth curvy pointed tip. Each kernel has two equal halves as in legumes. The kernels are cream white color with firm yet delicate texture and smooth surface. Cashews have buttery texture with pleasant sweet fruity aroma. The development of nut (fruit) and cashew apple appears to take place independently of each other. A period of 2 to 3 months elapses between fruit set and fruit maturity. About a week after pollination, the ovary swells and attains the size of a pea and it reaches maximum size in 30 days, hardens in the ensuing 10 days and declines in size by 10% at harvest. From the fifth week onwards, when the growth of nut ceases completely, the peduncle (flower stalk) starts growing rapidly and out grows the nut. This forms the cashew apple. The fruit ripens in 60 days. As the season advances the number of days required for the fruits to ripen is reduced from 60 to 45 days.

India has always been a major player in the production of cashewnut. The major states in India where cashew is cultivated are Kerala, Karnataka, Goa, Maharashtra, Tamil Nadu, Andhra Pradesh, Telangana, Odisha and West Bengal. The country's average annual yield per hectare is 706 kg (2014-15). As India is the largest processor country in the world, it is left with more quantity for exports that also makes it the largest exporter in the world cashew kernel market.

Innovative production technologies

The cashew tree grows in the tropics and subtropics requiring high humidity and fertile soil. Related to the mango and pistachio, the cashew can grow to a height of 15 m and may bear fruits in the second year, be productive in the fourth year, and reach maximum yields in around ten years. In order to sustain in the international market, productivity has to be increased. Up to 1970, the productivity of cashew was around 630 kg/ha. Between 1975 and 1985, the productivity was low (430 kg/ha). Since, 1985, the productivity has been steadily increasing from 430 kg/ha to 865 kg/ha in 2000 (Balasubramanian, 2000; Bhaskara Rao and Nagaraja, 2000). This is mainly due to improved technologies available and replanting of large areas of old plantations and the availability of necessary high yielding planting material through government agencies and private nurseries. Research institutions and private nurseries are producing nearly a million cashew grafts annually.

Though cashew is a hardy crop which can be grown in wastelands and degraded/ marginal lands, cashew responds very well under improved package of practices. Several technologies were sqdeveloped in cashew and available to farmers for implementation. One of the possible solutions to enhance the production and productivity of cashew in India is to plant clonal material (softwood grafts) of high yielding cultivars and to adopt proper soil, water and nutrient management in cashew. Second approach is to adopt high density planting system or intercropping in cashew with canopy management and third approach is by expansion of cashew area both in traditional and non-traditional areas. Some of the innovative production technologies for cashewnut are discussed.

High-yielding Varieties: Proper selection of high yielding variety suitable for a particular agroclimatic condition is very important for sustainable and economic production. A large number of high yielding varieties of cashew developed by the ICAR-Directorate of Cashew Research, Puttur and other Research Stations of the State Agriculture/Horticulture Universities were identified for cultivation in different agro-ecological regions. Information on these cultivars developed and released over a period of last three decades has been published (Abdul Salam and

Table 7.1. Cashew varieties developed by different research stations in India.

Research station	Cashew varieties
Cashew Research Station, Bapatla, Andhra Pradesh	BPP-1, BPP-2, BPP-3, BPP-4, BPP-5, BPP-6, BPP-8
ICAR Research Complex for Goa, Ela, Old Goa	Goa-1, Goa-2
Directorate of Cashew Research, Puttur, Karnataka	NRCC Selection-1, NRCC Selection-2, Bhaskara
Agricultural Research Station, Chintamani, Karnataka	Chintamani-1, Chintamani-2
Agricultural Research Station, Ullal, Karnataka	Ullal-1, Ullal-2, Ullal-3, Ullal-4, UN-50
Cashew Research Station, Anakkayam, Kerala	Annakayam-1 (BLA 139-1)
Cashew Research Station, Madakkathara, Kerala	Madakkathara-1, Madakkathara-2, K-22-1, Sulabha, Dhana, Kanaka, Priyanka, Dharashree, Amrutha, Akshaya, Anagha
Regional Fruit Research Station, Vengurla, Maharashtra	Vengurla-1, Vengurla-2; Vengurla-3, Vengurla-4, Vengurla-5, Vengurla-6, Vengurla-7, Vengurla-8 Vengurla-9
Cashew Research Station, Bhubaneswar, Odisha	Bhubaneswar-1, Balabhadra, Jagannath
Regional Research Station, Vridhachalam, Tamil Nadu	VRI 1, VRI 2, VRI 3
Regional Research Station, Jhargram, West Bengal	Jhargram 1, Bidhan Jhargram 2

Bhaskara Rao, 2001). Cashew cultivars developed by different Research Stations in India are given in Table 7.1.

Propagation Technology: Cashew being a highly cross pollinated species, its progenies raised through seed propagation turnout heterogeneous. However, if high yields of superior quality are desired then the best clones must be selected and propagated vegetatively. One of the main hurdles in deriving the benefits of the new cultivars was the lack of a suitable vegetative propagation method till early 1980s. Commercial planting of the new cashew cultivars requires vegetative multiplication in the nursery on a rather large-scale. Several methods/techniques of vegetative propagation have been tried in cashew over the years with varying success. Various methods of clonal propagation tried in cashew are well documented (Agnoloni and Giuliani, 1977; Ohler, 1979; Swamy and Mohan, 1992; and Swamy, 1994a). In India research showed that softwood grafting technique is the best method suitable for commercial multiplication of cashew cultivars (Swamy, 1989; and Swamy *et al.,* 1993).

In case of softwood grafting, about 45 to 60- day-old seedlings are used as root stocks. One or two pairs of bottom leaves on the root stocks are retained and others are removed. The terminal portion of the root stock is decapitated at a height of about 15 cm from ground level where the softwood portion is available for grafting. Then a cleft of 6 to 7 cm deep is made. The pre-cured scion of about 3 to 5- month-old is selected and it is mended into a wedge shape of 6 to 7 cm length by chopping of little portion of wood and bark on either side and taking care to retain some bark on the remaining two sides. The length of the scion should be 10 cm. Then wedge of the scion is inserted into the cleft of root stock and the graft joint is secured firmly with a polythene strip of 30 cm length, 2.0 cm width and 100 gauge thickness. A white polythene cap of 20 cm × 4 cm and 200 gauge thickness is inserted over the scion and left in the propagation shed for two-three weeks. After three weeks when 70-80% sprouting is observed, the polythene caps are removed and the grafts are shifted to open conditions in the nursery and maintained till planting them in the field (Swamy, 1989; Swamy, 1994b). Under warm and humid climatic conditions, softwood grafting will be successful almost throughout the year with a mean graft success of over 70%. However, monsoon (June-November) is ideal for commercial production of softwood grafts (Swamy *et al.*, 1993). *In situ* softwood grafting can also be done on one-year-old cashew plants under field conditions. A success of 71% was obtained.

Top working technology: Softwood grafting technique has also been adopted in top working of unthrifty cashew trees or senile cashew orchards. Top working is the technology of rejuvenating the old, poor yielding, but healthy cashew trees of about 10 to 15 years-old by adopting softwood grafting technique. Such trees can be rejuvenated by grafting with scion sticks of improved and high-yielding cultivars on new shoots arising on beheaded stumps. Top working technology envisages beheading of cashew trees to an height of 0.75 to 1.00 m from ground level, allowing the juvenile shoots to sprout on the stumps and taking up *in situ* grafting of selected shoots with scions of high yielding cultivar. Top working offers possibility of boosting cashewnut production 3 to 4 folds in a short span of time. Few old trees may also be converted into desirable cultivar by top working in order to collect scion sticks for grafting (establishment of Scion Bank). However, the success with top working of cashew is not consistent and the success percentage varies depending upon the incidence of stem and root borer in different cashew plantations (Swamy and Bhat, 1992 and 1993). However, top working technology can be followed in homestead gardens with few plants. Top worked trees start flowering and fruiting in the very next year after grafting. May-June is the right time for beheading and July-August is the best time for grafting. However, precautions are to be taken to monitor each topworked cashew plant for the attack of stem and root borer (Rupa *et al.,* 2011).

Selection of land for cashew orchards: In several countries one of the myths for the cashew cultivation is that cashew is an ideal candidate crop for soil conservation, wasteland development and afforestation programme. In most of the countries cashew is relegated to poor soils leading to the present crisis of low productivity in most of the countries in Asia. However, cashew can thrive well in a wide variety of soils namely, hard laterite degraded soils, red sandy loam soils, sandy loam soils and coastal sands. Mahopatra and Bhujan (1974) suggested a rating chart for land selection for cashew. They have advocated that instead of considering the type of the soil alone, the class of a soil with a grading from

Classes I to V should be adopted while selecting the site for raising cashew orchards. Class I to III types of soil with medium acidic range to near neutral (6.3- 7.3 pH), with a slope of 0° to 15°, and with water table up to 10 m, was recommended as the best soils suited for higher production of cashew. However, in many countries, the other plantation crops like coconut and rubber compete for similar types of lands and hence only Class IV and V soils are at present committed to cashew. It is suggested that Class V soils which are unsuitable for good production of cashew should be avoided, while Class IV soils require strong soil conservation measures as well as other soil amelioration technologies.

Planting technology: Planting of soft wood grafts is usually done during monsoon (July-August) both in the west coast and east coast of India. Therefore, land preparation such as clearing of bushes and other wild growth, digging of pits for planting, should be done during pre-monsoon season (May-June). A spacing of 7.5 m × 7.5 m or 8 m × 8 m is recommended for cashew (156-175 plants/ha). A closer spacing of 4 m× 4 m in the beginning and thinning out in stages and thereby maintaining a spacing of 8 m × 8 m by the 10th year can also be followed. This enables higher returns during the initial years and as the trees grow in volume, the final thinning is done. However, in level lands it will be advantageous to plant the grafts in hedge row system of planting at 10 m × 5 m spacing which will accommodate about 200 plants/ha and at the same time leaving adequate inter-space for growing intercrops in the initial years of orchard establishment. Normally cashew grafts are planted in the pits of 60 cm × 60 cm × 60 cm size. The size of the pits can be 1 m × 1 m × 1 m, if hard laterite substratum occurs in the subsoil. It is preferable to dig the pits at least 15 to 20 days before planting and expose them to sun. The pits should be completely filled with a mixture of top soil, compost (5 kg) or poultry manure (2 kg) and rock phosphate (200 g). This will provide a good organic medium for obtaining better growth of plants. Planting of grafts is done preferably during July-August. Usually five to twelve month old grafts are supplied by the Research Stations and private nurseries in polythene bags. The soil in the center of the filled pit is scooped out. The polythene bag of the grafted plant is removed carefully without disturbing the ball of earth. Then the ball of earth is placed in the center of the pit where the soil was scooped out and it is covered with soil and pressed gently. Care must be taken to see that the graft joint remains at least 5 cm above the ground level at the time of planting. The grafted plant should be provided with a stake and tied with a plastic thread immediately after planting to avoid breakage at the graft joint due to wind etc. Staking should be continued during second and third year of planting also. Immediately after planting, the basin around the graft should be mulched with green leaves. This suppresses weed growth and conserves soil moisture. The side shoots arising from root stock (below graft joint) should be removed frequently. If any mortality is observed in the field, gap filling may be taken up during the next year (Bhaskara Rao *et al.,* 1993, and Swamy and Bhaskara Rao, 2000).

Training and pruning: During the first year of planting the sprout (new growth) coming from the root stock portion of the planted graft, that is from the portion below the graft joint, should be removed frequently. If these sprouts are allowed to grow, it usually results in the death of the grafted scion and only the root stock seedling will be growing and the very purpose of planting vegetatively propagated material is defeated. Therefore, this operation is absolutely essential during the first year of planting. Initial training and pruning of young cashew plants during the first 3 to 4 years is essential for providing proper shape. The plants are shaped by removing the lower branches which come up from the base during the first 3 to 4 years. Thereafter, little or no pruning is necessary. The plants should be allowed to grow by maintaining a single stem up to 0.75 to 1.00 m from ground level. This can be achieved by removing the side shoots or side branches gradually as the plant starts growing from the second year of planting. Weak and criss-cross branches can also be removed. Branches growing unwieldy may also be cut off. Proper staking of the plants is required to avoid lodging due to wind blow during the initial years of planting. Initial training and pruning of cashew plants facilitates easy cultural operations such as terrace making, weeding, fertilizer application, nut collection, plant protection, most importantly prevention of stem and root borer infestation by swabbing the trunk portion with carbaryl (0.2%) or coal tar and kerosene (1:2). The flower panicles emerging from the graft during the first and second year of planting should also be removed (deblossoming) to allow the plant to put up good vegetative growth. The plants are allowed to flower and fruit only from the third year onwards (Swamy and Bhaskara Rao, 2000).

Cashew being an evergreen plant puts forth new flushes every year. The twigs, shoots, and small branches of previous year's growth covered under shade tend to dry and thus a lot of dry/dead wood is produced every year on matured cashew trees and it is more on old trees aged about 20 to 30 years. Further, water suckers, weak and criss-cross branches and shoots produced inside the canopy fail to flower and even if they flower they fail to set fruits. Therefore, it is essential to prune dead wood, criss-cross branches, water suckers and shoots under shade at least once in two years. Pruning of such branches not only helps in maintaining sanitation of the plantation, better infiltration of light, efficient plant protection spraying, harvesting and inter cultivation operations, but also improves nut yield per tree. In older cashew plantations, removal of dried/dead wood, criss-cross branches, water shoots etc. should be attended to at least once in 2-3 years. This allows adequate sunlight to fall on all branches and allows proper growth of the canopy. Pruning of cashew plants should be done during August-September and the cut surfaces should be treated with Bordeaux paste (10%) to avoid fungal infection. If the cut surfaces are small in size, Bordeaux mixture (1%) spray can be given (Bhaskara Rao *et al.,* 1993).

Regular shape pruning should be done to achieve umbrella shaped canopy with uniform spread. During first 6 to 7 years the crop, canopy covers almost 100% of the given ground area. Pruning of branches is done to plants after 6 or 7 years. Because, during this period thick shade is formed due to overlapping of branches. This in turn reduces yield. It is at this stage towards peripheral end, branches are pruned back by 0.5 m radius around canopy to intercept 80% of light by the crop canopy and remaining 20% filtered to the ground penetrating through gaps of the canopy. Normally, pruning is done during May after the harvest of the crop. Soon after this, 10% Bordeaux paste is applied to the cut ends of such pruned branches. Detopping at a height of 3 m is necessary from 5th year onwards.

Dry branches are seen once ground coverage by crop canopy reaches 80% or above. Normally, the dry branches are seen during 7, 8, 9 and 10 years after planting. These dry branches have to be removed at least once in two years from 7^{th} year onwards. Thinning of original population to 50% is done by eleventh year (Rupa*et al.*, 2011 and Yadukumar, 2011).

Manuring and fertilization: Cashew can adapt to a wide range of soil fertility. Cashew is less exacting than many other horticultural crops in quantitative level of soil nutrients required and can survive and bear good crops on soils where the fertility is so meagre that other fruit crops would fail. Application of manures and fertilizers promotes growth of the plants and advances the onset of flowering in young trees. Application of 10 to 15 kg of farmyard manure or compost per plant is beneficial. This quantity can be limited to 25 kg/per plant. Nitrogen (N) and phosphorus (P) were found to be the most important nutrients during the pre-bearing stage, and at the bearing stage K together with N is important. Application of fertilizers, dosage, time and its schedule under different agro-climatic zones have been standardized. It has been found that under normal density planting system (200 plants/ha), farmyard manure or compost at a rate of 30-35 kg/plant or 17 kg of poultry manure/plant/year or 500 g N, 125 g P_2O_5 and 125 g K_2O + 10 kg farmyard manure/plant/year as the optimum dose for cashew. The recommended dose of fertilizer during first year after planting (YAP) is $1/5^{th}$ of the full dose, 2^{nd} YAP is $2/5^{th}$, 3^{rd} YAP is $3/5^{th}$, 4^{th} YAP is $4/5^{th}$ and 5^{th} year onwards is full dose. The optimal fertilizer dose for cashew under high density planting system (500 plants/ha) for the first 11 years is found to be 150 g N, 50 g P_2O_5 and 50 g K_2 O/ plant/year. The highest cumulative yield of 9.5 tonne/ha was obtained against 7.2 t/ha under normal density (200 plants/ha). The net profit was about 25% higher than control. Besides, there was an increase in the soil moisture content during the critical period, organic carbon and available nutrient contents and suppression of weed growth (Rupa *et al.,* 2011).

Irrigation and drip irrigation: Cashew is cultivated mainly as a rainfed crop and the areas in which cashew is planted are usually devoid of surface water sources. However, of late new plantations are being raised where supplementary irrigation during dry months is possible by tapping the underground water source. Experiments conducted in India indicated that supplementary irrigation at 200 liters/tree from November to March can enhance the fruit retention and also double the yield as compared with the plantations which do not receive supplementary irrigation. The yield increase was primarily attributed to the higher retention of the set fruits with supplementary irrigation as against the plot which did not receive any supplementary irrigation. Irrigation @200 litres/tree from November to March at fortnightly intervals (10 irrigations during the period) resulted in retention of 44% of the fruits which are set as against 30% of the fruits which are retained in other plots. Even the fruit set is doubled in the irrigated plots as compared to the control plots (Yadukumar and Mandal, 1994). This package can be adopted in the homestead gardens especially in rural areas, where it should be possible to give the supplementary irrigation without incurring large additional expenditure by the farmer himself. In China the supplementary irrigation is provided only during the establishment of the orchards. The monocrop orchards or the grown up orchards rarely do receive any supplementary irrigation, while the practice is seen in some of the gardens where intercrops are cultivated. In other Asian countries supplementary irrigation is rarely contemplated.

Continuous irrigation of cashew trees as soon as the dry season proceeds may not be useful. Water deficits result in poor kernel development. As the prolonged dry spells adversely affect cashew growth and production, summer irrigation may be beneficial. However, the bud remains dormant during rainy season and breaks only after the cessation of rains. Moisture deficit is a pre-requisite for bud break in cashew. Over irrigation may be harmful than under-irrigation and in cashew, it leads to excessive vegetative growth of the canopy. This, in turn, may result in reduced nut size and increased insect attack (Agnoloni and Giuliani, 1977) and should, therefore, be considered for adequate irrigation scheduling. Cashew does not withstand water stagnation and it should be ensured that there is proper drainage for all the plants both in the cashew orchards as well as in the homestead gardens (Bhaskara Rao *et al.*, 1993). Water logged condition may lead to gummosis. If protective irrigation is taken up during peak summer season it will have a good impact in increasing yield further. Irrigation would be needed to meet the water deficit particularly during the non-monsoon period. In this context, it would be relevant to note that cashew requires some dry periods for flowering and fruit setting. Hence, irrigation should be avoided during the post-monsoon period between August to December. Irrigation should not be given before or at the time of flowering as it would add to vegetative growth rather than fruiting (Jose and Singh, 2002).

Trials conducted at DCR, Puttur, indicated that nut retention and yield can be increased by irrigation. Irrigation @ 80 litres/plant once in four days through drippers during flowering and fruit development (December to March) (2,400 litre/plant/season) resulted in higher yield (Rupa *et al.*, 2011).

Fertigation in cashew: Trials were also conducted at DCR, Puttur, on drip irrigation coupled with graded doses of nitrogen ranging from 250 to 750 g N, 62.5 to 187.5 g P_20_5 and K_2O, respectively. It was found that irrigation alone at 60-80 liters without fertilizers increased the yield by 60- 70% when compared to trees receiving no irrigation and no fertilizers. When the same levels of irrigation once in four days during dry months with highest doses of fertilizers (750 g N, 187.5 g each of P_20_5 and K_2O) increased the yield up to 114-117% over the plots which received no irrigation and fertilizers (Anon, 1998).

Water soluble fertilizers like urea, DAP, and MOP are used for fertigation through drip lines from December-March along with application of 4 kg castor-cake (normal density planting system) to soil during August. Fertigation is done once in a week from December to March. With fertigation, the quantity of nutrients (through fertigation and organic manure) to be applied can be reduced to half the quantity of recommended nutrients. An increase of 100 and 226% in yield was observed in treatment receiving half of recommended dose of NPK in inorganic from (recommended dose: 500g N, 125 g each of P_2O_5 and K_2O/tree/year) of nutrients through fertigation and balance half applied in organic from through castor-cake as compared to the above dose applied through soil and irrigated separately and, absolute control (without manure and irrigation), respectively, indicating better nutrient use efficiency. Highest profit of ₹ 27, 294/ha (with B:C Ratio of 3:71) was obtained with the application of half recommended dose of nutrients through fertigation and balance half applied in the form of castor cake to soil, while the profit was ₹ 8,995/ha when he NPK dose was given to soil (Rupa *et al.*, 2011).

Soil and water conservation techniques: Cashew is generally grown as a rainfed crop and is being cultivated along steep slopes of hillocks where the fertile top soil is eroded and the substratum is exposed. Also, due to the non-uniform distribution of rainfall, cashew experiences severe moisture stress during its flowering and fruiting period (January to May). Hence, soil and water conservation (*in situ* moisture conservation) is very important for enhancing the productivity of cashew (Swamy and Bhaskara Rao, 2000; Yadukumar, 2011).

Opening of pits of size 1 m × 1 m × 1 m and filling of pits to two-thirds with soil mixed with organic manure and rock phosphate, improve the moisture and nutrient availability in the root zone during initial years and creates loose soil for the roots to penetrate. After planting, proper mulching needs to be done, which reduces the evaporation loss thereby enhances moisture conservation and improves the nutrient status of soil (Yadukumar, 2011).

Cashew is commonly grown in sloppy lands both in the west coast and east coast of India. Soil erosion and leaching of plant nutrients are generally expected under such situations. To overcome this problem, preparing terraces around the plant trunk and opening of catch pits are highly essential. Therefore, before the onset of south west monsoon (May to June), terraces of 2.0 m radius should be made before opening of the pits (usually terraces are prepared during the second year of planting). This helps in soil and moisture conservation resulting in very good growth of plants in the first year of planting itself. Terraces are prepared by removing the soil from the elevated portion of slope and it is spread to the lower side and a flat basin of 2.0 m radius. Terraces may be of crescent shaped with slope of the terrace towards the elevated side of the land, so that the top soil which is washed off from the upper side due to rain water is deposited in the basin of the plant. A catch pit (200 cm long × 30 cm wide × 45 cm deep) across the slope at the peripheral end of the terrace is made for withholding water during pre-monsoon and post monsoon showers in sloppy areas. A small channel connecting the catch pit sideways is made to drain out the excess water during rainy season. Catch pits not only help in harvesting, retaining and making the water available to the plant for a prolonged period but also cuts the velocity of the running water in the slopes, there by arresting soil erosion. Top soil eroded from the exposed portion of the hillocks also gets trapped in the catch pit. Thus, it plays triple role of preventing soil erosion, rain water harvesting and *in situ* moisture conservation. This *in situ* moisture conservation in catch pits will make moisture available to the cashew plant for additional period of 15-20 days during pre- and post-monsoon period (Swamy and Bhaskara Rao, 2000). In Tamil Nadu intercept bunds of 100 cm × 50 cm × 30 cm size are prepared in the cashew plantations. This breaks the velocity of runoff water and helps in impounding rainwater. Such impounded water is disc ploughed or raked soils have free access to sub-soil where it is safely stored for use during summer months (Bhaskara Rao *et al.,* 1993, and Yadukumar, 2011).

Besides proper soil and water conservation measures, mulching with coconut husk burial in trenches conserves more moisture besides coconut husks serve as a source of potassium (K). Soil and water conservation techniques increase the soil moisture content, nutrient content, plant growth and cashew yield. It reduces the runoff and soil loss. The soil and water conservation structures help to harvest the pre-and post-monsoon rainfall, conserve it in the soil and will be available to the plant for 15 to 20 days more. Soil and water conservation coupled with irrigation at critical stages reduces the immature nut drop due to soil moisture stress. It increases the soil moisture content, plant growth and thereby increases cashewnut yields (Yadukumar, 2011).

High density planting system: It has been reported that high density planting system of cashew is economical. The recommended spacing for cashew is 7.5 m × 7.5 m or 8 m × 8 m. Maintaining a tree density of 625/ha (4 m × 4 m) for the first 11 years and diagonal thinning thereafter to reduce the population to 50% resulted in maximum yield. High density planting system in cashew doubled the nut yield during the first 10 years of planting. Shape pruning is needed to maintain the canopy. Also, high density planting system with spacing of 6.5 m × 4 m (384 plant density/ha), 5 m × 5 m (400 plants/ha) and 5 m × 4 m (500 plants/ha) were found superior to normal spacing. High density planting system is more suitable for soils with low fertility and it helps to utilize the space available between cashew plants during the initial years of orchard thereby increases the yield per unit area. Further, high density planting reduces the weed growth by early canopy coverage, reduces soil temperature thereby increases the soil moisture content especially during peak summer season and provides mulching effect (Bhaskara Rao and Swamy, 2002; Rupa *et al.,* 2011; and Yadukumar, 2011).

The optimal plant density and fertilizer dose for cashew for the first 11 years has been standardized. The optimal plant population for high density planting system is 500 plants/ha with a fertilizer dose of 75 kg N, 25 kg P_2O_5 and 25 kg K_2O/ha/year. The highest cumulative yield of 9.5 tonne/ha was obtained as compared to 7.2 tonne/ha under normal density (200 plants/ha). The net profit was 25% more than that from control (normal density). There was a buildup of the soil moisture during critical period, soil organic carbon content and major nutrient contents in the soil, when high density planting system was adopted (Yadukumar, 2011).

Use of plant growth substances: Cashew tree produces innumerable flowers per panicle, of which less than 10% are perfect flowers. Under normal conditions, nearly 85% of the flowers (perfect) are fertilized of which 4 to 6% reach maturity, the remaining being shed away at various stages of development. Control of fruit drop and increase in fruit set by application of plant growth substances has been reported in cashew. It was reported that NOXA (βeta-naphthoxy acetic acid) and GA at 50, 100 or 200 ppm (1 or 2 sprays) during flowering gave increased fruit set and fruit retention. High percentage of fruit retention in cashew has also been reported by spraying growth regulators such as nutron (500 ppm) or ethrel (50 ppm) or planofix/NAA (45 ppm), during flowering period thrice at 15 days interval. Singh *et al.* (1992) obtained increased per cent of fruit set and yield per panicle by spraying NAA (15 ppm) and ethrel (50-100 ppm) during flowering period.

Weed management: Luxuriant weed growth is a common sight in neglected old cashew gardens. Weeds are not only harmful by competing with cashew plants for the nutrients and moisture but also cause inconvenience to take up effective plant protection measures and harvesting of fallen nuts, thus resulting in loss of yield. Therefore, maintenance of weed free plot is important and weeding should be done twice a year (June-July and November –December). Clearing of weed growth and wild growth is essential for conserving the available nutrients and moisture, as the weeds may compete for nutrients and moisture with cashew. Annually, two weedings are recommended for cashew plantations. The first round of weeding may be done before heavy rains start by uprooting the weeds within a radius of 2 m from the main trunk and the remaining weeds in the inter-space should be slashed to the ground level. The second round of weeding should be done during November – December to facilitate spraying, harvesting and picking of nuts. Alternatively, weedicides may also be sprayed 15-20 days after slashing the weeds, well before the start of heavy rains. Initially, agrodar 96 (2-4-D) @4 ml/litre of water and subsequently gramoxone @5 ml/litre of water may be sprayed. Glyphosate @5 ml/litre of water may also be sprayed. One more spray may be given during post-monsoon season (Bhaskara Rao *et al.,* 1993). Abdul Salam (2002) reported that depending upon the type of weeds and intensity of weed growth, weeding is to be done during August – September, either chemically or manually. Application of paraquat @0.4 kg/ha thrice at monthly intervals starting from July will effectively control all types of weeds. Application of glyphosate @0.8 kg/ha in June-July can also control the weeds effectively.

Mulching: Mulching the basins of plants prevents soil erosion and also conserves soil moisture. Mulching with organic matter prevents weed growth and reduces surface evaporation during summer and also regulates the soil temperature. As cashew is often planted in the areas which are totally dry and unsuitable for the cultivation of any other plantation crop, the availability of moisture will be very low. Therefore, it is necessary to conserve water received during monsoon season for a longer period by mulching the basins of the cashew plants either with green leaves or dry leaves soon after planting. The green matter obtained during weeding may also be utilized for mulching the cashew orchards at the base of individual trees soon after the fertilzer application (Swamy and Bhaskara Rao, 2000).

Inter-cropping in cashew orchards: Intercropping received very little attention when there was no systematic planting of cashew on a large scale. The main objective of raising inter-crops is to obtain some income from the land during the initial years of cashew orchards. Once the canopy of the cashew tree covers the area, it leaves very little scope for inter-cropping because of the dense nature of its canopy and shading of interspaces. Further, heavy leaf fall in cashew is not conducive for any field crops. Pineapple can be grown as a suitable inter-crop between two rows of cashew for the first seven years. The spacing to be maintained for cashew is 8 m × 8 m (156 tress/ha) or 7.5 m × 7.5 m (175 trees/ha) or 10 m × 5 m (200 trees/ha). Among the different inter-cropping trials tried pineapple as inter-crop during the initial years of the plantation has been found most profitable and feasible. Pineapple as an inter-crop across the slope between two rows of cashew plants in west coast region has resulted in 50 more cashew yield as compared to the sole crop of cashew. This was mainly due to conservation of soil moisture and control of weeds. Growing pineapple in trenches dug out across the slope between two rows of cashew plants would result in conservation of soil and water and also enhances the overall productivity of the system. This technology is useful in getting additional income during the payback period of cashew plantation and also in increasing yields of cashew by 50%. In addition to the increased yield in cashew due to growing of pineapple, it also gives net income from pineapple to the extent of ₹ 1 lakh for the first 7 years. Pineapple can be grown as a profitable inter-crop under irrigated as well as rainfed conditions in west coast region. Other suitable inter-crops are tapioca, turmeric, ginger, cucurbits, *Colocasia* and elephant foot yam (Rupa*et al.*, 2011 and Yadukumar, 2011).

In Indonesia intercrops such as peanut, sweet potato etc. are popular. In recent years, cashew is being intercropped in some areas with melon (sweet melon and water melon) and vegetables such as hot pepper. Growing of vegetables as intercrops is possible wherever supplementary irrigation is given to cashew. By cultivating melons, a large quantity of green manure will also become available for incorporation into the soil. In Myanmar several intercrops predominantly annuals such as sweet potato, sesame, peanut, maize, cassava, pigeon pea, etc. are popular with the cashew farmers. Banana is a popular intercrop in many cashew plantations in Sri Lanka. Pineapple, papaya, pomegranate and coconut are also cultivated as semi-perennial and perennial intercrops in some areas. In Sri Lanka, the common annuals grown in cashew plantations are legumes (cowpea, black gram, green gram), oil crops (sesame, groundnut) and condiments such as hot pepper and onion. Trials conducted at Si Sa Ket Horticultural Research Centre in Thailand showed that sweet corn, groundnut and vegetables can be profitably grown in the interspaces of cashew orchards in the initial years. Lack of moisture in the cashew orchards is one of the serious limitations for crop diversification. However, it is very important to include cultivation of intercrops in the management of cashew orchards in the initial years to get early returns from the land which is committed to cashew. This will also enable the farmer to adopt the recommended package of practices for cashew cultivation.

Cover-cropping and green manuring in cashew orchards: Leguminous cover-crops such as *Pueraria javanica, Calapagonium muconoides* and *Centrosema pubescens*, enrich the soil with plant nutrients and organic matter, prevent soil erosion and also help in conserving soil moisture. The seeds at the rate of 7 kg/ha when sown at the beginning of rainy season will establish these cover- crops in cashew orchards. The seeds should be soaked in water for six hours before sowing and are sown in 30 cm × 30 cm size beds, which are prepared in the interspaces of the main crop (cashew). These cover crops will also help in checking the soil erosion. As cashew responds to nitrogen, cultivation of the leguminous cover crops will also enrich the soils with nitrogen, which will be beneficial to the growth of cashew. However, it should be ensured that the basins of cashew trees are cleared before harvesting season, so that the growth of cover crops does not interfere with picking up of the fallen fruits. However, in the totally degraded laterite soils it is difficult to establish the cover crops easily. In China natural grass and leguminous cover crops are usually maintained at the time of land clearing in order to conserve soil. Green manure crops are also cultivated during the initial years. Creeping cover-crops such as *Peuraria phaseoloides, Centrosema pubescens* and bush cover-crops such as *Gliricidia maculata, Leucaena leucocephala* and nitrogen fixing trees such as *Acacia mangium* are the principal cover-crops grown in the inter-spaces of cashew orchards in Sri Lanka.

Green leaf manuring with *Glyricidia* and *Sesbania* in cashew resulted in higher nut yield and improvement in soil nutrient content. *Glyricidia* can be effectively and profitably grown in the interspaces between two rows of cashew as green manuring crops. The dry matter production of green biomass was about 7.65, 5.75, 2.25 and 1.63 t/ha/year from *Glyricidia, Sesbania*, sunhemp and cover crop, respectively. The nutrient addition to soil was about 186 kg N, 23.6 kg P_2O_5 and 126.2 kg K_2O and 141 kg N, 17.9 kg P_2O_5 and 162.3 kg K_2O/ha through *Glyricidia* and *Sesbania*, respectively (Rupa *et al.,* 2011).

Organic farming: In India, Cashew cultivation is mainly dependent on organic sources like leaf litter, farm yard manure, compost etc. Hence, there is ample scope for adoption of organic farming technology in cashew by farmers. Organic farming in cashew not only enhances the biological health of the soil but also helps in sequestering/isolating carbon in the soil. Since, major area under cashew in India do not receive any regular fertilizers, pesticides, fungicides and their productivity levels are moderate, there is a vast potential of bringing those areas under organic farming practices to exploit the marketing avenues available globally. The existing cultural practices recommended for cashew minus chemical inputs along with the organic management practices such as synergism in cropping systems including rotation intercrops, green manuring, vermiculture, mulching, biofertilizers, biopesticides, natural plant products for pests and disease management, encouraging natural enemies, adoption of optimum cultural practices at the right time, completely avoiding synthetic fertilizers, pesticides, fungicides, ensuring availability of locally available organic manures, recycling of farm waste, use of improved cultivars, are to be adopted for producing organically grown cashew (Sivaraman, 2002).

Cashew plantations have vast potential of organic biomass available for recycling. A mature cashew plantation provides about 5.5 tonnes of cashew biomass fall out (leaves, twigs, flowers and apples) per hectare. The biomass decomposes gradually and releases nutrients to the soil. Composting of cashew biomass can be used after 6 months as matured compost with 63% recovery. Alternatively, vermicompost can be prepared from cashew biomass by using earthworm *Eudrillus* spp. The available cashew biomass can be converted into around 3.5 tonnes of compost or vermicompost, which helps in meeting nutrient requirement of cashew by 50%. It is a low cost technology for adoption in the cashew orchard. Further, utilization of earthworms to enhance the decomposition process increases the aeration in sub-soil, adds micronutrients and enhances the microbial activity (Rupa *et al.,* 2011). Studies have indicated that C:N ratio for vermicompost is 9:1. The vermicompost contains approximately 1.21% N, 0.898% P_2O_5, 0.59% K_2O, 2.75% Ca, 0.82% Mg, 29.66 ppm Zn, 24.26 ppm Mn, 12.23 ppm Cu, and 162 ppm Fe.

Population of useful bacteria, fungi, *Actinomycetes,* and *Azospirillum* are 39 × 10^6, 39 × 10^5, 28 × 10^5, and 0.52 × 10^4cfu (colony forming units), respectively, (Yadukumar, 2011).

Harvesting and yield

Cashew harvesting is done by hand in all producer countries. In fact, botanical and morphologic features such as graduated ripening prevent mechanical harvesting, as flowers, small just set fruits and ripe fruits, come together in the same inflorescence (NOMISMA, 1994). Generally, ripe fruits fall off to the ground and are gathered manually. Harvesting the fruits is seasonal and it lasts for 2-3 months, since flowering per inflorescence and per tree is protracted and trees do not reach full bloom at the same time. Best quality nuts are obtained where freshly fallen apples and nuts are collected and the separated nuts are dried for 2-3 days to reduce moisture from 25% to below 9%. Then the nuts are stored in gunny bags or plastic bags. Nuts should be gathered at weekly intervals. The area under the tree should be weed-free and swept clean to facilitate nut collection. In the case of raw nuts which are not dried within 6-8 days of collection from the field, the CNSL gets into the kernels resulting in poor quality of kernels and there will also be fungal infection.

The nuts received from Vietnam are of poor quality due to improper drying. In order to get more weight at the time of sale, some farmers will be sprinkling water on raw nuts. This practice of farmers also results in poor quality of nuts. In some places due to theft problem farmers pick the immature nuts from the trees. This also results in poor quality of nuts. With proper drying, the kernels retain their quality, in particular the flavour. The nuts should not be allowed to absorb moisture during storage; equilibrium moisture content is about 9% at 27°C and a relative humidity of 70% (Van Eijnatten, 1991). The nuts should be stored in gunny bags in an air tight godown/warehouse. The bags should not be heaped on the floor. Wooden planks or paddy straw or paddy husk or saw dust may be kept or spread on the floor and then the seed bags are stacked. The bags should be kept 1 m away from the walls. There should not be any water leakage in the gowdown.

If cashew apples are desired for fresh consumption or for processing, then the ripe apples should be picked from the trees at short intervals (2-4 days). Average yields per tree increases from 3 kg at ages 3-5 years, to 4 kg at ages 6-10 years, 5-10 kg at ages 11-15 years and to more than 10 kg from 16^{th}– 20^{th} year. These values refer to nut production only, without peduncles (apples), but as nuts stand for 10% of the total production (nut+apple), their production may reach 1,000-7,000 kg/ha. Typical yields are between 700 and 900 kg of whole nuts or 150-300 kg of shelled nuts (kernels) per hectare (Martin, 1984).

Future thrust

Considerable progress has been accomplished over the last 50 years in terms of developing high yielding cultivars, fixing nutrient requirement, standardizing vegetative propagation technique, chemical control of major pests of cashew, cashew apple utilization and production of large number of planting material required for fresh planting and replanting programmes. Keeping in view the changing global scenario and to meet the demand and challenge in the international market, research programmes are to be intensified for increasing the production and productivity of cashew.

Currently, the concept of high density planting using dwarf genotypes with compact canopy is gaining more acceptance in cashew cultivation. In Brazil, dwarf root stock seedlings have been used for several years. More recently, research workers were able to succeed by using seedlings from *Anacardium microcarpum* Ducke, a slow growing species native of Brazil. These two types of root stocks, more markedly the latter, exert a dwarfing effect and induce earlier bearing upon the grafted trees. No symptoms of root stock – scion incompatibility have been observed so far. However, Chacko *et al.* (1990) reported that the spreading nature of the tree is not desired for commercial orchards as it does not allow high density plantings. Therefore, dwarf cultivars with more erect growth habit required for high density planting are to be developed.

There is a need to revisit the feasibility of producing bioethanol from cashew apple. The quantity of cashew apple is about 8 to 10 times of the quantity of cashewnut and at present it is estimated that about 90% of cashew apple is getting wasted in India except in Goa where feni is prepared from it. There is a need to provide modern technology to cashew farmers to produce juice and wine from cashew apple in order to help them to improve their income from cashew crop by value addition to cashew apple. In India this technology is already available and effort is needed to commercialise the preparation of wine from cashew apple and market it.

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8

Propagation and Nursery Management

PLANT PROPAGATION and nursery management are integral part of horticulture development in the country. Often, we consider 'Plant Propagation' and 'Nursery Management' are same, though they are altogether different but inter-related. In fact, mass multiplication of quality planting materials is the central theme of nursery management but nursery management is trade oriented dynamic process of efficient utilization of resources for better economic return. The word nursery is also used for young saplings raised by seeds. Besides seeds, there are various propagation techniques for perpetuation of clonal material. The main phases of nursery management are: (*i*) planning, (*ii*) implementation, (*iii*) monitoring and evaluation, and (*iv*) feed-back for further refinement whereas, the key elements of nursery are (*i*) the place, (*ii*) the plant and (*iii*) the person behind (Saroj, 2004).

Establishment of ideal nursery and production of quality planting materials is a vital component for development of good cashew plantations.In fact, cashew was introduced in India for afforestation of wastelands and spread over coastal regions by large-scale plantations of seedling in origin. Before standardization of vegetative propagation technique, cashew was multiplied by seeds and being a cross pollinated crop, a lot of variability in plant vigour, precocity, bearing habit, nut yield, fruit colour and its quality etc. was observed. Thereafter, the potential of cashew for its delicious kernel was realized and it was considered as one of the important export oriented horticultural crops. Crop improvement programmes were started by researcher to identify varieties with high yield potential and bold nut size. After identifying such types from the seedling population, the techniques for vegetative propagation were standardized to maintain the genetic purity of the mother plant. Now, cashew industry has been revolutionized with development of soft wood grafting technique for the mass multiplication of cashew quality planting materials. However, the clonal multiplication of rootstocks in cashew is yet to be standardized, thus the raising of rootstocks by seeds are still continue.Though, use of dwarfing rootstocks is adopted in cashew propagation in Brazil.

Seed propagation

The seed propagation is not only done for raising of rootstocks but in varietal evolution also, the seedling population is raised by the seeds to assess the hybrid for desired traits. Still the concept of seed garden in cashew is not popular and mature seed nuts collected from the orchard and after drying, seeds are sown for raising the seedling rootstocks. However, only seeds (6-8 g) and free from any damage should be used. The current season collected mature nuts are used for raising of seedlings. After collection of cashew fruits along with nuts from the field, nuts may be detached from the fruits and sun dried for about 3-4 days. The properly dried nuts can be stored in gunny bags on a cool and dry place.The seeds can be stored in baskets and sacs also but the best method of storage of seeds is in air tight tins. The seed nuts floating after soaking in water should not be used for sowing. Overnight soaking of selected seed nuts in water before sowing improves germination. It is also advisable that up to seven months old seeds can be used and thereafter germination reduced drastically and after 12-14 months of storage, germination ceases fully. However, seed propagation is not advised because of the following limitations;

(i) The plants raised by seed nuts are not true-to type.
(ii) The plants raised by seed nuts posses a lot of variability with respect to plant vigour, yield and quality.
(iii) The orchards raised by seedlings have long gestation period.
(iv) Because of variation in growth behavior among seedling plantations, mechanization is difficult.
(v) Cultural operations are also difficult in orchards raised by seedlings.
(vi) The yield potential of seedling raised orchard is also low.
(vii) Sometimes, there is possibility of transmission of seed borne diseases.

Vegetative propagation

Wide variability in plant vigour, nut and apple characters and yield of seedling progenies has led to initiate the research on vegetative propagation of cashew, since vegetative propagation is essential to establish uniform cashew orchard of high-yielding variety. The importance of vegetative propagation are:

(i) The planting materials produced by vegetative methods are true-to-type and genetically similar.
(ii) Vegetatively propagated plants are uniform in growth and short stature.
(iii) Short gestation period, hence early bearing compared to seedling progenies.
(iv) Easy in intercultural operations.
(v) Higher yield and quality produce.
(vi) Various methods of vegetative propagation have been attempted with considerable success.

Cutting: Propagation by the cutting is most practical method of vegetative propagation but unfortunately very little success has been obtained in case of cashew. Peixoto (1960) reported that propagation of cashew by cuttings is possible. The rooting was obtained with lateral shoots and water shoots from lateral buds. He stated that large quantity of carbohydrates in relation to the available soluble nitrogen in the shoots favours rooting. The rooting can be improved by ringing the bark or by wrapping a thin wire around the twig, forty days before separating it from the twig. Milheiro (1969) reported that in Mozambique cuttings from mature twigs only rarely produced some roots and with green twigs, no rooting was obtained at all. The first successful trial on cutting was done by Argles (1969) in Mysore, where he used etiolated shoots (30 days before taking cuttings) in the month of November and got 40% rooting. Retaining leaves on cutting improved rooting but cuttings with flowers did not root well. The response was increased by dipping the cutting base in sugar solution (15%). The best treatment for callus formation was 15°C and for rooting 24°C. Coester and Ohler (1976) obtained satisfactory results with cuttings taken from cashew tree growing in green house, treated with 1% IBA and planted in perlite+coarse sand mixture. They retained leaves of cuttings, sprinkled water daily, covered with plastic and maintained humidity between 90-95% during day time and 100% during night time. Day temperature was kept 25-28°C and night temperature at 15°C. Thus, shade, good aeration of rooting medium, high relative humidity and exogenous hormonal treatments are important factors determining the success of the cuttings.

Propagation of cashew by stem cutting was not successful at Baptala, Andhra Pradesh and Ullal (Karnataka) stations (Rao, 1979 and Krishna Murthy *et al.* 1985). Nageswara Rao *et al.* (1988a) reported that even juvenile shoot cuttings are difficult to root probably due to low level of endogenous rooting factors. Further, Nageswara Rao *et al.* (1988b) observed highest rooting percentage, number of roots and root length with post ringing of 180 days. The ringed cuttings were treated with IBA (10,000 ppm) by quick dip and placed in vermiculite for rooting under mist. The hardening of rooted cuttings was better under restricted mist than continuous mist as far as the root dry weight and field establishment were concerned (Nageswara Rao *et al.*, 1989). Overall, propagation by cuttings gave less success, more expensive and plant raised by cuttings have poor tap root system thus and vulnerable to strong winds.

Layering: Layering is another method of cashew propagation. In older trees, lower branches tend to trail on ground, if covered with soil and keeping moist may produce roots. However, the ground layers cannot be transported to other places, thus it may not be efficient method of cashew propagation. Encouraging higher branches to root into pots placed on a support has been tried in Madras but this was not successful (Argles, 1969). Sometimes, broaken, bend and damaged plant can be rejuvenated by this method. Rao (1979) reported that cashew branches of 2.5 cm thickness trailing near the ground were girdled and pressed in the soil were produced profuse rooting from June to October under Bapatla conditions. However, mound layering/stool layering tried at CPCRI, Regional Station, Vittal has revealed that it is possible to obtain profuse rooting when etiolated shoots are cinctured and treated with 10,000 ppm IBA. In this technique, heading back of main trunk and encouraging coppicing from the ground level followed by girding of shoots and covering with soil can give some success. The cinctured shoots induce roots within 30-45 days. Nagbhushanam and Menon (1980) reported good success through mound layering with treating the shoots after girdling by IBA 10,000 ppm while Suryanarayana and Melanta (1989) observed significant decrease in rooting of stool layers with increase in age of shoots.

Air layering was one of the successful methods of vegetative propagation of cashew till 1980. Naik (1949) first reported that layering done during rainy season readily rooted within two months with high percentage of success at Fruit Research Station, Kodur (Andhra Pradesh). Abraham (1956) also attempted air layering in cashew successfully. Rao and Hassan (1957) reported that maximum rooting was obtained when air layering was done during flowering season. Even in less humid region of East-Coast and during flushing period in West-Coast, it was successful. The percentage of success of establishment of layers is depends on seasonal variation in different regions (Rao, 1958). The influence of parent tree, age and type of shoots, position of cincturing, use of rooting media, use of plant growth regulators etc. were also studied by different workers. Chhokar and Singh (1967) obtained 85% rooting by treating the shoots with 75 ppm IBA in lanolin paste. Rai (1970) also got good success in air layering of cashew shoots. Whereas, Acharyya and Das (1972) reported that treating the shoots with 300 ppm IBA in petroleum jelly gave maximum successful layers (85%). Similar observations made by Sadhu *et al.* (1972) by using *p*-hydroxybezoic acid alone and additive effect in combination with IBA. Krishna Murthy *et al.* (1985) narrated that use of IBA 300 ppm shortened the period of rooting emergence with maximum number of rooted layers. Indole Acetic Acid (IAA) at 250 ppm gave highest percentage of rooting with higher length of roots and more number of roots per shoot.

Nagabhushanam and Menon (1978) have assessed prospects of vegetative propagation of cashew by air layering and suggested that air layering can be done on non-flowered shoots of previous year's growth of pencil thickness and brown in colour after ringing and treating with IBA. Under east coast conditions, the better success of air layers was found when trees are in resting phase (monsoon season) than during the period of growth and reproduction (October to April) (Rao, 1979 and Palaniswami *et al.*, 1979). July- August appears to be most ideal period for air layering in East-Coast region, when rooting and field establishment both is good. Whereas, during summer season (January to April), cashew trees are in active phase in the West-Cost and was found suitable for air layering with 73-100% success (Damodaran, 1979; Nagabhushanam, 1979b; Nagabhushanam and Murthy, 1979; Valsakumari *et al.*, 1979 and Krishna Murthy *et al.*, 1985). Damodaran (1979) reported that the best time for air layering was February-March, which will enable detachment of layers in May-June and subsequent planting in field for better establishment.

The air layered shoots of trees below ten years rooted early than 20 years old trees (Rao and Hassan, 1957, and Krishna Murthy *et al.*, 1985), whereas Damodaran (1979) reported that age of tree had no effect on extent of rooting of air layers. It was also found that the one year old shoots rooted better than current season growth (Rao and Rao, 1957). The longer shoots rooted better as having relatively more number of leaves which have been conducive for higher rooting due to increased availability of photosynthates (Krishna Murthy *et al.*, 1985). Besides length of shoots, Damodaran (1979) reported that non-flowered shoots gave significantly higher percentage of rooting than flowered shoots. He further reported that the thicker shoots (girth of 4 cm and above) were found more vigorous in growth during first year of orchard life as compared to medium shoots (3-4 cm) or thin shoots (< 3 cm). Ringing/cincturing of shoots at nodal region gave better success (Rao and Hassan, 1957 and Krishna Murthy, 1985).

In order to assess different kinds of rooting media, Rao and Hassan (1957) and Krishna Murthy *et al.* (1985) reported positive response while Damodaran (1979) and Palaniswami *et al.* (1979) did not find good impact of rooting media on rooting success. Among different types and thickness of wrapping materials, polythene film of 100 gauge proved to be the best for rooting of air layers (Rao and Hassan, 1957 and Krishna Murthy *et al.*, 1985). Survival of layers under field conditions is normally poor, hence post-separation treatment and providing conducive conditions are very essential. Krishna Murthy *et al.* (1985) suggested that layers must be defoliated after separation to minimize transpiration loss. Whereas, Rajeevan and Srinivasan (1979) reported that for better survival layers must be planted in decomposable containers of coconut husk and straw pot. It was also suggested that air layers after separation may be dipped in cow dung-urea solution (100 g urea in 100 litres of cow dung slurry for about an hour) and thereafter planting in polybags (45 cm ×30 cm) of 500 gauge (Anon., 1979).

Budding: Budding preferred over other vegetative methods because of better efficiency, as from single scion shoots more than 4-6 buds can be taken for budding operation. In India, Naik (1949) had first reported successful budding in case of cashew. Thereafter, Phadnis *et al.* (1974) successfully demonstrated patch budding during October-November with 67% successin Maharashtra. Whereas, Hameed (1976) reported 76% success of patch budding during July in Tamil Nadu. Bhatee (1977) claimed that better success can be obtained with bud graft on older rootstocks (2 year) raised in polybags. In fact the best time for budding is when the bark can easily be removed from the wood which is the indicator that the tree is in active growth phase. Under East-Coast of Vridhachalam conditions, *in situ* patch budding in July gave 71% success (Palaniswami *et al.*, 1979), at Bapatla 32-41% during June-September (Rao, 1979) and less than 16% (T budding) under Odisha conditions during January-February, June-July and September (Das and Mishra, 1979).

Grafting: After preliminary trial on approach grafting conducted at Kodur (Andhra Pradesh), the first systematic work on propagation of cashew by approach grafting was initiated at Central Cashewnut Research Station, Mangalore; wherein 11- months-old seedlings with a girth of about 4.5 cm and a height of 50 to 60 cm were used. Nagabhushanam and Vekata Rao (1977) reported 49% success when veneer grafting was performed in the month of September with 15 to 20- months-old seedlings at cashew Research Station, Bapatla (Andhra Pradesh). The wedge grafting was successfully tried on cashew seedlings raised in polythene bags with pre-cured or fresh scion (Bhandary *et al.*, 1974).

In case of epicotyls grafting, Bhandary *et al.* (1974) reported that 21 days old seedlings when grafted with thin scion (0.3 cm) gave 63% success at Dharwar. Konhar and Das (1985) reported that 5 to 7- days-old seedlings are most suitable for grafting throughout the year except in March under Odisha conditions with 56 to 100% success. Whereas, Nagbhushanam (1983) reported 10 to 15- days-old seedlings are ideal for epicotyls grafting during monsoon period (June-November) at Vittal (Karnataka) with 86% success. Sawke (1984) reported that with 6 to 10 days old rootstocks, from February to May was congenial for grafting under Vengurala conditions with 60 to 74% success. Khrisna Murthy *et al.* (1985) observed that February to May were ideal time for epicotyl grafting with 72 to 80% success at Mangalore. Konhar and Das (1985) stated that softwood grafting on seedlings of 15 to 60 days can be done throughout year except October and

November under Odisha conditions with 53 to 100% success. To avoid mortality of epicotyls grafts, modified method of epicotyle grafting was suggested by Seshadri and Rao (1985) wherein the of the rootstock is removed leaving bottom two leaves intact. Then a longitudinal cut of 4 to 5 cm from tip was made on the rootstock so that each half contains one leaf followed by inserting wedge of scion and tied with plastic strip. Flush grafting with 15 to 21- days-old flushes as scion stick in case of epicotyl grafting or softwood grafting has also been reported from AICRP centre Madakkathara, Kerala (Veeraraghavan, 1990 and Pushpalatha *et al.*, 1090).

Among various methods tried, softwood grafting was found to be the best technique for vegetative propagation of cashew (Sawke *et al.*, 1985; Swamy *et al.*, 1993). Under warm humid conditions of Konkan, Maharashtra, the technique was successful (65-86%) throughout the year except in December. The percentage of success of softwood grafting technique varied in different agroclimatic regions. Under Ullal conditions, softwood grafting gave 70-75% success during March-May (Krishna Murthy *et al.*, 1985). While Swamy *et al.* (1988) incated that monsoon period (June-November) is ideal for commercial production of soft wood grafts with highest success in September (82.3%), followed by October (78.5%) and August (72.5%). Konhar and Das (1985) obtained 90 to 100% success during January and February months under Bhubaneswar conditions. According to Kumar *et al.* (1989), the best time for softwood grafting of cashew is May followed by April. Ghosh (1990) obtained 70% success in the month of February under Jhargram conditions while Radhakrishna *et al.* (1992) reported 79.80% success in the month of December under Bapatala conditions. Clonal propagation trial by softwood grafting in cashew under Northern dry zone of Karnataka showed higher rate of success (87%) in the month of January followed by October (60%) (Mahesha *et al.,* 2005). Now, this is most widely adopted method of cashew propagation in the country. *In situ* soft wood grafting by wedge method on one year old cashew plants under field conditions having bronze coloured leaves with 71.4% success was also standardized by Amin (1978).

Grafting operation: In this technique, about 45-60 days old rootstocks raised in polybags and current season scion shoots are used for grafting purpose. The grafting operations should be done either in shade net house or under shady place. There should be proper arrangement of irrigation by sprinkler system. Two pairs of bottom leaves are retained in the selected root stock and other leaves are removed using a sharp grafting knife. At a height of 15 to 20 cm from ground level where soft wood portion is available on the root stock, a transverse cut is made and the terminal shoot is removed. A cleft of 4 to 5 cm deep is made in the middle of the decapitated stem by giving a longitudinal cut. A matching thickness scion shoots of 10-20 cm length should be selected. The cut end of the scion is shaped to wedge of 4-5 cm long by chopping the bark and wood from two opposite sides. The cut surfaces of scion should not be soiled by touching with fingers. The wedge cut of the scion is inserted into the cleft of the rootstock in order to make a perfect contact of cambial layers of both root stock and scion. The graft joint is tied firmly with 1.5 cm wide and 30 cm long polythene strip of 100 guage thickness followed by covering with inverted narrow white HD polytube/polycap of

12 cm × 4 cm size to protect the scion stick from drying up and to create conducive microclimate for union and subsequent to encourage sprouting of the terminal buds. After two weeks the polytubes/caps are removed gently. After sprouting, graft can be shifted or shade net can be removed. Within 3 to 4 weeks, most of the grafts will sprout, which are ready for sale/planting within 5 to 6 months after attaining height of about 30-45 cm. Frequent shifting of grafts by holding the root stock to prevent from striking roots into ground should also be done.

In-vitro propagation

Efforts were made to develop tissue culture protocol from cashew explants. However, the regeneration protocol from matured explants are yet to be developed although reports are available regarding the multiplication and field establishment of cashew regenerated from young cashew nodal cuttings (Thimmappaiah and Shirly, 1999). Somatic embryogenesis was induced from nucellar tissue cultured from 2 to 3- week-old immature nuts. So far nucellar tissues from 14 varieties were tried for embryogenesis. Embryogenesis and germination of somatic embryos was achieved in two varieties (Thimmappiah, 1997; Shirly and Thimmappaiah, 2005). Thimmappiah *et al.* (2002a) also got success in micrografting of cashew.

Nursery management

Nursery is the place where plants are raised either by seeds or vegetative means with due care before transplanting at desired place.Nursery management includes different components for production of quality planting materials which are discussed here under. As far as possible, all components should be in the vicinity of a confined area of nursery for better feasibility of working.

(i) *Establishment of scion bank and handling of scion shoots:* Establishment and maintenance of scion bank is prerequisite of a successful nursery. After proper field preparation, the pits of 2 cubic fit should be dug out at a distance of 4m × 4m and thereafter pits are filled with FYM and good soil (1:1). The Scion Bank should be established with thevegetatively propagated recommended cultivars of the region. In order to get continuous supply of scions, sufficient plants should be accommodated in scion bank. The plants in the scion bank should be maintained by heading back to a height of 1.5 m from ground level and regular pruning of dead and dried branches should be done. Pruning of tees may be carried out annually during September–October. The flower panicles should be removed every year in order to get more number of scions. Proper nutrition, irrigation and aftercare of scion bank are very essential.

In case of cashew, the ideal scion shoots are non-flowered, 3-5 month old current season's growth, about 10-12 cm long, straight, pencil thickness, brown coloured with dormant plumpy terminal bud. Clipping off leaf blades, leaving petiole should be done about a week before detaching the scion shoots from the mother plant. The scion sticks should be taken from the mother plants early in the morning to avoid desiccation. Soon after separation from the mother plant, scion sticks should be dipped in water and wrapped in polythene/placed in polybag of 100 guage and brought to the nursery shed for grafting. For long period storage or transportation at longer distance, the scion sticks wrapped in sphagnum moss/

cotton cloth and placed in a polythene bag of 100 guage, can be kept for 3-4 days without any deterioration.

(ii) *Media and containers for raising of rootstocks:* Proper filling media is required for satisfactory seed germination and subsequent seedling growth. For cashew, the filling mixture is prepared in the proportion of 1:1:1 (red soil: sand: compost) in heavy rainfall areas and 1:1(red soil: compost) in low rainfall areas and mixed with 5g of rock phosphate. However, vermicompost, poultry manure, coco-pith etc. are also used as filling mixture. Fill the mixtures in the polybags upto the brim and arrange in nursery beds of 10 numbers in each row to a desired length. In between two polybag beds, there should be sufficient space for grafting operation.

Various size and colour of polybags were tried for raising of rootstocks of cashew but more commonly used high density polybags are 25 cm × 15 cm size of 300 guage and black in colour. If the grafts are to be maintained only for about six months before planting in the field, the size of ploybags can be reduced to 20 × 15 cm. Make 15-30 holes of 0.5 cm diameter uniformly on the polythene bags by punching for ensuring drainage of excess water during heavy rains. In low rainfall areas the number of drainage holes can be reduced also.Now a day, various types of root trainers are also available which should be tried for raising of rootstocks.

(iii) *Raising of rootstocks:* The current season harvested nuts, sun dried for 3 days, about 6-8 g weight are used for raising of rootstocks. The graded seed nuts with specific gravity more one should be used for sowing. This can be ascertained by soaking the seed in water and seeds floating on surface should be discarded. Seed nuts should be soaked in water over night before sowing in polybags filled with FYM: soil (1:1)/vermicompost: soil (1:2). Pre-soaked nuts are sown in the centre of the polybag with stalk end up at a depth of 2.0 – 2.5 cm. At the time of sowing, the soil in the polythene bags should be moist and loose. Immediately after sowing seed nuts, light watering should be done with sprinkler. Polythene bags should be covered with paddy straw/dry grass/palm leaves to facilitate early germination. The seed nuts usually germinate within 15-20 days after sowing during monsoon season and within 8-10 days during summer months. Daily watering with sprinkler is required for germination and growth of seedling. The mulch material should be removed once the emergence of seedlings observed. These seedlings will be ready for grafting in 45-60 days after germination.

It has been reported that use of biofertilizers (*Azospirillum*, *Azotobacter* and VAM) increased the germination percentage of nuts, plant growth, number of graftable seedlings and reduced the incidence of fungal diseases in the nursery (Sinish *et al.,* 2005). Oblisami *et al.,* (1985) also reported that inoculation of *Azotobacter* resulted in higher root growth of cashew seedlings. Lakshmipathi *et al.* (2013) reported that osmopriming of seed nut by GA_3 (200 ppm) for 48 hours has increased seedling growth and vigour index; thereby obtained healthy seedlings in short period for grafting operation. In order to prevent damage to germinating nuts, apply Malathion dust (5%) or spray Chloropyriphos (1%) and drench with Bordeaux mixture (1%) to avoid damping off young seedlings.

(iv) *Growing structure:* There are various growing structures available to grow seedlings of annuals, rootstocks of annuals and perennials and as such growing of vegetable and flowers under controlled conditions. Thesse growing structures are based on ecological situations, type of covering material used, growing needs and cost involvement with or without misting system. Some structures are fully auto operated; some are partially controlled while some are manually managed. In hi-tech structures, there is fully controlled system of temperature, humidity, fogging and photoperiod. In India, most of the nurseries are operated either in open conditions or in partial shade net houses. For cashew nursery, after grafting operation, partial shade is required. In general, green shade net or polyhouses are used for this purpose to create better microclimatic conditions inside the structure for quick union of rootstock and scion and subsequent sprouting of scion shoots. Once, shoots are sprouted, shade net can be removed for better exposure of spouts to sun light but optimum humidity must be maintained by regular watering with sprinkler. Moreover, proper sanitation and maintenance is required to maintain growing structures.

(v) *Irrigation, nutrition and weed management:* In nursery management, raising of rootstocks, grafting operation and aftercare of grafted plants are very essential operations where moisture, prevailing humidity, temperature and nutrition pay a crucial role. Since, seedlings are tender in nature at initial stage, proper and timely irrigation is very important to obtain healthy growth. At the same time, avoid excess irrigation which otherwise also cause of wilting of seedlings due to fungal attack. There should not be water stagnation in and around nursery beds. In case of cashew, the proper filling mixture contains sufficient nutrients for the growth of seedlings and no additional supplement is required. However, foliar feeding of micronutrients, plant growth regulators and use of bio-consortia improve healthy seedling. In general, complete nursery should be weed free but any weed growth inside polybags should not be allowed and removed manually. Any symptom of pest and disease occurrence must be taken care immediately. Any sprouts below the union should also be removed.

(vi) *Hardening and disposal of plants:* Plants prepared in the nursery are succulent and tender enough, therefore proper hardening is required before disposal. In fact, hardening is done to make the plant tissues firm so as to withstand against possible adverse conditions during transportation and assure high field survival. Hardening should be done by increasing of irrigation intervals/ withholding watering and partial followed by full exposure to sun light which may stop the growth of plant. However, hardening process should be gradual in order to avoid severe setback. Thus, only after attaining about 5-6 months age with 5-7 functional leaves and properly hardened plant should be sold or planted.

Timely disposal of plants is also important to get good income. Keeping the plants for longer period in the nursery not only involves additional expenditure but the quality of planting materials is also reduced due to coiling of roots. Sometimes planting materials remain unsold, if they are raised delay in the season. The nursery owner must contact well in advance to the growers either directly or by correspondence/advertisement so as to dispose the planting materials timely for planting in the season. Timely lifting of polybag plants and proper packaging is also important so that plants should not be damaged during long distance transportation. As far as possible, there should be minimum time gap between lifting of the plants from the nursery and planting at desired site. In case, if polybags are torn off, the grafts are carefully re-bagged using a new polybag without disturbing earth ball.

(vii) *Plant standard:* Based on experimentation and experiences, the standard of soft wood grafting in cashew is given as under;

Parameters	Standard
Method of propagation	Soft wood grafting by wedge method
Type of root stock	Healthy (Green foliage, free from leaf eating cater pillar, without any symptom of dieback and nutrient deficiency), 0.5-0.7 cm diameter
Size of polythene bag	25 × 15 cm (300 guage)
Age of root stock	45 to 60 days
Age of scion shoots	3 to 5 months
Diameter of scion	0.5 to 0.7 cm
Height of union matrix	15 to 20 cm above ground level
Length of scion sticks	10 to 12 cm
Season for grafting	Throughout the year, preferably June –November
Grafted plants/height	30 to 45 cm
Grafted plant stem girth	2 to 2.5 cm
Conditions of grafted plant	Healthy, graft joint should be perfect without any girdling, with 5-7 functional leaves, free from side sprouts from rootstock

Accreditation of nursery

Certification and accreditation of nursery is essential to establish brand value of quality planting materials. For accreditation, the nursery owner must have to maintain all records related to production of planting materials. The accreditation of nursery is done by a group of experts through physical verification. Based on the status of nursery the accreditation agency will award certificate of accreditation. In general, certification of nursery is done by respective state department based existing nursery act. However, in case of cashew such certification was not taken up earlier by the government department as most of the cashew nurseries were started in public departments like ICAR, SAUs, Directorate of Cashew and Cocoa, Kochi (DCCD), Forest Department, Horticultural Department and Cashew Corporations. Now a lot of private nurseries are started in private sector also. Initially, accreditation of cashew nursery was started by National Horticulture Board but now the responsibility of cashew nursery accreditation also entrusted to DCCD, Kochi both for public and private sector nurseries. Therefore, to ensure the quality and genuineness, growers are advised to purchase the planting materials either from government owned nurseries or from any accredited nurseries.

Economics of graft production

Establishment of cashew nursery is a profitable enterprise if managed properly. However, it depends upon the availability of input, labour, skilled grafter and other nursery infrastructures. An estimate on economics of graft production has made based on the prevailing rates as presented in table 8.1. The assumption was made for producing 50,000 saleable cashew grafts at the rate of about 70% success. Thus, to obtain 50,000 saleable cashew grafts about 72,000 grafting has to be done. Moreover, there are some components like, establishment of shade net, procurement of scion shoots and sillpauline; the cost can be minimized. As per this estimate, total cost involve for production of 50,000 saleable cashew grafts is ₹ 7,93,350/. If it is sold at ₹ 20/graft, one can earn ₹ 2,06,650/year as net profit. Moreover, this profit margin can be increased by utilizing family manpower, maintenance of own scion bank, reduction of miscellaneous cost as the materials

Table 8.1. Economics of cashew graft production.

Material	Quantity	Rate (`)	Amount (`)
A. Input cost			
1. Seed nut	600 kg	80/kg	48,000
2. Bags			
a) 25 cm x 15 cm (Black) 300 guage	500 kg	140/kg	70,000
b) 30 cm x 30 cm 100 guage	25 kg	175/kg	4,375
c) 20 cm x 4 cm 200 guage (cap) (for 20,000 grafts/month)	27 kg	180/kg	4,860
3. Black sheet 300 guage (2m width) (120 kg for grafts, 80 kg for seedlings)	200 kg	130/kg	26,000
4. Potting mixture			
a) Soil	8 loads @ 200 cft/load	730/load	5,840
b) Sand	7 loads @ 200 cft/load	4,000/load	28,000
c) Compost/Cattle manure	7 loads @ 200 cft/load	9,000/load	63,000
5. Chemicals			
a) Copper Sulphate	20 kg	220/kg	4,400
b) Lime	20 kg	30/kg	600
c) Chlorpyriphos	1.5 litres	850/kg	1275
6. Scion sticks	72,000 Nos	1	72,000
	3,28,350		
B. Labour cost			
1. Grafting including preparation of potting mixture and bag filling, sowing/maintenance of seedlings and pre-curing/scion collection	50,000	8/graft	4,00,000
2. Maintenance of remaining graft in the Nursery for 3-4 months	15,000	2/graft	30,000
			4,30,000
C. Miscellaneous (Shade nets, Sillpauline, Poles etc.)	—	—	35,000
Total cost (A+B+C)			7,93,350

The rates of various inputs are based on present prevailing rates in the local market, 2015.

can be used in subsequent years also, cost towards maintenance, reducing the cost of soil etc.

Conclusion

Among various vegetative propagation techniques, softwood grafting is most viable and commercially feasible method for multiplication of cashew varieties. It is recommended that all the new plantations should be raised only with clones of high yielding varieties for enhancing production and productivity of cashew in our country and to meet the increasing demand of raw cashewnut of processing industries. However, there is a strong need to standardize the *in-vitro* technique for mass multiplication of cashew. Efforts should also be made to standardize the dwarfing clonal rootstocks for different purposes and resource situations. Appropriate nursery management practices and plant standard must be followed for improving efficiency in production of quality planting materials. Efforts should also be made to minimize the use of polybags and thereby reducing environmental hazards.

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9

Nutrition Management

CASHEW is grown on a diverse range of soils, from the sandy seacoast to laterite hill slopes, pure sandy soils to sandy loam, laterite soil, deep loam and red latosols, but many of these soils have low effective cation exchange capacities and low exchangeable base status. Majority of the cashew growing soils in India are lateritic, red and coastal sands which are acidic in nature and poor in soil fertility. The runoff and soil erosion are very high in steep slopes. The deficiencies of Mg, Zn, B and Mo are on the rise in cashew growing soils. There are 17 essential elements for the plants, which require to supply in sufficient quantity for optimum and sustainable yield. If availability, a single essential element is below the critical level of crop growth and yield will fall even if the other elements are in sufficient supply. Research results showed tremendous positive response to regular applications of fertilizers and improved management practices which resulted in two to three fold increases in nut yield. Cashew requires regular fertilizer application to ensure early and high-yields in new/young plantations, and regular high yields from mature plantations. In general, majority of the cashew growers do not apply fertilizers, hence the nutrients being mined by the plants are not replenished. Integrated Nutrient Management (INM) practices involving conjoint application of chemical fertilizers, organic manures/green manuring and biofertilizers which constitute an efficient nutrient management strategy in cashew are essential to maintain/enhance the soil quality and for sustainable production. Recycling of cashew litter, use of microbial inoculants for mobilizing nutrient from slowly available soil pools, foliar nutrient spray and plant growth promoters can enhance the cashew productivity. More attention needs to be given for recycling of recyclable cashew biomass, *in situ* compost production, green manuring etc.

Nutritional management in nursery

Initial development of seedlings depends upon the nutrient reserve of cotyledon. The macronutrients contained in the cotyledons can provide around 54% N, 45% P, 17% K, 1% Ca, 16% Mg and 36% S necessary for seedling development for up to 75 days after planting (Ximenes, 1995). Cashew with large nut size (8 to 12 g) gave initial seedling growth advantage over that of small sized nuts (6 g) only at the juvenile stage but as the plants age advances the influence fizzles out (Ibiremo *et al.,* 2012).

The production of cashew grafts currently is on the rise, with the expansion in cashew cultivation and the increase in average tree density in orchards.

Enhancement of growth rate using biofertilizers and production of healthy grafts would lower costs in the nursery and ultimately lower the price of grafts. Furthermore, young seedlings planted in orchards are highly sensitive to uncongenial environmental conditions, damage by pests, and competition from weeds. Improvement of plant establishment in the orchard and increased growth rates would be beneficial, as commercial yields would be reached earlier. It has been shown that biofertilizers (*Azospirillum*, *Azotobacter* and VAM) increased the germination percentage of nuts, plant growth, number of graftable seedlings, and reduced the incidence of fungal diseases in the nursery (Kumar *et al.,* 1998; Ramesh *et al.,* 1999; and Sinish *et al.,* 2005). Inoculation of *Azotobacter* resulted in higher root growth (Oblisami *et al.,* 1985), and yield (Singh, 1997) of cashew.

Cashew has been described as a host plant for vesicular arbuscular mycorrhiza (VAM) (Sivaprasad *et al.,* 1992). Mycorrhizae increase the resistance of plant root systems to soil-borne diseases (Perrin, 1990). Additionally, plants colonized by mycorrhizal fungi showed to survive better than uncolonized plants under suboptimal growing conditions and in marginal soils (Lioi and Giovannetti, 1987). VAM (25 g/bag) is helpful for better graft uptake at the grafting (Sridhar *et al.,* 1990). It has been demonstrated that inoculation of cashew with mycorrhizal inoculum had higher concentrations of K in both leaves and roots (Haugen and Smith, 1993). Among VAM, *Acaulospora laevis* and *Gigaspora mosseae* are better symbionts for inoculating cashew (Lakshmipathy, 2000). While Ananthakrishnan *et al.* (2004) reported among VAM (*Glomus fasciculatum*) is superior in terms of increased shoot length, internode number, number of leaves, stem diameter, root length and root number under nursery conditions.

A fertilizer dose of 150:20:100 (ppm) N:P:K to rootstocks and grafts of cashew @100 ml/plant/week resulted in higher plant height, stem girth and number of leaves (Manjunatha, 2001). Jagadeeshkumar (2001) observed improvement in growth when potting media of 100 kg was supplemented with 200 g N + 100 g P + 200 g K. Addition of cocoa pod husk (C P H) at 3% by volume as substrate to soil is effective for raising cashew seedling in the nursery as it enhanced growth of cashew seedlings (Agele and Agbona, 2008) who also found that C P H improves the soil pH, organic carbon, N, K, Na and Ca contents of the soil besides increasing the contents of ash, N, K and Na in the cashew leaves. Diva Correia *et al.* (2003) evaluated the use of mature and immature coir dust for preparation of substrates for grafted dwarf cashew seedlings and reported that coir dust either from mature or immature fruit was suitable for seedlings growth, being able to replace the low humid gley/clay soil at 20 per cent. Both substrates showed great facility to remove the seedlings from liner pots as well as good root aggregation to substrates.

Nutritional management in cashew plantations

For achieving high yields, the nutrient demand of the crop should be met. When the soil cannot supply the level of nutrient required for adequate growth, external nutrient applications become necessary. To sustain growth and obtain high yields, it is important to provide adequate supplies of all nutrients in proper balance. Proper nutrient management provides nutrients at the appropriate rate, timing, and with the appropriate method to produce an economically optimal crop in terms of both yield and quality. Balanced use of organics, fertilizers and biofertilizers plays an important role to maintain soil fertility in long run. It minimizes the risk of causing pollution by loss of nutrients via runoff, leaching, emissions to the air or other mechanisms.

Manures and fertilizers are the important inputs which account for 20 to 30% of the total cost of production, moreover, the fertilizer use efficiency is low due to various losses and soil fixation. The availability of soil nutrients to cashew plants depends on several factors. Low levels of available nutrients in the soil may be due to low amounts in the parent material from which the soil is derived, fixation and immobilisation of nutrients, or leaching losses of nutrients under high rainfall conditions. Nutrient imbalances in the soil may also cause limited availability of nutrients. Low nutrient levels may also result from continuous cultivation because of removal of nutrients by cashew plants without subsequent replenishment, leading to nutrient mining in the soil. Soil and plant relationship studies confirmed that high clay content, high pH, high base saturation, poor drainage or seasonally high watertable and the presence of stones or hard pan within 100 cm of soil depth reduced the tree size (Falade, 1984a). Aikpokpodion *et al.* (2010) have demonstrated the negative correlation of low clay and organic matter contents of the soils with the mineral and nutrient contents of the foliage and nuts.

Due to its extensive root system, cashew can draw its nutrients from large volumes of soil, and as a result it can perform reasonably well on poor soils where other crops fail to do so. When cultivating cashew on soils containing all the minerals required, but only available in low quantities per unit of area, the trees may not react strongly to fertilizer applications, and this may have led to the rather general, but wrong opinion in the 1960's, that fertilizing of cashew is uneconomical (Ohler, 1979). In India cashew is a neglected horticultural crop among the farmers and usually grown on marginal soils and also on wasteland mostly unsuitable for other economic crops. For a long time Indian farmers have thought of cashew as a drought tolerant crop, able to grow in poor soils, with little management. As a result of that low input approach and thereby resultant in low nut yields (Rupa and Kalaivanan, 2012). Cashew is grown in many soil types of the savanna zones of Nigeria. It is less selective and demanding in terms of soil types and fertility requirements compared with other plantation crops (Ohler, 1979). The vast majority of cashew trees grown in East and West Africa receive no or very little fertilizer, however they are reasonably well spaced which allows the extensive root system to absorb nutrients from a large volume of soil and the deep penetrating tap root is able to extract water and nutrients from sub-soil layers not accessible to most plants. In spite of cashew's ability to grow in poor soil (when well-spaced), it does respond positively to improvements in soil fertility.

Nutrient dose and response: Nitrogen is the mineral nutrient that cashew requires in the greatest amount. It has more influence on tree growth, production and quality of cashew than any other nutrient. It serves as an important constituent of the protein makeup of plant tissue and is a structural component of the chlorophyll molecule. The major nutrient requirement of cashew plant demands more liberal application of N followed by K, while P is needed in comparatively lesser quantity (Rupa and Kalaivana, 2012). Nitrogen and P were most important nutrients during the pre-bearing stage, but at the bearing stage, K together with N is also important. The response of cashew to applied N is tremendous and the same is observed universally. Increase in cashew yield due to N application was reported by several workers (Lefebvre, 1973; Reddy *et al.,* 1982; Rao *et al.,* 1984; Veeraraghavan *et al.,* 1985; Ghosh, 1988; Mathew, 1990). Ghose (1990) reported that number of nuts/plant and nut weight was the highest at 600 g N/tree/year. However, Latha *et al.* (1994) obtained response to N up to 1000 g/tree. It was found that higher dose of N increases the flowering duration but a depressing trend was noticed at higher level of P and K application (Ghose, 1989). Application of 750 g N/tree/year resulted in maximum scion production (Shingre *et al.,* 2003). Urea is the most commonly used nitrogenous fertilizer in India. However, in Nigeria urea and sulphate of ammonia are generally used. Falade (1984b) reported that sulphate of ammonia was superior to urea particularly when medium or high doses of N were applied to cashew.

Phosphorus is the second most limiting nutrient after N in the nutrition of cashew. It plays an indispensable role for many life processes such as photosynthesis, synthesis and breakdown of carbohydrates, and the transfer of energy within the plant. Phosphorus deficiency is common in cashew growing acid soils in which the mineral fraction is dominated by kaolinite and sesquioxides. Conflicting reports are observed regarding the response of cashew to P fertiliser. Rao *et al.* (1984) observed no response to P application in sandy loam soils. Similarly, Veeraraghavan *et al.* (1985) found no effect of P on cashew in laterite soils of Madakkathara. It was observed that the main effect of P to increase the yield was limited to a dose of 25 kg/ha, but when applied with N fertilizer, P application increased yield upto a dose of 75 kg/ha (Sawke *et al.,* 1985). However, Kumar (1985) reported positive influence of P on nut yield. Richards (1993) reported that soil P is a major limiting nutrient in P deficient soils of Australia. According to him, P application increased nut number and nut yield. Phosphate fixation of water soluble P is greater in cashew growing acidic soils dominated by kaolinitic type of clay mineral but allows the use of rock phosphate as a good source of P to cashew crop. Of phosphatic fertilizers for use on acid soils in India, the slow-release and more efficient ground Mussoorie (rock) phosphate is popular.

Potassium is the second largest nutrient next to N required by cashew. Potassium is necessary for several basic physiological functions like formation of sugars and starch, synthesis of proteins, normal cell division and growth, and neutralization of organic acids. It helps to reduce the influence of adverse weather conditions like drought, cold, and flooding. It also imparts tolerance to diseases and reduces water uptake. Application of K was found to increase the cashew nut production particularly in the presence of N (Lefebvre, 1973). Significant positive effects of K on growth and yield of cashew were reported by Ghosh (1988) and Ghosh (1990). But Veeraraghavan *et al.* (1985) could not observe positive effect of K application in cashew. Kumar (1985) obtained linear response for K upto 150 g K_2O/tree. Phosphorus and K application at higher level improved the nut yield (Sawke, 1980). Significant positive effect of K on yield of cashew tree was reported by Ghosh (1988; 1990). Increased nut weight and nut yield due to application of higher levels of NPK was reported by Ghosh and Bose (1986), Harishu Kumar and Sreedharan (1986), Ghosh (1990), and Kumar *et al.* (1995). Muriate of potash (Potassium chloride) is the common source of K.

Field experiments have so far not been conducted with varying levels of nutrients other than N, P and K. No specific recommendation is available on management of S, Ca and Mg in cashew. However, S deficiency can be corrected by supplying S sources of fertilizers either as basal or foliar spray. Foliar spray of zinc sulphate and copper sulphate at the emergence of the flush, panicle initiation and fruit set stages also contributes S to some extent. While Ca deficiency can be managed by lime application in acidic soils or by applying any Ca source based fertilizer. Use of rock phosphate as P source will also supply Ca to plants. Magnesium deficiency can be rectified by applying Mg sources of fertilizers either as basal or foliar spray. Its deficiency can also be corrected with the application and incorporation of lime, thus neutralizing the acid and adding Ca and Mg to the base exchange site. Foliar spray of magnesium sulphate 0.5% at the emergence of the flush, panicle initiation and fruit set stages is recommended.

Cashew plants require an adequate supply of micronutrients (Fe, Mn, Zn, Cu, B, Mo and Cl) for their normal physiological and biochemical functions. Micronutrient deficiencies are widespread and have been documented in various cashew growing soils throughout India. Currently, out of seven micronutrients, deficiencies of Zn, B and Mo are more common in cashew growing acid soils. Fe and Al toxicity is a distinct problem. The deficiency and toxicity limits of micronutrients in plant are rather narrow. This calls for location specific management of micronutrients in cashew so that these do not become toxic to plant. Foliar feeding is often the most effective and economical way to correct micronutrient deficiencies in horticultural crops. Foliar application of nutrients normally reduces the loss through adsorption, leaching and other processes associated with soil application. Deficiencies of Fe, Mn, Zn, Cu, B and Mo can be corrected by foliar sprays of 0.5-1% ferrous sulphate, 0.5-1% manganese sulphate, 0.5% zinc sulphate, 0.1% copper sulphate, 0.1% solubor and 0.1% Mo salts respectively to cashew at the emergence of the flush, panicle initiation and fruit set stages.

Application of fertilizers, dosage and the time and its schedule under different agro-climatic zones have been standardized (Veeraraghavan *et al.,* 1985; Harishu Kumar and Sreedharan, 1986; Grundon, 2001**;** Salam *et al.,* 2008**;** Yadukumar *et al.,* 2009). It was demonstrated that the dose of N 200: P 75: K 100 g/tree/year (Ghosh and Bose, 1986); N 250: P 125: K 125 g/tree/year (Subramanian and Harris, 1995); N 500: P 200: K 250 g/tree/year (Nanda Kumar *et al.,* 1998) and N 500: P 100: K 250 g/tree/year (Mahanthesh *et al.,* 2006), is optimum for higher nut yield. About 10 to 15 kg farmyard manure (FYM)/plant/year is recommended in addition to primary nutrients (N, P and K). Dosage of fertilizers given to cashew plant in major producing states of India are furnished in Table 9. 1. Based on the initial fertility status of soil, nutrient dose may vary from location to location. Judicial nutrient management practices should be based on soil and tissue analysis. For analysis in cashew, index leaf samples (4^{th} and 5^{th} leaf from tip of matured branches) is used. Limited information is available on the optimum leaf nutrient concentration in cashew.

Table 9.1. Recommended dose of fertilizers to cashew

State	Nutrient dose for mature cashew plantations (5^{th} year of planting) (g tree/year)		
	N	P_2O_5	K_2O
Kerala	500–750	125–325	125–750
Karnataka	500–500	250–125	250–125
Tamil Nadu	500	200	300
Andhra Pradesh/ Telangana	500–1000	125	125
Maharashtra	1000	250	250
Odisha	500	250	250
West Bengal	1000	250	250

Source: DCR, Puttur and AICRP on Cashew in different Centres

Experimental results from ICAR-DCR, Puttur (Karnataka) suggested that 500 g N and 125 g each of P_2O_5 and K_2O and 10 kg poultry manure/ tree/year under normal density planting system (10m × 5m; 200 trees/ ha) and 250 g N and 50 g each of P_2O_5 and K_2O and 10 kg poultry manure/ tree/year under high density planting system (4m × 4m; 625 trees/ha) gave the best results. In high density planting system of cashew, the fertilizer recommended is reasonable up to 80-100 per cent canopy coverage which is normally achieved during the initial 6 to 8 years after planting. After certain stage of the crop, reduction in recommended dose of fertilizers per plant may be necessary due to the nutrient build up in soil due to the deposit of cashew biomass fall out. It has been estimated that by systematically recycling all the waste biomass produced by cashew, it is possible to get back 20.7 kg N, 10.5 kg P_2O_5 and 30.8 kg K_2O/ha/year (Yadukumar *et al.,* 2003).

Quantitative estimation of soil fertility and fertilizer recommendations (QUEFC) for cashew was developed by Salam *et al.* (2008) using MS Excel to estimate the fertilizer N, P and K requirement of cashew for different soil fertility regimes, yield levels and tree ages. This model demands three inputs namely available N content in the soil (kg/ha), expected yield level (kg/tree) and age of the tree for formulating site specific fertilizer requirements of cashew.

Organic manures and bio-recycling: Researches carried out in several countries have already pointed out the interest in manuring the cashew. Since major areas under cashew in India do not receive any regular fertilizers/ pesticides/fungicides and their productivity levels are moderate. Majority of the cashew produced in India is organic by default with partial utilization of naturally decomposed cut weed biomass and cashew leaf litter (crop residue) deposited in the orchard. Hence, there is a vast potential of bringing those areas under organic farming practices to take advantage of great demand globally for organically produced cashew. Cashew can organically be grown in North-Eastern Hills Region (NEH Region), which can fetch higher price in international market. The major constraint in adopting organic farming in cashew is effective management of insect pests especially tea mosquito bug (TMB) as there are no organic means of insect pest management in cashew like biocontrol or use of botanicals. But organic farming research in cashew needs intensification for producing quality nuts especially for export purpose.

Cashew plantations have vast potential of organic biomass available for recycling. The availability of leaf litter from cashew plantations of 10 to 40- year-old varied from 1.38 to 5.20 tonne/ha (Guruprasad *et al.,* 2007). About 5.5 tonne of available cashew biomass waste per ha can be converted to 3.5 tonne of compost or vermicompost and helps in meeting nutrient requirement to cashew by 50% (Yadukumar and Nandan, 2005). The two years mean value for total dry weight of canopy biomass fall out was 55% as leaves, 27.3% as apples, 5.6% as kernels and 12.1% as shells. The major portion of N, P, K, Ca and Mg of canopy biomass came from leaves, branches, kernels and apples. The amounts of nutrient elements recycled in canopy fallout can partially meet the nutrient requirements of cashew. It has been shown that the nutrient composition of organically recyclable biomass compost with 20% cowdung slurry was 0.91-1.5% N, 0.34-0.6 % P and 0.39-0.46% K (Yadukumar and Nandan, 2005). About 15.5–37.7% of tree total requirements of macro-nutrients are recycled from canopy biomass fallout of leaves, cashew apples and flowers from six-year-old cashew trees in Australia (Richards, 1993). In the decomposed leaf litter, organic carbon content ranged from 0.7 to 1.61% , total N from 0.18 to 0.25%, available P_2O_5 from 0.13 to 0.228% and K_2O from 0.29 to 0.40% (Kumar and Mahabaleshwar Hegde, 1999). The micro-nutrient concentrations (Zn, Mn, Cu and Fe) were higher in the litter fall compared to the green leaves in cashew (Isaac and Nair, 2002).

Biofertilizers: Biofertilizers are microbial inoculants which are capable of mobilizing nutritive elements from non-soluble to soluble form through biological process. Biofertilizers help in improving soil characters, plant growth, yield and quality by fixing atmosphere N, mobilizing sparingly soluble P and by facilitating the release of nutrients through decomposition of leaf litter. Augmented fertilizer cost and the consciousness of environmental pollution due to fertilizer runoff and leaching demanded the use of biofertilizers for the development of balanced nutrition guidelines. However, very little work has been done on the use of biofertilizers in cashew. Inoculants of *Azotobacter* sp. and *Azospirillum* spp. either sole or in combination have been shown to improve N nutrition of plants through biological N_2-fixation and also secretion of some growth promoting substances which affect the growth, nutrition and microbial activity in the rhizosphere (Zayed, 1999). The phosphate solubilizing microorganisms (*Pseudomonas*) play an important role in conversion of unavailable inorganic P (Ca-P, Fe-P and Al-P) into available inorganic P forms through secretion of organic acids and enzymes. Arbuscular mycorrhizal fungi (AMF), on the other hand are ubiquitous in soils throughout the world and play an important role in affecting the plant growth through mobilization of nutrients.

Green manuring: Green manuring is a practice of ploughing or turning into the soil undecomposed green plant tissues for the purpose of improving physical structure as well as fertility of the soil. It has been reported that in the absence of organic manures, the soil health declines. The farmyard manure (FYM) is limited in supply, suggesting that green manure may be a more feasible substitute for fertilizer N. Green manuring maintains and improves soil structure by addition of organic matter, minimize P, K fixation in soils, produces humus, which enhances the utilization of fertilizer nutrients by plants and helps in reducing leaching losses by enhancing water retention ability of soil. Growing green manuring crops like *glyricidia*, sesbania, sunhemp and cover crops between two rows of cashew resulted in the nutrient addition of 186 kg N, 23.6 kg P_2O_5 and 126.2 kg K_2O through *glyricidia* and 141 kg N, 17.9 kg P_2O_5 and 162.3 kg K_2O/ha through sesbania (Yadukumar *et al.,* 2008).

Integrated nutrient management: Integrated nutrient management (INM) involving inorganic fertilizers with organic manures and biofertilizers has greater potential in stabilizing the yields over a period of time. Information on INM in cashew is very meagre. Cashew responds well to fertilization. Organic manures must be applied at planting, addition of FYM @6 tonne/ha provides for the better growth of young plants. It has been shown that *Azospirillum* spp. inoculation with compost of organically recyclable biomass available in cashew orchard produced significantly higher nut yield and net returns than the nutrients applied in inorganic form only (*NRC-Cashew Vision-2025*). Green leaf manuring with *glyricidia* and *sesbania* in cashew resulted in higher nut yield and improvement in soil nutrient content (Yadukumar *et al.,* 2008). But INM in various cashew cropping systems is warranted to maximize productivity. Inadequate and imbalanced use of inorganic fertilizers with little or no use of organic manures and biofertilizers have made the cashew soils not only deficient in certain nutrients, but also deteriorated the soil health. Under these circumstances, integrated use of organic manures, inorganic fertilizers and biofertilizers assumes great importance for sustainable cashew production and maintaining soil health. The organic manures and biofertilizers not only supply essential plant nutrients, but also improve the soil physical, chemical and biological health.

Method of fertilizer application: For the efficient utilization of applied nutrient, it is indispensable to know the active root zone, so the nutrients may be placed around this zone, to be made available to the plant. According to studies of Wahid *et al.* (1993), cashew trees are surface feeders with about 50 per cent of the root activity being confined to the top 15 cm of the soil and about 72% of root activity was found within a 2 m radius from the tree trunk. This suggested that application of fertilizers within a radius of 2 m from the main stem results in efficient utilization of the applied nutrients. The recommendations of N, P and K fertilizer rates vary with orchard age (i.e. planting, young trees < 5 years old, and mature trees > 5 years old). During the 1^{st}, 2^{nd}, 3^{rd}, 4^{th} and 5^{th} year of planting $1/5^{th}$, $2/5^{th}$, $3/5^{th}$, $4/5^{th}$ and 5^{th} year onwards full quantity is to be applied. Application of fertilizers in young plants can be done in shallow trenches at about 30 cm away from base of plants. As growth advancements, distance for application of fertilizers from base of plants should be increased and in mature trees this can be done at about 1.5 to 2.0 m away from the trunk. George *et al.* (1984) standardized the methods of fertilizer application to cashew and reported that application of N, P and K fertilizers in two circular trenches (1.5 and 3 m from the trunk) for sandy soils, a single trench method (25 cm wide and 15 cm deep circular trench at 3 m from the trunk) for sloping ground, and the band method (in a circular band 1.5 to 3 m from the trunk + soil incorporation) for flat ground are best suited.

To increase the efficiency of applied nutrients, they should be made available at an appropriate time, corresponding new vegetative growth phase, fruit growth phase and they should be placed near the active roots. The root activity of cashew in relation to phenological phases studied by Beena *et al.* (1995) employing ^{32}P

soil injection technique reported that 'flushing and early flowering phase (September to December)' is the most appropriate time for fertilizer application in cashew orchard. The annual dose of fertilizers to cashew are to be applied in two split doses, the first split dose at the onset of the pre-monsoon period and the second split dose during the post-monsoon period when the soil moisture condition is at its optimum; if only one application is given, it should be in the post-monsoon period when enough moisture is available. For most macronutrients, soil application is still recommended because of the large quantities required. Nevertheless, fertilizer applications to the soil are subject to various fates involving leaching, runoff, and fixation to forms unavailable to plants. Fertigation is a technique that allows the application of fertilizers to plants through irrigation water. In this system one can lower the dose of fertilizer application with a consequent increase in the number of applications. When nutrients are supplied with irrigation water, efficiency of nutrient absorption is increased.

Foliar feeding: Foliar application is the quickest method of getting nutrients into plants over the short term when a nutritional deficiency is diagnosed, however, should not be relied upon for long-term tree nutrition. Nutrient application through foliar is based on the principle that the nutrients are quickly absorbed by leaves and transported to different parts of the plant to fulfill the functional requirement of nutrition. Foliar application is not a substitute for soil applied N, P and K fertilization. However, some macronutrients can be foliarly applied at rates sufficient to influence young tree growth, yield and fruit quality. This method is highly useful for the correction of micronutrient deficiencies. Generally, urea and some micronutrients can easily be applied through foliar means. Sometimes, even K and P can also be applied foliarly. Foliar application of nutrients may result in early foliar initiation, more fruit set and yield per plant. Foliar sprays of nutrients (urea 2 to 4%; Diammonium phosphate (DAP) 1%; orthophosphoric acid; $ZnSO_4$ 4%; Copper (Cu) 0.3 to 0.6%) at the emergence of the flush, panicle initiation and fruit set stages ensure better fruit set and also enhance nut yield in cashew (Ankaiah and Rao, 1987; Sapkal, 2000). Yellow leaf spot in low soil pH (4.5-5.0) could be corrected by foliar sprays of molybdenum (Mo) salts (Subbaiah *et al.,* 1986). Foliar application of growth regulators Planofix, Nutron, IAA, IBA, NAA, 2,4-D and ethrel were favourable for increased total number of flowers, hermaphrodite flowers, sex ratio, fruit and yield per panicle, and also improve physico-chemical composition of apples and nuts (Ghosh, 1988; Singh *et al.,* 1992). In zinc deficient soils, foliar spray of Zn (2 kg $ZnSO_4$+ 1 kg lime in 450 L of water/ha) showed quick response (Mandal, 1992).

Nutrient removal by cashew

Proper fertilizer recommendations provide plant nutrients that are necessary to sustain maximum production and profitability while minimizing environmental pollution. The knowledge of nutrient removal, nutrient uptake patterns by crops and capacity and availability of nutrients in the soil reservoir aids to formulate precise fertilizer recommendations. In other words, the basis for estimating the nutrient needs is the removal through crop and the growth. Though the exact estimated for different varieties are not available, the average quantities of nutrients removed by cashew tree has been worked out. A substantial amount of nutrients is removed annually by the cashew tree. Cultivation of cashew without subsequent replenishment leading to low nutrient levels in soils. Nutrients removal by a cashew tree of 30 years old has been studied by Mohapatra *et al.* (1973) (Table 9.2). The quantity of the harvested dry matter and nutrients removal through apple, kernel and shell varied with varieties. The uptake of nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), sulphur (S), iron (Fe), manganese (Mn), zinc (Zn) and copper (Cu) was the largest through apple. The order of nutrients removed by the cashewnuts and apple was N > K > Mg > P > S > Ca and K > N > Mg > P > S > Ca, respectively (Fragoso, 1999). According to Ximenes (1995) and Lima *et al.* (2003) extraction of nutrients from the cashewnut follow the order as N > K > Ca > Mg > P > S. The nutrient requirement to produce one kg of cashewnut was 64.1 g N, 2.05 g P, 24.7 g K, 4.19 g Ca, 1.57 g S, 525.7 mg Fe, 63.6 mg Mn, 87.8 mg Zn and 26.5 mg Cu per tree (Beena *et al.,* 1995). The annual nutrient uptake required by cashew trees of 70 months of age in Australia were 2.1 kg N, 0.45 kg P, 1.32 kg K, 0.54 kg Ca and 0.57 kg Mg in order to maintain the structure of the tree (Richards, 1993). An eight-year-old cashew tree removes 610 g N, 58 g P, 394 g K, 52 g Ca, 39 g Mg, 34 g S, 2.12 g Fe, 343 mg Mn, 390 mg Zn and 130 mg Cu in Australia (Grundon, 2001).

Table 9.2. Estimated removal of nutrients (kg/tree) by a cashew tree

Plant parts	N	P (P_2O_5)	K (K_2O)	Average N:P:K ratio
Leaf, stem and root	1.721	0.406	0.800	4: 1: 2
Fruit (155 kg)	0.370	0.117	0.282	3.2: 1: 2.4
Nuts (24 kg)	0.756	0.229	0.183	3.3: 1: 0.8
Total	2.847	0.752	1.265	3.8: 1: 1.7

Studies on quantities of N, P and K accumulation in different plant parts of cashew by Reddy and Reddy (1987) showed that the concentration of N is higher in the bark (2.09%) and the lowest in the wood (1.00%). The leaves and the stem portions had almost the same concentration of N and P, however, it was the highest in the stem portion (0.132%) and the lowest in the wood (0.045%). On the other hand, K concentration was the lowest in wood and the highest in bark. The constant removal of produce without or with insufficient replenishment of plant nutrients causes a steady decline of soil fertility. This mining of plant nutrients, leads to severe depletion of soil fertility.

In studies on nutrient budgeting and nutrient balance in a six-year-old cashew plantation of 'Bhaskara' variety under high density planting system (625 trees/ha), showed a negative N, P and K balance of 113, 38 and 92 kg/ha in control plot where no fertilizer was applied. A strong positive N balance ranged from 137 to 251, P balance from 34 to 75 and K balance from 89 to 164 kg/ha/year was obtained in trees with two-thirds and full dose (750 g N and 150 g each of P_2O_5 and K_2O per tree/year) of fertilizer treatments. In treatments with one-third dose of fertilizers, a positive N, P and K balance of 40, 19 and 40 kg/ha/year was found (Yadukumar *et al.,* 2009).

Leaf nutrient concentration

The concentrations of nutrients in the leaves of cashew plants vary as a function of plant age, leaf age, mobility of the nutrient within the plant, season of the year, environmental conditions, and the genotype under study (Kumar *et al.,* 1982; and Bezerra *et al.,* 1999). In an experiment performed by Kumar *et al.* (1982), great variations in the concentration of N, P and K were found in function of leaf age and season for the common cashew plant growing under a dry, non-fertilized regime. They also demonstrated that the process of fruit development causes a decrease in the levels of these nutrients in the leaf, which could be a consequence of ion translocation to the developing fruit. The concentration of N, P and K in leaf was high at flushing and early flowering phase. According to Richards (1993), the concentration of Mg and Cu in leaf was high during flowering and fruiting phase. The concentration of Fe in leaf was high during maturity phase. The concentration of S, Mn and Zn in leaf was high at post-harvest phase. Leaf N, P, K, Ca and Mg concentrations vary from 1.52 to 2.06, 0.045 to 0.14; 0.40 to 0.96, 0.10 to 0.54 and 0.16 to 0.34 respectively. Mathew (1990) reported that leaf N was highest (2.76%) in flowering phase and lowest (1.24%) in pre-flushing phase. Latha (1992) also reported that the leaf N content was highest (3.02%) at flowering and lowest (1.93%) at flushing phase while, Beena *et al.* (1993) stated highest leaf N concentration at flushing and early flowering phases and lowest at fruiting and maturity phases.

Dwarf cashew plants cultivated under dry and non-fertilized conditions showed variations in leaf concentration of macronutrients along a cycle of production. The variations were associated with leaf age and the phenological changes of the plant over the course of a year. Increasing levels of N, P, K, Mg and S up to the beginning of the reproductive phase (rainy season), and decreasing thereafter (with the exception of K which remained unvaried) during flowering and fruit development (dry season). The levels of Ca also tended to increase with the age of the leaf (Bezerra *et al.,* 1999). The macronutrient concentrations in the leaves of cashew in Brazil decreased in the following order: N > K > Ca > Mg > S > P. The concentration of N, P, K, Mg and S increased up to the beginning of the reproductive phase (wet season) and decreased shortly afterwards during flowering and fruiting (dry season), except for K which remained more or less constant. Ca contents tended to increase with leaf age.

In studies on nutrients concentration in the index leaf (4th and 5th leaf from tip of matured branches) of 16 cashew varieties *viz.,* NRCC Selection-2, Bhaskara, Ullal-1, Ullal-2, Ullal-3, Vengurla-1, Vengurla-3, Vengurla-4, VRI-3, Madakkathara-2, Dhana, K-22-1, Priyanka, Kanaka, VTH-30/4 and VTH-174 collected from 10 years old trees indicated that the nutritional cashew tree demands differ in accordance with variety. The concentration of leaf N (1.02-1.70%), P (0.10-0.15%), K (0.36-0.62%), Ca (0.20-0.45%), Mg (0.14-0.30%), Fe (34.58-72.71 mg kg^{-1}), Mn (12.86-33.95 mg kg^{-1}), Zn (12.85-21.71 mg kg^{-1}) and Cu (7.66-15.29 mg kg^{-1}) showed a significant variation with respect to varieties. Out of 16 varieties used in this study, four varieties were deficient in N, eight varieties were deficient in P, all varieties were deficient in K and Mg, all varieties were sufficient in Ca and Cu and 14 varieties were deficient in Zn (Rupa *et al.,* 2013).

Diagnostic norms developed using soil testing/Plant analysis

Soil and plant analysis give an indication of what plant nutrients the soil has in store, the status of nutrient concentration in the plant. The main objective of plant mineral nutrition is increasing net income through efficient fertilization management. To attain this goal, it is initially necessary to correctly determine the yield limiting impact of a given nutrient. Current methods include both soil and plant tissues analysis. Soil testing on a regular basis and fertilizing according to soil test recommendations are critical parts of a sound nutrient management programme, but nutrient deficiencies or excesses of specific nutrients can still occur for a variety of reasons. Besides nutrient amounts, the balance between different nutrients can play an important role in the development of nutritional problems in a crop. The soil analysis method is based on the assumption that the chemical extractants simulate the root system acquisition of soil nutrients in a comparable manner. The major limitation in soil analysis is soil sampling, which is supposed to actually represent the soil portion explored by the roots (Reuther and Smith, 1954).

Tools for diagnosing nutrient disorders in growing crops include plant tissue analysis and visual symptoms of nutrient deficiency and toxicity. The advantage of plant tissue analysis was already observed in early studies of Chapman and Brown (1950). Tissue analysis is considered a more direct method of plant nutritional status evaluation than soil analysis, but that method must necessarily involve a well defined plant part analysis (Hallmark and Beverly, 1991). Among the several tissues to be considered for nutritional diagnosis purposes, leaves constitute the main plant sampling material (Chapman and Brown, 1950). Leaf analysis can be a very useful tool for plant nutritional diagnosis, since adequate procedures are available for data analysis. Because of the dynamic nature of the leaf tissue composition, strongly influenced by leaf age, maturation stage, and the interactions involving nutrient absorption and translocation, the tissue diagnosis may be a practice of difficult understanding and utilization (Walworth and Sumner, 1987). Several methods for nutritional diagnosis using leaf tissue analysis have been proposed and used, including the critical value (CV), the sufficiency range approach (SRA), and the diagnosis and recommendation integrated system (DRIS). Very limited efforts have so far been made to work out the leaf nutrient standards in cashew.

Ghosh and Bose (1986) suggested that the leaf N concentration of 1.51 per cent in the month of April is considered optimum for higher nut yield. Haag *et al.* (1975) suggested that leaf N concentration ranging from 2.4 to 2.58 per cent indicate sufficiency and 0.98 to 1.38 per cent indicate N deficiency; leaf P concentration ranging from 0.16 to 0.2 per cent indicate sufficiency and 0.11 to 0.14 per cent indicate P deficiency; and the leaf K concentration ranging from 1.11 to 1.29 per cent indicate sufficiency and 0.20 to 0.26 per cent indicate K deficiency in cashew. Falade (1978) observed highest growth at a leaf P concentration of 0.118 per cent in cashew seedlings. The DRIS norms specific to cashew do not exist.

Mathew (1990) standardized the optimum time and leaf position for sampling of foliar diagnosis. It was reported that 'after the opening of all the flowers of a panicle' and 'prior to flushing and before fertilizer application' are the best periods for sampling N and K respectively. The first group of leaves of the flower bearing shoot (leaf No.1 and 2 near to the inflorescence) is considered as the best for foliar diagnosis in relation to N and K. As the yield of cashew was not correlated with leaf P irrespective of leaf positions, it was not possible to recommend any specific leaf group for determining P status of the plant.

Harishu Kumar and Nair (1982) reported higher contents of N, P and K in cashew leaves after fruiting season but leaves from the top and bottom half of the tree did not show any significant difference in mineral contents. Fully mature leaves of the current season growth had significantly higher N, P and K contents in post fruiting period compared to the pre-fruiting season. The N/P and N/K ratios were low in the fully mature leaves. It was reported that the leaf sample collection from three composite samples of five trees per sample during pre-fruiting season, and six composite samples of trees during post-fruiting season is enough from 1 ha area.

It was found that leaf nutrient status of October flush is indicative of crop performance (Satyanarayana Reddy and Rao Rama Rao 1985). Leaf N content of 1.51% in April is considered optimum for higher nut yield (Ghose and Bose, 1986). High yields were attained when N concentration in a mature leaf (1 to 4 leaves from the apex) of a quiescent vegetative shoot leaves in May-June were about 2 per cent, but this assessment occurs at a time when it is not feasible to correct N deficiency. The largest mature leaf (3-9 leaves from the apex) of the vegetative flush that emerges with the inflorescence leaf of the preceding November, used in conjunction with the quiescent vegetative shoot leaf, was proposed as a diagnostic tool to guide N rate decisions at Dimbulah, Australia (O'Farrell *et al.*, 2010).

Deficiency/Toxicity symptoms

Symptoms due to deficiency of mineral nutrients induced in cashew seedlings under laboratory conditions (Falade, 1978; Ohler and Coester, 1979). Very low and very high levels of macronutrients resulted in stunted growth and had appreciable effect on the absorption, translocation and distribution of nutrients in cashew (Falade, 1978). Ohler and Coester (1979) grouped the minerals into three groups *viz.,* (a) Fe, Mg, K, N and Mo, deficiency of which proved lethal during the trial in the order of severity, (b) S, Ca, Mn, and Zn deficiency, symptoms of which developed early but were not lethal and (c) P, B and Cu deficiency, symptoms which developed slowly and were not severe in their effects.

Falade (1978) reported the synergistic and antagonistic effects of various elements on cashew seedlings under laboratory conditions. Yellow leaf spot of cashew widely found to occur in the west coast of South India is possibly due to deficiency of a single or combination of mineral nutrients (Menon *et al.,* 1979). Information in India relating to nutrient deficiency/toxicity symptoms in cashew has not progressed much. Sand culture studies conducted for inducing the symptoms of deficiency of various nutrient elements from Hoagland's nutrient solution resulted in differential growth behavior and concentration of the nutrients in leaf tissue (Gopikumar and Aravindakshan, 1986).

Conclusions and future thrust areas

In India, a greater part of the cashew growing soils are lateritic, red and coastal sands which are acidic in nature and poor in soil quality. Most of the plantations are on undulated topography and subjected to soil erosion. Due to its extensive root system, cashew can draw its nutrients from large volume of soil, and as a result it can perform reasonably well on poor soils where other crops fail to do so. Nevertheless, fertilization is necessary to achieve and sustain commercial cashew production. Fertilizer use on cashew is now sub-optimal in many regions, and application of additional fertilizer is often profitable. Lack of proper nutrition is one among several factors for slowdown in productivity in cashew system. To ensure high economic productivity of cashew and to sustain the available soil nutrient status at a desired level, correct doses of manures, chemical fertilizers and microbial inoculants must be applied, based on use of reliable diagnostic tools. Efforts have so far been made to work out the soil and leaf nutrient standards in cashew. Concerted research efforts are therefore needed to develop optimum concentrations and/or optimum ranges of nutrients useful for correct diagnosis and improvements of nutrient status of cashew plants. Also, need to promote balanced, efficient and environmentally sound nutrient management strategies in cashew/cashew based cropping systems employing integrated nutrient management for high yield and quality.

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10

Irrigation Management

CASHEW TREE is considered drought tolerant to some extent and is generally grown as an unirrigacted crop, but the yield can be increased two-fold, if irrigated. Low productivity is the main concern in cashew cultivation in India. Of several factors associated for such low yields, the low moisture availability during the fruiting season which normally coincides with the onset of dry season in the cashew growing areas is one of the factors. Although, the cashew may grow and produce in regions with mean annual rainfall distribution ranged from low rainfall (300 to 600 mm in Gujarat) to high rainfall (2,700 to 3,000 mm in west coast and NEH region) with a drought of 4 to 5 months. In cashew flushing, flowering and fruit development stages are critical phases that decide the nut yield. Any form of stress, (biotic or abiotic) during these phases can decrease the yield substantially. Due to the non-uniform distribution of rainfall, cashew experiences severe moisture stress from December to May, which adversely affects its flowering and fruit set causing flower drying and immature nut drop. The water deficit and rainfall during fruiting season (February to May) in major cashew growing regions were given in table 1. Water availability strongly influences flowering and fruit set and can affect fruit drop, fruit size, yield, nut quality characteristics and canopy development. Studies in India have shown that nut yield can be enhanced by

Table 10.1: Water deficit and rainfall during fruiting season in major cashew growing regions

Cashew growing region	Water deficit (mm) during fruiting season				Ten years Average rainfall (mm) during fruiting season
	February	March	April	May	
West Coast					
Vengurla, Maharashtra	86	132	143	117	67 (2.3%)
Puttur, Karnataka	90	142	112	140	237 (7.1%)
Madakkathara, Kerala	110	126	59	183	415 (11.7%)
East Coast					
Vridhachalam, Tamil Nadu	96	139	90	124	41 (3.4%)
Bapatla, Andhra Pradesh	114	90	124	83	284 (17.5%)
Bhubaneswar, Odisha	101	153	155	63	93 (8.0%)
Jhargram, West Bengal	54	150	155	63	243 (15.0%)

Figures in parenthesis indicate % of the mean annual rainfall received
Source: AICRP on Cashew

providing protective irrigation with 200 litre of water per tree once in 15 days from January to March during the summer season. Research results in Brazil and other countries have shown that irrigation could increase productivity up to 300 per cent depending on the region. Therefore, scheduling based on plant water balance in consonance with soil and climate is appropriate. Since lot of water loss is caused during the conveyance, it is essential that appropriate delivery system is used which enhances the efficiency. The water has to be applied to root zone to save the losses. Drip irrigation is the most efficient irrigation system with saving of water between 40 and 60% over other irrigation systems. In drip irrigation only a portion of the soil area around each plant is irrigated. Water movement into and through the soil from point source such as drip irrigation increases the capacity of soil water movement phenomenon affecting the dimension of wetted volume, movement of fertilizer in the soil solution/irrigation water.

Water requirement, time and method of irrigation

Irrigation scheduling, knowing how much water to apply and when, has a direct influence on tree health as well as nut yield and quality. Right irrigation scheduling requires an understanding of how much water can be held in the plant root zone. To maintain the optimum level of water in crop and to schedule irrigation, an estimation of water requirement is prerequisite. Water requirement of a crop depends on crop, soil type and atmospheric demand for the water. Generally, crop water requirement is defined as the depth of water needed to meet the water loss through evapotranspiration (ET_{crop}) as a healthy crop under non-restricting soil conditions and attaining full production potential under the given growing environment.

Fresh grafts when planted require sufficient soil moisture for initial establishment and hence cashew is planted during monsoon. Whenever there is drought situation after planting they need protective irrigation. The irrigation through pitcher (holed pots) is recommended in dry land situations. Under drought situation, irrigation is one of the most important factors in establishing the newly planted grafts well. Care must be taken to keep the soil moist but not waterlogged. The root ball of a newly planted graft must be kept moist to supply the plant with water until its roots grow into the soil. Newly planted grafts need to be watered every three to seven days, depending on the soil type and weather conditions. Because of their deep tap root system, established cashew trees can survive in the dry season without irrigation, but premature nut drop is a common problem. Irrigation during critical phases of established cashew trees improves nut yield.

Requirement of water by cashew plants differ according to climatic conditions, planting density, age of the crop, canopy area and management practices. Experimental results from ICAR-DCR, Puttur (Karnataka) on fertigation studies in cashew, showed that, under normal planting density (7 m × 7 m), the effective canopy coverage per tree is 12.56 m^2. The quantity of irrigation water calculated based on the effective canopy area was 12.56 litre/tree/day from December to January (daily open pan water evaporation is 5 mm) and 20 litre/tree/day from February to March (daily open pan water evaporation is 6.5 mm) to meet 20% of the cumulative pan evaporation (CPE). Similarly, for 40% CPE and 60% CPE, the irrigation rate was 24 litre/tree/day and 38 litre/tree/day from December to January and 36 litre/tree/day and 58 litre/tree/day from February to March, respectively. In order to meet 20% CPE, four drippers of 2 litre/hour discharge rate can be fitted at two equidistant points 1 m away from the base of the tree. Similarly, to meet 40% and 60% CPE, four drippers and six drippers of 4 litre/h discharge rate can be fixed. Drip irrigation can be given for 1 h 30 min during December and January and 2 h in February and March. Under high planting density (4m × 4m), based on the effective canopy spread of 7 m^2, the quantity of irrigation water required was 7 litre/tree/day from December to January (Daily open pan water evaporation is 5 mm) and 9 litre/tree/day from February to March (Daily open pan water evaporation is 6.5 mm) to meet 20% of the CPE. While to meet 40% CPE and 60% CPE, the irrigation rate was 14 litre/tree/day and 21 L/tree/day, respectively from December to January and 18 litre/tree/day and 27 litre/tree/day, respectively from February to March. In order to meet 20, 40 and 60% CPE, two drippers of 2 litre/h, two drippers of 4 litre/h and three drippers of 4 litre/h, respectively discharge rate can be fitted at two equidistant points 1m away from the base of the tree. Drip irrigation can be given for 1 h 45 min during December and January and 2 h 15 min in February and March (Yadukumar and Rejani, 2008; Yadukumar *et al.,* 2009). Quantity of water to be applied and frequency of irrigation should be standardized for a cashew crop under different agro-climatic conditions.

Planting of cashew is usually done with the onset of monsoon in June or in August. If a long dry spell is expected between two rains, it is necessary to give protective irrigations. However, it is advised to irrigate newly planted grafts/seedlings for the initial period of two years till their root system is established well. Though cashew plant is hardy and drought tolerant, it responds well to irrigation. Cashew experiences severe moisture stress from December to May, which adversely affects flowering and fruit set causing nut drop. Experimental results show that irrigation during dry periods can improve canopy development, flowering, fruit set, fruit size and yield of cashew. Once the tree starts producing nuts, irrigating at a rate of 200 litre/tree once in 15 days during the period from January to March is beneficial for cashew which results in doubling up of the yield. Drip irrigation improves nut retention which leads to increased production. Normally, drip irrigation of 60-80 L of water/tree can be given once in four days from second fortnight of December to end of March in west-coast region. In east coast region, it can be given during dry periods at the time of flowering, nut setting and nut development.

Case study for estimating water requirement of cashew tree

- To meet 20% CPE
- Age of the tree: 5 years
- Canopy spread: 4 m, Canopy spread= canopy diameter = mean of EW and NS length
- Canopy area πr^2 where r = radius of the canopy.
- If the radius is 2 m, the total area covered by individual tree canopy is $3.14(\pi) \times 2^2 = 12.56\ m^2$ (ground coverage by canopy)

Daily CPE = 5 mm, 20% of CPE = 1 mm, Therefore, quantity of water to be given to meet 1 mm of water in 12.56 m^2 area = 12.56 × 1/1000=0.01256 cubic M, 1cubic M =1000 litre. Therefore, 0.01256 cubic M =12.56 litre/tree/day.

- Like this quantity of water required to be given is calculated depending upon canopy coverage and daily water evaporation.

The water requirement of cashew crop was estimated by Mishra *et al.* (2008) on daily basis for all months of a particular year and the net average seasonal water requirement of crop as per their estimate was 997 mm. Water requirement of cashew can be calculated based on evaporation rate in the given area and crop factor (K_c). For cashew, K_c varies from about 0.8 at peak flowering to 1.1 at peak nut set. Cashew needs irrigation from the onset of flowering to late nut set. Supplementary irrigation for younger plants may be required during drier parts of the year and to assist with fertiliser applications. Trees irrigated with sprinklers will need about 500 L/tree/week and 50 per cent of the water requirement can be saved with drip irrigation. The amount of water use will increase from early flowering to peak nut set; thereafter it will decline. Irrigation should be stopped before starting harvest, to avoid nut germination on the ground (Website: www.deedi.qld.gov.au).

Roots can extend to great depths (>5 m), while cashew is wide-spreading rooting habit is critical to its successful adaptation to semi-arid/dry conditions. The optimum temperature for CO_2 assimilation is in the range of 25–35°C. Progressive closure of the stomata occurs at saturation deficits of the air >1.5 kPa. In the field, differences in rates of gas exchange between irrigated and unirrigated cashew trees only become apparent three or four months after the end of the rains, the stomata playing an important role in maintaining a favourable leaf water status in dry conditions. Sap flow measurements indicate transpiration rates of 20–28 L d^{-1} $tree^{-1}$. Irrigation can be beneficial during the period from flowering to the start of harvest, but reliable estimates of water productivity have yet to be established. The best/only estimate is 0.26 kg (nut in shell) m^{-3} (irrigation water) (Carr, 2014).

The ability of unirrigated cashew trees to draw moisture below 1.8 m depth was apparent from the experimental results as such trees gave virtually zero water use over recorded depth at peak nut set, yet they were able to give yield ranging from 20 to 70 per cent of the highest irrigated yield (Richards, 1993). He further stated that this poses the question of the long term irrigation requirements of well-established cashew trees. He raised questions whether such mature trees with presumably dry root system require wet season fertilizer application only as in the case of no irrigation and or require irrigation reduced to a critical period only in order to produce economic yields.

Schaper (1991) reported that leaf gas exchange was lower and water potential higher in leaves of unirrigated cashew trees near peak flowering compared to irrigated trees, but that both declined after flowering commenced compared with pre-flowering, wet season levels. Further, he reported that stomatal regulation in cashew appears to prevent leaves from losing water faster than their roots can replace it by absorption. Non production of new shoots in March, April and May in unirrigated tree was the mechanism to withstand stress situations whereas in

Table 10.2. Average values of crown projection areas, percentage of soil covered by the plant and volume of water to be applied in irrigation as a function of plant age

Year of crop	Crown projection area m^2	Soil covering* (%)	Volume of water** (L/plant/d)
1^{st}	1	2	5
2^{nd}	5	10	25
3^{rd}	15	30	70
4^{th}	25	50	120
5^{th} +	30	60	145

*Assuming the spacing between plants is 7 m × 7 m.

**If the area wetted by the nozzle is greater than the crown projection, the volume of water to be applied should be chosen as a function of the wetted area.

Source: Miranda, F.R. de., 2005; unpublished data.

irrigated trees new shoots were produced in March, April and May but then these shoots never flowered during that season. Advantage of these new shoots is mostly for the better production of flushing shoots after the rainy season (October onwards) thereby total canopy area increased and total flowering laterals increased/ tree considerably.

In Australia, Schaper *et al.* (1996) reported that the plant could be irrigated only between flowering and harvest without decreasing yield compared to irrigating during the entire drought period. This saves much water. The water needs of the plant vary with climate, the plant's foliar area, the growth phase of the plantation and with the irrigation method used. During periods of high evapotranspiration, 5 L of water/day are recommended for each square meter of soil surface shaded by the plant crown or area wet by the emitters (Table 10. 2). The frequency of irrigation depends on the water retention capacity of the soil and should vary between two and four days, for sandy and clayey soils, respectively. With drip irrigation, the volumes of water recommended in Table 10. 2 may be reduced by about 15%. The number of drippers per plant should increase gradually, according to the age and stature of the plant, from one dripper during the first year to up to four, six or eight mature plant in clayey, medium textured and sandy soils, respectively. Richards (1993) reported that water requirement by five-year-old cashew tree growing in sandy soil and under high evaporative demand is about 400 to 500 L/tree/week which equated about 30 L/m^2 of canopy area. It has been reported that in normal density planting system, irrigation required is 80 L/ tree once in four days and total thirty irrigations (2,400 litre/season) are required (Anon., 1998).

Drip irrigation or more broadly known as micro-irrigation is mainly suited for orchard and plantation crops where it saves 30-70 per cent irrigation water and increase yield by 25-80 per cent. Evidences from drip irrigation trials have clearly indicated the advantages like water saving, higher productivity, limited weed growth, better management of assets, off season maturity, better fruit quality and reduced incidence of insects, pests and diseases (Sivanappan, 1987 and Dhandar and Sharma, 2002). It is recommended to use micro-irrigation (spray or drip), because of certain advantages like decreased incidence of leaf sickness and weeds, water saving by decreasing losses by evaporation and greater efficiency of water use. Micro-irrigation can also be adapted to different soil and topographies; there is a saving in labour costs and efficient application of fertilizers via irrigation water (fertigation). The initial cost of a system of micro-irrigation for cashew varies from ₹ 3,000 to ₹ 4,500 (US$ 1,000 to 1,500) per hectare. Where spraying is used it is recommended to have one jet per plant, with a nominal flow of 30 to 70 L/h and wetting diameter of 3.5 to 5.0 m. In dripping, a minimum of four drippers per plant ought to be used per mature plant in clayey soils, and up to eight drippers per plant in sandy soils. To choose between spray and dripping as a system of irrigation, the water availability (quantity and quality) should be considered. In dripping there is a greater savings in water and energy, because the loss of water by evaporation from the soil surface is less and the system operates at a lower pressure. On the other hand, the risk of emitter blocking is greater than with spray irrigation, thus better filtering, especially when surface water with a lot of organic matter is used. Dripping also offers the advantage of not wetting the fruits that fall onto the ground, allowing less frequent collecting where the primary product required is the nut (www.ipipotash.org).

Bucks *et al.* (1979) reported that the most serious problem in trickle irrigation is clogging of emitters or applicators. Recommendations and guidelines are to be followed for preventive maintenance which include water filtration, chemical treatment, pipeline flushing and field inspection. A suitable type, size, and capacity of a filtration unit is required. Chemical treatment should be considered for prevention of emitter clogging. Proper procedures for the flushing and field inspection of trickle irrigation systems are also essential.

Water used for irrigation contains measurable quantities of dissolved substances which as a general collective term called salts. Salts in soil or water reduce water availability to the crop to such an extent that yield is affected. Irrigation water quality is evaluated based upon total salt content, sodium and specific ion toxicities. The suitability of water for irrigation is determined not only by the total amount of salts present but also by the kind of salts. Relatively high sodium or low calcium content of soil or water reduces the rate at which irrigation water enters soil to such an extent that sufficient water cannot be infiltrated to supply the crop adequately from one irrigation to the next. No specific quality standards apply to cashew irrigation, however, the general water quality standards can be used. Electrical conductivity of irrigation water should not exceed 0.8 dS/m and total dissolved ions should be less than 600 ppm.

Fertigation for efficient water and nutrient management

Fertigation is the technique of supplying dissolved fertilizer to crops through an irrigation system (Haynes, 1985). Fertigation aids to reduce the water and fertilizer requirements. Fertigation also helps to increase the availability and uptake of nutrients as it delivers water and nutrients to the root zone. Fertigation is aimed at maximizing the profit of growers and minimizing the environmental pollution as it overcome the problems of loss of fertilizers due to runoff or leaching, save labour and increase fertilizer use efficiency. Fertigation became possible after development of micro-irrigation systems. Drip irrigation system is ideal for fertigation. Highly soluble fertilizers are applied through irrigation system to prevent clogging of emitters. The liquid fertilizers are not commonly available in our country and the cost is also high. The nutrients most frequently applied in fertigation are those with greater mobility in the soil, like N and K (Oliveira *et al.,* 2003). Urea is widely used for fertigation since it readily dissolves in water. Numerous formulations containing two or more nutrients are available for fertigation. To apply nutrients by fertigation, tanks of the solution, where the fertilizers are pre-diluted in water, and an injecting device are necessary. The types of injectors most utilized in fertigation are: injector pumps, venturi and differential pressure tanks. There are many advantages of fertigation: (*i*) uniform application of nutrients; (*ii*) application of nutrients according to the needs of the plant and the rate of uptake; (*iii*) greater efficiency of nutrient use due to its mobility in the wetted zone of the soil where the root system is concentrated; (*iv*) savings on labour and agricultural equipment; (*v*) reduction in soil compaction from the use of heavy equipment; and (*vi*) ability to apply nutrients more frequently thus reducing nutrient losses (Santos *et al.,* 1997). Fertigation needs to be carefully managed to avoid soil acidification and salination in the root zone. To avoid blocking the emitters the fertilizers used should be fully soluble in water and should not form precipitates, especially calcium and iron phosphates.

Experimental results from the Directorate of Cashew Research, Puttur (Karnataka) suggested fertigation schedule for cashew under different planting density. A dose of 250 g N, 62.5 g P_2O_5 and 62.5 g K_2O/tree/year to cashew plants through fertigation and castor cake 4 kg/tree through soil application for obtaining optimum yield under normal planting density of 7m × 7m is suggested. While, under high planting density of 4m × 4m, a dose of 125 g N, 31.25 g P_2O_5 and 31.25 g K_2O/tree/year through fertigation and castor cake 2 kg/tree through soil application is optimum. The fertilizer sources *viz.* urea for N, diammonium phosphate for P and muriate of potash for K can be used for fertigation. The annual recommended dose can be given in five splits starting from October to December, and from January to February, the monthly dose can further be split into four doses and apply once in a week through drip irrigation system (Yadukumar and Rejani, 2008; and Yadukumar *et al.,* 2009).

Response of cashew to supplementary irrigation

Experiments conducted at AICRP-Cashew, Vengurla (Maharashtra) indicated that the growth and yield attributing characters of cashew variety ‘Vengurla-7’ did not vary significantly among the treatments. The fruit set/m^2 was the highest (89.87/m^2) in irrigation @ 60% CPE. Mean No. of nut per panicle was the highest (16.65) in irrigation @ 80% CPE. Cumulative yield for nine harvests was maximum (29.84 kg/tree) in the irrigation treatment at 40% CPE. Experiments conducted at AICRP-Cashew, Vridhachalam (Tamil Nadu) revealed that irrigating the cashew plants variety VRI-3 at 80% of cumulative pan evaporation enhanced plant height, trunk girth, canopy spread and canopy surface area. The flowering was early in trees receiving irrigation at 80% CPE.

Experiments conducted at AICRP on Cashew, Chintamani (Karnataka) revealed that, among different levels of irrigation, irrigating the crop at 80% CPE recorded significantly highest plant height (5.11 m) and stem girth (88.08 cm). There was no significant difference in canopy spread among irrigation levels. Maximum E-W and N-S spread was recorded in 80% CPE (8.36 m and 8.42 m). Nut yield varied significantly among the treatments. The highest nut yield of 14.75 kg/tree with a nut weight of 7.4 g and shelling per cent of 32.1 and cumulative yield of 5 harvests (54.55 kg) was observed in 80% CPE.

Irrigation effects on cashew

Studies on effect of black polyethylene mulch and supplemental irrigation of 60 L water/tree given manually at 15 days interval from the emergence of panicles and 6 to 8 total irrigations during each season on fruit retention of cashewnut by Nawale *et al.* (1985) revealed that the polyethylene mulch +irrigation treatment recorded the maximum fruit retention of 66.15% and followed by the irrigation alone (58.04%) and polyetheylene mulch alone (52.83%). The correspondence fruit retention in control (no polyethylene mulch and no irrigation) was 44.98%.

Studies conducted by Yadukumar and Mandal (1994) on the effect of supplementary irrigation on fruit retention and yield at The then NRC on Cashew, Puttur, Experimental Station, Shantigodu in 1986 on the existing cashew trees of 13 years old with four different treatments, *viz.* (a) Fortnightly irrigation at a rate of 200 L/tree from (i) November to January; (ii) January to March; (iii) November to March; and (iv) Control (No irrigation). The observations on fruit retention taken from February to April revealed that there has been increase in fruit retention in irrigated plot as compared to control. During 1988, it was also seen that irrigating from November to March (10 irrigations) was significantly superior to other treatments of irrigations: November - January and January - March (5 irrigations each). Analysis of 2 years pooled data also showed similar results. Irrigation has increased fruit retention (nut retention) which ultimately increased the yield. The economics worked out for all the treatments to decide definite recommendations to the growers revealed that 10 irrigations from November to March gave net profit of ₹ 12,508/- per ha which was ₹ 6,864 above the control plot, and ₹ 4,552/- and ₹ 5,420/- above other irrigation treatments.

In young cashew, application of 30 litres of water/tree at 15 days-interval increased the nut yield by 393% as compared with unirrigated plants in West Bengal (Ghosh, 1995). Drip irrigation @ 43 mm/week from April to October increased nut yield by 20% in Australia (Schaper *et al.,* 1996). Oliveira (2002), who found that, when irrigation was applied to cashew plants, nut yield increased mostly due to the increase in the number of nuts per tree, while nut weight decreased with plant aging. The occurrence of decreasing nut size with increasing yield may be explained by the fact that plants with more fruits can supply less photosynthates to each fruit. The response to irrigation varied among cashew genotypes. Irrigation increased nut yield of dwarf cashew clones CCP 76 and CCP 09. The highest nut yield was obtained with cashew clone CCP 09 irrigated when accumulated pan evaporation reached 10 mm. Cashew alternated years of high nut yield with years of low yield, even when irrigation was applied. Irrigation did not influence nut weight of clones CCP 76 and CCP 09 (Oliveira *et al.,* 2006).

Mishra *et al.* (2008) evaluated the economic feasibility of drip irrigation with black linear density poly ethylene (LDPE) mulch on the loamy soil in coastal Odisha and reported that the drip irrigation is economical and cost effective when compared with conventional basin irrigation. It was shown that an increase of 108% in nut yield and 122% in net seasonal income obtained with 80% irrigation requirement through drip irrigation + black LDPE mulch with the highest benefit cost ratio of 3.1 over the conventional ring basin irrigation. Mulch alone could increase the yield by 16% even in the absence of drip.

Irrigation and fertilizer effects on cashew

The irrigation and fertilizer experiments in cashew conducted in Northern Territory of Australia indicated substantial reduction in yield, tree size and yield efficiency associated with absence of fertilizers and irrigation inputs (Richards, 1993). Application of fertilizer increased yield significantly compared to that of unirrigated and or unfertilized trees. He has reported that rate of irrigation had limited impact on yield, size and efficiency in similar size trees producing at high, medium and low rates of irrigations (600, 490, 290 litre/tree once in a week) within irrigation and fertilizer frequency treatments. At medium and high level of irrigation the yield and kernel recovery increased significantly compared to low irrigation levels for trees applied after commencement of flowering. Further, it was reported that the combination of irrigation treatments and fertilizer frequency interacted to effect tree size with smallest tree canopy in the absence of fertilizer with or without irrigation. Kernel recovery was influenced by the combined effects of irrigation and fertilizer as post-flowering irrigation at low rates, unirrigated and unfertilized treatments, gave significantly lower recovery rates.

It has been documented that irrigation in the absence of adequate nutrition is wasteful (Richards, 1993). Irrigation and nutrient application together gave larger tree canopy, greater yield and improved efficiency although the phenolology cycle was not affected. Irrigation at low rates was the most efficient in terms of water use efficiency but carries the risk of reduced yield and kernel recovery rate. Richards (1993) reported that duration and intensity of flowering for both irrigated and unirrigated tree from 1988 to 1990 in cashew showed similar patterns in each year. In 1990 the unirrigated trees gave significantly lower peak flower level than irrigated trees. The pattern of 1990 flowering was different from that of previous years and showed a delay in flowering at the beginning before recovery in the seventh week and a quicker decline in flowering after the peak was reached. He reported that in cashew significant variations in water use and KC (crop coefficient) values range from 0.45 to 1.0 depending upon the ground cover and size.

The highest nut yield (3.8 kg/tree) was obtained from trees provided with 80% recommended dose of fertilizers as water soluble fertilizers through drip irrigation, compared to trees supplied with recommended dose of NPK through soil without drip irrigation (Kumar *et al.,* 1998). Latha and Salam (2001) found that in rainfed trees, application of N 500 g/tree/year produced 0.77 kg nuts/tree while trees applied with no N resulted in zero yields. In irrigated trees (40 L/tree/day), N application of 1.5 kg/tree/year resulted in an increase in yield by 54% compared to rainfed trees. When the irrigation level was increased to 80 L/tree, the yield increase was 124%.

In studies on drip irrigation and graded N, P and K on the productivity of cashew by Yadukumar (2001) have shown that the maximum total root production (119.30 kg/tree) in the trees receiving the highest irrigation (irrigation through drip @ 80 litre/tree once in 4 days) and fertilizer (750 g N, 187.5 g P_2O_5 and 187.5 g K_2O/tree/year) was ten times more than trees receiving no fertilizer and irrigation (12.39 kg/tree). Similarly, fine root production in irrigated and fertilizer applied trees were also more (8.74 kg/tree) in control plot trees where no fertilizer and irrigation was provided (0.58 kg/tree). Irrigation had profound influence on the production of male and bisexual flowers/panicle. It significantly increased bisexual flowers compared to the ones in the unirrigated tree in eighth year (22.24 to 31.91% increase over control). Trees receiving higher levels of irrigation (60 and 80 litre/tree) retained significantly more per cent of nuts (67.30 and 70.64%) compared to low level of irrigation (20 litre/tree) and no irrigation (52.90 and 41.62%). Tree receiving no irrigation and fertilizer retained minimum of 36.32% nuts whereas trees receiving 80 litre of irrigation/tree and middle and higher doses of fertilizers (500 g N, 125 g P_2O_5 and 125 g K_2O/tree/year; and 750 g N, 187.5 g P_2O_5 and 187.5 g K_2O/tree/year) retained 72.17 to 70.66% nuts, which is 36.05 to 34.34% higher over control (untreated trees).

Cumulative yield for five years from 4th to 8th year after planting indicated that with irrigation the yield increased by 37.64 to 63.54% over trees receiving no irrigation. The overall significant increase in yield in trees receiving 80 litre per tree once in four days was observed over lower level of irrigations (20, 40 and 60 litre/tree). Significantly higher yield was realised in trees receiving highest fertilizer dose (750 g N, 187.5 g each of P_2O_5 and K_2O/ha) over lower doses of fertilizers and control. The increase in yield was by 45.62% over control (No fertilizer application). Irrigation alone without fertilizer application, the yield ranged between 11.94 kg/tree and 14.86 kg/tree compared to yield of tree receiving no irrigation and fertilizers (8.63 kg/tree). Under unirrigated conditions, response to fertilizer applications was significant. It was observed that application of lower to higher doses of fertilizers increased yield significantly. Interaction effect of irrigation and fertilizers revealed that irrigation at 60 to 80 L/tree once in four days with highest dose of fertilizers increased yield significantly by 76.84 to 83.70% respectively, over trees receiving no irrigation and fertilizers (Yadukumar, 2001).

Total profit for the first eight years after planting indicated that irrigation increased profit by 22.71 to 51.91% over trees receiving no irrigation. The overall increase in profit in trees receiving 80 litre water/tree once in four days was highest of 51.91% over unirrigated tree. Highest profit was recorded in trees receiving highest fertilizer dose (750 g N, 187.5 g each of P_2O_5 and K_2O/tree/year) indicating 48.03% increase over control (No fertilizer application). Without irrigation and fertilizer, the net profit for the first eight years was only ₹ 42,192/ha. However, medium dose of fertilizers (500 g N, 125 g each of P_2O_5 and K_2O/tree/year), under unirrigated conditions the profit was ₹ 60,097/- per ha which is 42.43% higher than control plot. The highest level of irrigation and fertilizer resulted in an increase in profit of 135% over the control plot (Yadukumar, 2001).

Trees receiving higher levels of irrigation (40 to 80 litre/tree) produced nuts having significantly higher shelling per cent (31.68 to 32.28 with increase by

1.19 to 2.69% over control) than trees receiving no irrigation and lower irrigation (29.59 and 30.78%). Kernel weight of irrigated tree significantly increased over the kernel weight of nuts of unirrigated trees. Kernel weight of the nuts of irrigated tree was 1.69 to 1.82 g whereas, it was only 1.47 g in the case of kernel of nut of unirrigated trees. Shelling per cent has increased significantly as a result of increased kernel weight which indicated that kernel filling was better in nuts of trees receiving irrigation. Increase in shelling per cent due to irrigation and fertilizer application will contribute to higher kernel recovery. Increase in nut weight and kernel weight contributes in realising higher yields (Yadukumar, 2001).

Drainage

Cashew plants do not withstand water stagnation and exhibit poor growth in poorly drained soils, with the resultant low productivity. To get optimum yield, a proper drainage in cashew orchards as well as in homestead gardens is essential. Drainage, the removal of excess water from the active root zone during rainy season facilitates favourable soil moisture conditions for the growth of plants. High water table and soil moisture content during critical periods of reproduction phase may also affect flowering of trees and subsequent productivity. The water table in the orchard should be below the active root zone i.e. one to one and a half meters below the ground level. With shallow water tables, a salinity problem may also exist due to upward movement of water and salts from the ground water as the water evaporates from the soil or is used by the crop. Such a salinity problem is related to high water tables and the lack of drainage; it is only indirectly related to salts in the irrigation water.

Adequate drainage includes both surface and sub-soil drainage. Surface drainage is essential to remove excess surface water quickly during and after heavy rains. This is achieved by bedding unless the natural topography has a slope of at least 0.5%. Beds may contain from 1 to 4 rows of trees. The height and slope of beds need only be enough to move surface water (0.5% or more), assuming sufficient profile drainage. Surface water can be diverted into collection ditches by means of drop pipes. Water that soaks into the soil and thereby resulting in raising the water table should be removed by subsurface drainage. This may be done through the use of subsurface drains or open ditches. Both surface and subsoil drainage are required for water management in poorly drained soils during high rainfall. Proper drainage not only improves soil aeration but also prevents salt accumulation in soils. However, lands with poor drainage and high water table can also be utilized for cashew cultivation by adopting techniques such as planting cashew on raised beds, about 1.5 - 2 m from the base level.

Conclusions

Cashew is a drought tolerant plant. Because of their deep taproot system, established cashew trees can endure the dry season without irrigation. Though not essential, irrigation could prove to be a main benefit to production, largely by preventing premature nut drop. Cashew needs irrigation from the onset of flowering to late nut set and lack of proper moisture in the soil leads to severe flower and fruit drop. Watering at an interval of 10-15 days during fruit setting and development period is advantageous to reduce fruit drop and to increase fruit retention, size and to get better nut quality. About 2 to 3 months prior to flowering, irrigation should be withheld, otherwise decrease in flowering and promotion of vegetative growth will be resulted. Studies in India have shown that nut yield can be enhanced by providing protective irrigation with 200 litre of water per tree once in 15 days from January to March during the summer season. Research results in Brazil and other countries have shown that irrigation could increase productivity by up to 300% depending on the region. Requirement of water by cashew plants differ according to climatic conditions, planting density, age of the tree, canopy area and management practices. Under normal planting density, (7m × 7m), the drip irrigation requirement is 60% Cumulative Pan Evaporation (CPE) which is equal to 38 litre water/tree/day from December to January and 58 litre water/tree/day from February to March. While in high planting density (4m × 4m), the drip irrigation requirement is 20% CPE, equivalent to 7 litre/tree/day from December to January (Daily open pan water evaporation is 5 mm) and 9 litre/tree/day from February to March (Daily open pan water evaporation is 6.5 mm). Irrigation in the absence of adequate nutrition is uneconomical to cashew. The application of fertilizers through the irrigation water has the advantages of increasing the efficiency of the fertilizers and reducing the cost of labour and machinery for its application. Fertigation allows the application of nutrients with greater frequency, without increasing the cost of the application, minimizing losses by volatilization and leaching and optimizing nutrient absorption by the roots. Experimental results showed that, if fertigation is followed there will be saving of 50% fertilizer. In addition to these, the most valuable resource ‘water’ is also saved up to 40-60% when the fertilizer is applied through drip irrigation systems over the conventional method.

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11

Insect-Pest Management

INSECTS are extremely diverse and important in ecosystems (Finnamore, 1996). In India, approximately 23.3% of the crop yield is lost every year due to the ravages of insect pests (Dhaliwal *et al.*, 2007). Cashew plantations grown organically resemble a 'single species forest' afford a relatively stable microclimate and food resources for various insect communities. All stages and portions of the plants are susceptible to attack and damage may appear either at the seed bed, nursery, plantation, or in the warehouse. Certain pests affect the cashew plant only temporarily, while a few live for several generations on the plant. In some instances, the attack may cause even the death of the plant, but in most cases the pests only weaken the plant thereby reducing yield. Globally more than 180 species of arthropods are associated as pests with cashew (Sundararaju, 1993). All parts of the plant *viz.* leaf, stem, bark, root, flower, apple and nut are fed upon by at least one pest species, resulting in 11 – 55% loss in yield if left unchecked. Annually 50 per cent of crop loss was reported due to pests and diseases in cashew (Hari Babu *et al.*, 1983).

History of cashew entomology

The most important records of observations on the insects affecting cashew are those of Ayyar (1932, 1940, 1941 and 1942). Insects like tea mosquito bug, *Helopeltis antonii* (Sign.), cerambycid borer, *Plocaederus ferrugineus* (L.), red banded thrips, *Selenothrips rubrocinctus* Giard, flower thrips, *Rhynchothrips raoensis* (G.), leaf caterpillar, *Cricula trifenestrata* (W.), leaf miner, *Acrocercops syngramma* (M.), leaf rolling weevil *Apion amplum* (F.), and scales *viz. Ceroplastes floridensis* Comst and *Lecanium latioperculum* G. have been reported by him.

Davis (1949) reported *Catacanthus* sp. in the west coast particularly of the erstwhile Travancore state. Abraham (1958) described as many as 40 insect pests, including a few stored product pests of cashew from erstwhile Madras state. Similarly, a few insect pests were mentioned subsequently by Madhava Rao (1955), Basu Choudhauri (1962), Khan (1963). Basheer and Jayaraj (1964) also listed 43 insect and non-insect pests of cashew and processed kernels under storage. First report of mites as pests of cashew was by Rodrigues (1967) from Mozambique. Beccari and Gerini (1968) reported more than 50 species of pests and considered ten of them as major pests. The pests of cashew in Tanzania was extensively recorded by Northwood and Kayumbo (1970) that include *H. schoutedeni* Reut, *H. anacardii* (Miller), *Pseudotheraptus wayi* (Brown), *Macocrynus loripes* and *Nudaurelia belina*. Subsequently, many insect pests were reported as pests of cashew by Nair and Remamony (1964), Remamony (1965), Basu Choudhuri and Misra (1973), Misra and Basu Choudhuri (1974), Sreeramulu *et al.* (1974), Pillai *et al.*, (1976), Ohler (1979). During 1979, a total of 194 species of insects and mites have been listed as pests of cashew occurring in different countries (Pillai, 1979).

As far as India is concerned, Pillai (1979) reported 84 species (79 insects and 5 mites species) and Rai (1984) reported an additional 26 species (17 insects and 9 vertebrates species) infesting cashew. Later significant contributions made by Jena *et al.* (1985), Ayyanna *et al.* (1985), Sundararaju (1993) included additional 70 species (55 insects, 3 mites and 12 bird species) into the list of cashew pests and hence the total species occurring on cashew in our country during 1994, both in field and storage reached up to 180 that includes 151 species of insects, 8 species of mites and 21 species of vertebrates. World wide lists of pests of cashew have been published for few countries, which include check-list of cashew pests and details of life histories and management of cashew pests. The literature survey for the cashew pests reported so far in the world covers 311 species of insects pests, 18 species of mites, two species of gastropods, 30 species of nematodes, 15 birds species, 12 species of other vertebrate animals and 26 species on stored cashew (Table 11.1). This is a clear indication that number of species infesting cashew plantations has increased over time.

Pest scenario in cashew

Every part of cashew tree is infested by one or the other pest. However, depending on the climate, location and age of the plantation, each geographic region has its own distinctive pest complex. Documentation of pest diversity across different cashew growing regions is essential to devise effective management strategies. Each geographical region has its own distinctive pest fauna, which is composed mainly of indigenous species. The perennial nature of cashew under

Table.11.1. Pest diversity in cashew in terms of number of species

Insect pests		Non-Insect pests	
Insect orders	No. of species reported	Class	No. of species reported
Field condition			
Hemiptera	90	Nematoda	30
Coleoptera	84	Acari	18
Lepidoptera	84	Aves	15
Orthoptera	17	Other vertebrata	12
Thysanoptera	17	Gastropoda	02
Isoptera	10		
Hymenoptera	05		
Diptera	04		
Sub- total	311	Sub- total	77
Stored product pest			
Coleoptera	20	Vertebrata- Rodents	01
Lepidoptera	05		
Sub- total	25	Sub- total	01
Total	414		

monoculture harbours several pests throughout the year with seasonal variations in population density. The production of desirable quantity of quality cashew nuts is often hampered by insect pests belonging to various insect orders (Table 11.1).

Of 336 species of insect pests recorded through out the world, 311 species occur under field conditions and 25 species occur under storage conditions. Among the field pests reported, 191 are prevalent in India, while 120 are noticed in other cashew growing countries. Among the insect pests, only a very few occur commonly both in India and other cashew growing countries. Out of 18 mites, only five are reported from India. Similarly, out of 30 nematodes reported so far in cashew, 15 are present in India. The species of major insect orders that attack cashew are Hemiptera, Coleoptera and Lepidoptera comprising 90, 84 and 84 insect species, respectively followed by Thysanoptera and Orthoptera each with 17 species. Among all the insect pests, tea mosquito bug (TMB) and cashew stem and root borer (CSRB) are the two major insect pests in almost all the cashew growing regions of the world.

Global pest scenario: Globally, more than two hundred arthropod species are associated with cashew; of which a small number of key pests are common throughout the world *viz*., tea mosquito bug (*Helopeltis* spp.), cashew stem and root borer (*Plocaederus* spp.), leaf miner (*Acrocercops* sp.) and thrips (*Selenothrips rubrocinctus* Giard, 1901). Damage by different insect species, at different intensities, is generally widespread throughout all cashew growing countries. Many insect pests have the ability to move long distances and could become a pest at a new place in future. In addition, as the area of cashew expands, pest dynamics can also change.

Brazil: A total of 106 arthropod pests are associated with cashew trees involving 99 insects and seven mites (Bleicher and Melo, 1996, Mesquita *et al.,* 1998). Apart from TMB and CRSB, *Selenothrips rubrocinctus* is also an abundant and serious pest (Cavalcante *et al*., 1975). Several mites and nematodes are also reported damaging cashew (Ohler, 1979). *Thagona postropaea* Dyar, *Stenoma cathosiota* Meyrick and *Anacampsis* cf. *phytomiella* Busck are also found important. Three prime weevil borers *viz. Marshallius multisignatus* (Boheman) in Amazonas, Brazil and in the French Guyana; *M. anacardi* Lima in Rio de Janeiro, *M. bondari* Rosado-Neto in Bahia are responsible for death of a high number of trees especially dwarf types (Bleicher *et al*., 2010).

African countries: The main insect pests of cashew in East Africa are *Helopeltis anacardii, H. schoutedenii* and *Pseudotheraptus wayi* Brown (Hemiptera: Coreidae) and damage varies from year to year and place to place (Boma *et al*., 1998; Clive and Caligari, 1999). *Helopeltis* sp. and coreid bug, *Pseudotheraptus wayii* (coconut bug) are very serious in Kenya (Agboton *et al*., 2013). In Ghana, among 170 insect species recorded, devastating pests are *H. schoutedeni*, and coreid bug, *Pseudotheraptus devastans* (Dist.). Other important pests include, *Anoplolepis curvipes* F., *Homoecerus pallens* F., *Clavigralla shadabi* Dolling, *Analeptes trifasciata* F. and *Diplognatha gagates* (Forst.) and *Pachnoda cordata* Drury (Dwomoh *et al*., 2008). *Helopeltis* spp. is prevalent throughout Guinea, Guinea Bissau and Cote d'Ivoire causing significant losses especially in Guinea

(Clive and Caligari, 1999). *Anoplolepis curvipes* damage is widespread in West Africa and is particularly serious in Cote d'Ivoire and Ghana. *Pachnoda* sp. is present in Guinea. Similarly, the damage by *S. rubrocinctus* is high in Guinea Bissau and by *A. terebrans* and *S. rubrocinctus* in Cote d'Ivoire (Coulibaly, 1979). Damage of *A. trifasciata* is mainly seen in Nigeria, but it has been reported as a problem throughout East Africa. Other minor pests are aphids, leaf miners, leaf rollers, termites in Guinea Bissau and mealy bugs in Cote d'Ivoire.

In Nigeria, cashew production is impaired mostly by problems associated with its pest complex. A total of 141 species have been reported on cashew (Eguagie, 1972). Among the pests, TMB, CSRB, *S. rubrocinctus, Analeptes trifasciata* F. and P. *cordata* are the major pests (Asogwa *et al.*, 2008a). The TMB, *H. anacardii* and *H. schoutedeni* are the most important pests of cashew and they remain as the major constraint in Tanzania (Agboton *et al.*, 2013) while *Acrocercops syngramma, Hilda patruelis* Stal. and *Aphis craccivora* are minor pests (Bohlen, 1973). In West Africa, *P. wayi*, *Mecocorynus loripes* Chevrolet, *S. rubrocinctus*, *Pseudococcus longispinus*, and stem girdler, *Paranaleptes reticulata* Thomson are pests (Acland, 1980; AIC, 2002). In Zambia, *Salagena* sp. was reported for the first time as a pest of cashew (Latis, 1990).

China: The main pests are CSRB, TMB (*Helopeltis* sp.) and apple and nut borer (*Nephopteryx* sp.). Recently, cashew spotted midge (*Hyalospila leuconeurella*) is found to be a leading pest attacking mostly cashew apples and also trunk, branches, leaves, shoots and flowers (Xianli and Van der Geest, 1990).

Vietnam: The shoot borer, *Alcides* sp. is found to be very severe followed by TMB (*H. antonii*) and leaf miner (*Acrocercops* sp.). Other pests reported are stem borer (*P. ferrigineus* and *P. obesus*), mealy bugs, and coccids but at moderate levels (Hien and Binh, 1997).

Indonesia: In Indonesia, *Cricula* sp. and *Helopeltis* sp. are common (Supriadi, 1996). While in Philippines, common pests are termites, leaf miner, twig and root borers and tea mosquito bug (Magboo, 2013).

Thailand: Leaf miner, *A. syngramma* is found serious in Thailand (Kuroko and Lewvanich, 1983).

Srilanka: TMB (*H. antonii*) and CSRB (*P. ferrugineus*) are the major pests of cashew (Jeevaratnam and Rajapakse, 1981; Rajapakse and Jeevaratnam, 1982) and TMB alone causes about 30% yield loss (Ranaweera, 2000). Other pests that are of minor importance are leaf miner (*A. syngramma*), leaf and blossom webber (*Macalla moncusalis* Walker) (Ratnasekera and Rajapakse, 1999).

Australia: Scirtothrips dorsalis (Peng *et al.*, 2004), TMB (*H. pernicialis*) and Fruit spotting bug (*Amblypelta lutescens*) (Peng *et al.*, 2005, Stonedahl *et al.*, 1995) are the principal insect pests (Peng *et al.*, 1995).

Indian scenario

In India alone, more than 190 pests are reported on cashew in different cashew growing states including Andaman and Nicobar. Among them, CRSB and TMB are serious in most of the cashew growing regions. Some pests are region and season specific causing considerable damage. The status of pests in different cashew growing regions of India is presented in Table 11.2. Secondary pests

Table 11.2 Status of cashew pests in different cashew growing states and Union territories of India.

State	Primary	Secondary		Reference
		Pests	Minor	
Maharashtra	TMB, CSRB, flower thrips	ANB, mealy bug, STC, LBW, leaf thrips, leaf miner, white grubs	Termites, bark eating caterpillars, leaf webbers, eaf eating caterpillars	Godse, 2002; Parab, 2010
Andhra Pradesh	CSRB, thrips (*R. cruentatus*), LBW, termites in red soil area	TMB, STC, ANB, leaf weevil (*M. discolour*), root grubs	*Amblyrhinus poricollis*, leaf eating caterpillars, leaf beetles, mites	Ayyanna *et al.*, 1985; Punnaiah *et al.*, 1989; Punnaiah and Devaprasad, 1996.
Karnataka	TMB, CSRB	leaf miner, ANB, LBW, STC, thrips (*S. dorsalis*)	Leaf and bark eating caterpillars, leaf folders, leaf beetles and weevils, aphids, thrips	Krishnamurthy *et al.*, 1985; Kuberappa *et al.*, 1987; Thirumala raju *et al.*, 1991; Sundararaju, 1993
Tamil Nadu	CSRB, TMB, LBW	Leaf folders, aphids and thrips (*S. dorsalis*)	Hairy caterpillars, leaf weevils	Senguttuvan *et al.*, 1994; Ambethgar and Bhat, 2008, Panda, 2013
Chhattisgarh	TMB, CSRB, termite (*M. pakistanicus*)	Leaf miner, ANB, LBW	Hairy caterpillars, loopers, leaf beetles	Bhatnagar and Sharma, 2004
West Bengal	CSRB, TMB	leaf miner, LBW, bark eating caterpillar	ANB, root grub (*Holotrichia serrata*)	Chatterjee, 1989; Chatterjee and Ghosh, 1995
Goa	TMB, CSRB, leaf miner, LBW, STC, ANB	Thrips (*S. dorsalis*), mealy bug (*Ferrisia virgata*), TMB (*P. maesarum*)	Leaf feeding bugs *viz., Dalpoda* sp., *Erthesina fullo, C. incarnates, Plautia crossata* (Dallas), *Caenobius* sp.	Raju *et al.*, 1983; Sundararaju, 1984
Odisha	STC, flower thrips, CSRB	LBW, TMB, *Microserica quadrinotata*	ANB, leaf beetles, mites	Jena *et al.*, 1985; Jena *et al.*, 1987; Jena, 1990; Mohapatra *et al.*, 2000
Kerala	TMB, CSRB	Leaf miner, ANB	*Anigraea albomaculata, Cricula trifenestrata, Belinota* sp., termites	Misra and Basu Choudhuri, 1974; Verma, 1987; Pathummal beevi *et al.*, 1993
Andaman and Nicobar	TMB (*H. romundei*), CSRB	leaf miner, LBW, *Aulonogria* sp., *Citripestis eutraphera*, *Drymophoetus multicostatus*, *Egropa* sp., *Hyperaxis quadraticollis*, *Neculla* sp.	Many including leaf beetles	Jacob *et al.*, 2004

TMB, Tea mosquito bug; CSRB, Cashew stem and root borer; STC, Shoot tip caterpillar; LBW, Leaf and blossom webber; ANB, Apple and nut borer.

generally occur at sub economic levels, but can become serious due to various factors, one among is indiscriminate use of insecticides against key pests.

A. Major pests

Tea mosquito bug (Helopeltis spp.*)*

Tea mosquito bug (TMB) is considered as the most important pest of cashew in almost all cashew growing countries of the world. Of the 41 recognized species of *Helopeltis,* 26 are restricted to Africa and 15 are distributed in Australasian region (Stonedahl, 1991; Stonedahl, *et al.,* 1995). In India, apart from *Helopeltis antonii* (Plate 11.1), other species like *H. theivora*, *H. bradyi* and *Pachypeltis measarum* Kirk. (Miridae) are also recorded as pests of cashew. Apart from cashew, large numbers of crops are attacked by *Helopeltis* spp. including tea, cocoa, guava, neem, drumstick, cotton, rose apple, mango, all spice, black pepper, ber etc (Abraham and Remamony, 1979, Pillai *et al.*, 1979, Devasahayam and Nair, 1986) and few weed species of cashew plantations (Vanitha *et al.*, 2014).

Plate 11.1 *Helopeltis antonii*

Among the TMB species, *H. antonii* is the dominant one occurring on cashew. Review papers by Devasahayam and Nair (1986), Sundararaju and Baktha-vatsalam (1994), Sundararaju (1996) and Sundararaju and Sundarababu (1999) provide detailed information on its distribution, nature and extent of damage, biology, natural enemies and host plants. Typical feeding damage by *Helopeltis* spp. appears as a discoloured necrotic lesion around the point of entry of the labial stylets into the plant tissue Plate 11.2. The lesion can be elongate or spherical, and becomes darker with age as the tissue around the stylet entry dies, in response to the enzymatic action of the salivary secretions (Stonedahl, 1991). In the salivary gland of *H. antonii*, hydrolytic enzymes (protease and lipase), oxido-reductase enzymes (catechol oxidase, catalase and peroxidase) and free amino acids were detected. These salivary enzymes cause phyto-toxaemia on host plants as well as detoxification of defensive chemicals. Free amino acids existing in salivary secretions protect the salivary enzymes against defensive chemicals of host plants (Sundararaju and Sundarababu, 1996).

The *H. antonii* is distributed in most of the cashew growing regions of Kerala, Karnataka, Goa, Maharashtra and Tamil Nadu (Pillai *et al.,* 1976); Goa (Sundararaju, 1984); Andhra Pradesh (Rao and Srinivasan, 1984); Odisha (Jena *et al.,* 1985); also in Madhya Pradesh (Sundararaju and Sundarababu, 1999). Loss in nut yield of 25 to 50% has been reported from Karnataka, Goa, Kerala and West Bengal (Abraham and Nair, 1981; Chatterjee, 1989).

Nymphs and adults of this pest suck sap from tender shoots, panicles, immature

Plate 11.2 TMB damage symptoms on shoot, panicle and developing apple

nuts and apples of cashew. Their feeding causes drying up of new flushes, shrivelling and abortion of immature nuts (Singh and Pillai, 1984). The egg and nymphal period last 6-12 and 7-14 days, respectively and a single insect can cause blightening of tender shoot or panicle within 3-4 days of feeding. The rate of development is affected by weather factors especially temperature (Sundararaju and John, 1992; Satapathy, 1993). It is a low-density pest which could cause 36-75% damage at a mean population level of 0.15-0.36 nymphs or adults per shoot/ panicle (Sundararaju and Sundarababu, 2000).

Helopeltis spp. exhibit a continuous cycle of generations throughout the year like other tropical mirids, (Stonedahl, 1991; Sundararaju, 1996). On cashew, the build up of the *H. antonii* commences during October/November synchronising with the emergence of new flushes, after the cessation of the monsoon. The population reaches a peak during January, when the trees are in full bloom. The pest prevails in the field till May and is absent during the monsoon (June-September) especially in older plantations (Pillai *et al.,* 1984; Rai, 1984; Sundararaju, 1984; and Satapathy, 1993) or exists in negligible numbers (NRCC, 1993). But in young plantations, the pest is noticed throughout the year with a higher intensity during February and March (Sathiamma, 1977). The life table studies carried out with *H. antonii* on cashew, neem and guava revealed that rapid build up of population is more likely on neem and cashew than on guava (Sundararaju, 1996; Sundararaju and Sundarababu, 1999) and on cocoa compared to henna (Srikumar and Bhat, 2013). The population growth of TMB indicated independent relationship of weather factors. Hence for undertaking insecticidal control, only farm based monitoring of TMB damage and population from first month of flushing to fruit set appears to be most appropriate (Sundararaju, 2005).

The fungi *Gloeosporium mangiferae* and *Phomopsis anacardii* have been reported to cause blossom blight in association with *H. antonii* (CCRS, 1966; Nambiar *et al.*, 1973). The feeding injury by the bug is attributed as one of the causes of infection and manifestation of die-back disease caused by *Collectotrichum gloeosporioides* and *Botryodiplodia theobromae*. The die-back disease progressing beyond the feeding region towards the lower part of shoots and panicles lead to wilting of whole leader shoot or branches.

Management: Among the released varieties, Amrutha, Damodar and Raghav are found least susceptible in Kerala while Priyanka and Anagha are highly susceptible (Beevi and Mahapatro, 2007). Cashew accessions *viz.,* VTH 153, Kunthur 24, Goa 11/6, VTH 153/1, 9/78 and 51 different cashew types in Karnataka, accession No. 665 in Kerala and BLA 39-4 in West Bengal are reported as least susceptible to *H. antonii* (Sathiamma, 1979; Ghosh and Chatterjee, 1987; NRCC, 1988; Sundararaju and John, 1993). But, none of the workers confirmed intensity of typical resistance. Though least susceptible cashew types contain higher phenols (Annapoorna and Nagaraja, 1988) that cannot be implicated towards resistance, since *H. antonii* has potential salivary detoxification mechanism (Sundararaju and Sundarababu, 1996). Besides, existence of antibiosis mechanism in cashew types is also remote, since least susceptible accessions like Kunthur 24 and Goa 11/6 had not shown any inhibitory effect on the growth of *H. antonii* (NRCC, 1994).

Under biological control, though the eggs of *Helopeltis* spp. are laid deep and concealed, they are often attacked by a range of hymenopteran parasitoids. There are five speices of egg parasitoids *viz. Telenomus cuspis* (Platygasteridae), *Erythmeles helopeltidis* (Mymaridae), *Chaetostricha* sp. (Trichogrammatidae), *Ufens* sp. (Trichogrammatidae) and *Gonatocerus* sp. (Mymaridae) parasitize the eggs of TMB, and thus take care of TMB population to certain extent in field conditions especially at low pest density (Sundararaju, 1996; Sundararaju and Sundarababu, 2000). All these species are solitary endoparasitoids, host specific and are difficult for mass culture. Among the parasitoids, *T. cuspis* is the major ones, which could cause even up to 50% egg parasitism in TMB during certain months (Sundararaju, 1996). Nymphal parasitoid of genus *Leiophron* (Hymenoptera: Braconidae) has also been reported on *H. antonii.* Besides, a parasitic mite namely, *Leptus* sp. (Erythraeidae) also kills TMB adults, but occurs at very low intensity (Srikumar and Bhat, 2014). But, mass rearing of any of these parasitoids could not be successful in laboratory and hence can not be exploited for controlling TMB at present. Besides, specific strains of the entomopathogenic fungi namely, *Beauveria bassiana* and *Metarizhium anisopliae* are also found effective against TMB.

Besides parasitoids, predators also appear to play an important role in the natural control of *Helopeltis* spp. Predators include spiders, reduviids, ants, mantids and pentatomid bugs. *Crematogaster wroughtonii* Forel (Formicidae) has been recorded as a predator on nymphs of *H. antonii* on cashew (Ambika and Abraham, 1979). A total of 35 spiders were recorded from the cashew fields of Madakkathara, Kerala. In which, nine spiders were found to be feeding on TMB adults in captivity. Most of the studied spiders preferred adults than nymphs, while *Oxyo;es sunandae* Tikader, *Telamonia*

Plate 11.3. Telamonia *dimediata* predating a

elagans Thorell and *Hyllus diacanthes* preferred nymphs (Beevi and Mahapatro, 2008). Consecutive surveys for three years conducted at DCR, Puttur revealed occurrence of 117 species of spiders belonging to 18 families in cashew. Field observations revealed *T. dimidiata* (Plate 11.3) and *Oxyopes shweta* are the major predators of *Helopeltis* spp. The spiders *viz., Argiope pulchella, Cyclosa fissicauda, Eriovixia laglazei, Neoscona mukerjeri, Nephila pilipes, O. sunandae, Bavia kairali, Carrhotus viduus, Epocilla aurantiaca, Hyllus semicupreus, Achaearanea mundula, Camariacus formosus* and *Thomisus lobosus* were also recorded as superior predators of *Helopeltis* spp. (Bhat *et al.*, 2013).

So far, biological control programmes against *Helopeltis* spp. have not been attempted under field conditions. Almost it appears that natural enemies, while playing an important role in controlling TMB, cannot maintain populations of *Helopeltis* spp. below economic thresholds. Integrated control programmes with reduced pesticide use and the monitoring of natural enemies have been suggested as reasonable alternatives to blanket spraying (CIBC, 1983). This would allow population of natural enemies to increase and provide more suitable environments for investigations of improved biological control (Stonedahl, 1991).

Chemical control is the short term strategy for increasing cashew yield by effective control of *H. antonii* (Nambiar *et al.*, 1973). Proper surveillance for initial pest damage symptoms during flusing, flowering and fruiting period of cashew are essential to decide on the spraying time for effective pest management. Since, Economic Treshold Level (ETL) is not arrived for TMB, first round of insecticidal spray need to be given whenever the incidence occurs at 5 - 10% damage. Second spray may be repeated within 3 - 4 weeks and third spray can be given as and when required. If inflorescence damage is severe (beyond 50%) further sprays can not help. The insecticides *viz.* monocrotophos (0.05%), carbaryl (0.1-0.15%), methyl parathion (0.5%), quinalphos (0.05%), dimethoate (0.05%), fenthion (0.05%), phosalone (0.07%), phosphomidan (0.03%) were also reported to be effective against *H. antonii* (Sundararaju, 1984b; Chatterjee, 1989; Godse *et al.,* 1993). However, carbaryl and monocrotophos had maximum residual action for seven days and found to be superior to other insecticides (Sundararaju *et al.,* 1993). In Panruti area of Tamil Nadu, indiscriminate insecticidal sprays of various formulations against *H. antonii* led to resurgence of other sucking pests like mealy bugs (*Ferrisia virgata* Cock.) (Sundararaju, 1996).

All the insecticides tested shown no ovicidal action but l-cyhalothrin followed by carbaryl and monocrotophos exhibited highest residual action for seven days against late instar nymphs and adults of TMB (Sundararaju, 2004; Raviprasad *et al.*, 2005; Bhat and Raviprasad, 2007). The sequential sprays of monocrotophos, l-cyhalothrin and carbaryl registered the least per cent TMB damage and higher nut yield (Naik and Chakravarthy, 2013). Although, cashew is an insect pollinated crop, spraying of these insecticides during flowering season did not influence the fruit set (Pillai *et al.*, 1984; Rai, 1984, Sundararaju *et al.*, 1993). Chemicals that can be sprayed in rotation against TMB are: lambda cyhalothrin (0.6 ml/lit), profenophos (1.5 ml/lit), acetamiprid (0.5 g/lit), triazophos (1.5 ml/lit), imidacloprid (0.6 ml/lit) and carbaryl (1g/lit).

There is a scope of development of pheromones for monitoring as well as managing TMB. Studies taken up at ICAR-Directorate of Cashew Research (DCR), Puttur revealed presence of pheromonal activity in *H. antonii*, where lot of males got attracted towards single virgin female. The female sex pheromone blend may be a useful tool for monitoring and managing TMB in future.

Cashew stem and root borer

Cashew stem and root borer, *Plocaederus ferrugineus* L. (Coleoptera: Cerembycidae) is another important species that infests cashew in most parts of cashew growing areas in India (Abraham, 1958; Rai, 1984) and a few other cashew growing countries (Asogwa *et al.*, 2008b). Two other species, *viz.*, *P. obesus* G. and *Batocera rufomaculata* De G. are also reported in cashew. *Plocaederus* spp. is serious both in west and east coast tracks of India. Infestation of pest varies from 1.6 to 10.0% in Kerala, Karnataka, Tamil Nadu, Chhattisgarh, Andhra Pradesh, Odisha and Maharashtra (Pillai *et al.*, 1976, Misra and Basu Choudhuri, 1985, Jena *et al.*, 1985, Raviprasad and Bhat, 2010, Ayyanna and Rama devi, 1986, Haldankar *et al.*, 2004; Mohapatra, 2004).

Plate 11.4. Initial damage symptom of Cashew stem and root borer

Plate 11.5 Cashew stem and root borer grubs

Adults of *Plocaederus ferrugineus* are dark reddish brown, medium-sized beetles (25 to 40 mm in length) and are sluggish on the day of emergence, mating starts on the second day, and repeated matings occur during the life time of the adults. Adults of *B. rufomaculata* are greyish, measuring 50 cm in length and has yellowish or orange spots on the forewings. The grubs of this species are apodus (legless) and pupate without forming any calcareous cocoon. The grub period lasts for about 6 months and the adults of *Plocaederus obesus* are chestnut coloured, longicorn beetles, measuring about 40 cm in length and with slight pubescence. Eggs are usually deposited in the crevices of the bark of main trunk up to one metre height from ground level and also on the exposed roots and in soil close to collar region of the tree. Eggs are pale white, ovoid and smooth measuring about 4.5 mm × 2.0 mm. The nascent first instar grubs feed on the tissue near the site of oviposition and extrusion of fine dusty frass is noticed within few days of hatching (Plate 11.4). The larval period continues for 6 to 7 months. The fully grown grub measuring about 100 mm in length enters into heart wood for pupation and makes a circular exit hole of 1.5 cm width for adult emergence. The pupation takes place inside a calcareous cocoon. The adults form within 40 to 60 days but lie quiescent within the cocoon and emerge out after 45-60 days. Under laboratory conditions, pupation occasionally occurs without calcareous cocoon (Pillai, *et al.*, 1976; Raviprasad and Bhat, 1998, Mohapatra and Jena, 2007).

Infestation of CSRB (Plate 11.5) can be identified by the presence of small holes in the collar region of the trees, gummosis and extrusion of frass through the holes, yellowing and shedding of leaves and drying of twigs. The tree is killed within a period of 1-3 years depending upon the pest load and even two-year old plants can be killed by a single grub during its course of development and as high as 90 grubs of different stages of development are seen damaging 15-20 years old trees (Sundararaju *et al.,* 2002). Whenever, more than 50 per cent of the bark circumference is damaged at the collar region, the tree will succumb to death with yellowing of leaves. Sometimes, the unexposed stout lateral and taproots are extensively damaged without any external symptoms and such trees may look very healthy or with sickly appearance and suddenly die without any yellowing of leaves.

Plocaederus ferrugineus also occur on *Bombax malabaricum, Boswelia serrata, Buchanania latifolia, Diospyros melanoxylon, Hardwickia binate*, *Lannea grandis*, *Holigama* spp. and *Buchanania lanzan* S. (Beeson, 1941) Likewise, *P. obesus* is recorded also on *Shorea robusta* (Lefroy, 1909), and *B. rufomaculata* on mango, silk cotton, jack, rubber, fig, guava, pomegranate, apple and walnut (Ayyar, 1963; Butani, 1979). Even though, the occurrence of the pest is noticed throughout the year in both East and West Coast regions, relatively large population of grubs and severe infestation could be seen in the coastal Karnataka and Andhra Pradesh during March-May and May-July, respectively (Abraham, 1958; Ramadevi and Murthy, 1983; Jena *et al.*, 1985).

Management: Controlling this pest is difficult as the borer remains in a cryptic condition in the interface of bark and hard wood and normally escapes from natural enemies. Secondly, application of pesticides is not very effective as the grubs remain inside a thick protective layer. Its infestation is severe in unattended plantation and infested trees act as source of inoculum (Jena, 1990). For this reason, it is important to intercept early and take up prophylactic management measures to reduce the intensity of pest infestation. Phytosanitation of the cashew plantation helps to reduce the pest population in a given location and leads to lesser fresh incidence of the pest in the subsequent years. Deep planting of cashew grafts/seedlings can be done to prevent exposure of roots for egg laying by CSRB adults. The newly planted grafts should be trained to have branching at a height of 0.75-1.0 m from ground level for facilitating better inspection and adopting pest management techniques effectively. Once the larvae enter into heartwood to turn into pupa, it is difficult to locate and kill them. Hence, a gear wire/any bending metal wire may be inserted through the hole to reach the grub or pupa so as to kill it.

As biological control strategy, the eggs of cashew stem and root borer are recorded to be parasitized by *Avetianella batocerae* Ferriere (Encyrtidae: Hymenoptera) which, however is not commonly encountered. Under field conditions, occasionally later stages of CSRB grubs are infested by an entomopathogenic fungus namely *Metarhizium anisopliae* in few trees (Bhat and Raviprasad, 1996), however, the intensity of natural infection is very less. Mycopathogen like *Beauveria bassiana* also causes mycosis in grubs of CSRB. Mixing of spawn of these mycopathogens with organic matter like FYM, neem cake and cashew apple can enhance the spore load under the field condition. The spores could survive for three months under field condition (Bhat and Raviprasad, 1996; Ambethgar, 1999). Pouring spore suspension of *M. anisopliae* and *B. bassiana* through borer holes was found effective compared to swabbing and soil application of spores (Saminathan *et al.,* 2004). Soil application of 250 g of *M. anisopliae* and *B. bassiana* spawn in combination with 500 g of neem cake in October and November, minimized the borer infestation to 7.40% and 11.10%, respectively as against 20.35% infestation in the untreated control (Sahu and Sharma, 2008). However, swabbing conidial suspension of *M. anisopliae* as prophylactic measure was not found effective (Mohapatra and Jena 2008). Phytosanitation by mechanical removal of grubs followed by pouring fungal inoculum on the infested portion helped to improve the efficiency of *M. anisopliae* and *B. bassiana* by realizing 16.0 to 25.0% recovery of the infested trees (Meshram and Soni, 2011).

In addition, the entomopathogenic nematodes belonging to *Steinernema* and *Heterorhabditis* are found to be effective in inducing mortality of grubs in lab conditions. Studies conducted at DCR, Puttur to evaluate the effectiveness of three species of entomopathogenic nematodes (EPN) *viz. Heterorhabditis indica* Poinar (Rhabditida: Heterorhabditidae), *Steinernema abbasi* Elawad (Rhabditida: Steinernematidae) and *Steinernema bicornutum* Tallosi (Rhabditida: Steinernematidae) against the grubs of *Plocaederus* spp. and *B. rufomaculata* indicated that all three nematodes induced mortality of *Plocaederus* spp. grubs in a mean duration of 14.11, 12.88 and 12.37 days, respectively. The younger grubs (<45 days) of *Plocaederus* spp. showed equal susceptibility to all the three speices of EPN. While *H. indica* was effective on *B. rufomaculata* grubs inducing mortality within a mean duration of 7.43 days. Studies on survival of the IJs in soil and persistence of virulence indicated that all the three species of EPN could survive in soil upto 150 days (Vasanthi and Raviprasad, 2012). However, it is required to further evaluate the efficiency of the EPN IJs under field conditions.

Several insecticides have been evaluated at various research centres for over two decades. It is to be noted that any insecticidal treatment without removing the pest stages will not be effective as the grubs remain inside a thick protective layer. Hence, the pest stages have to be carefully removed by chiseling of the tunnels in the infested portion especially with the fress frass and destroyed. Then, the chiseled portion should be swabbed thoroughly with chlorpyriphos (0.2% *i.e.* 10 ml/lit) and subsequently the base should also be drenched with insecticidal solution. Repetition of the treatment should be done, if fresh pest infestation symptoms occur after 30-45 days. Recently, treatment of 10 ml Chlorpyriphos +

50 ml kerosene and 10 ml of DDVP + 50 ml kerosene was effective and economical in control of CSRB followed by 5 ml Chlorpyriphos + 40 ml kerosene (Jalgaonkar, 2015). An important consideration is not to damage more than 50% of the bark circumference, as this will lead to girdling and death of the treated trees. In case, more than 50% of the bark circumference has been damaged or the leaf canopy has turned yellow, such trees need not be treated, as they do not recover. These trees have to be uprooted and the pest stages should be destroyed, and the timber can be used for other purposes including firewood.

Emission of plant volatiles due to injury alone strongly lures borer adults for reinfestation while age of the tree as well as thickness of the girth is not related to borer incidence (Chakraborthi and Chakraborthy, 2009). The volatiles emitting from the frass of the Cashew stem and root borer (CSRB) infested trees are found to attract female beetles for subsequent ovipostion in and around those infested trees. Though male as well as female sex pheromone activity exists in CSRB adults, attraction of egg laden females towards kairomone (plant volatile) is recorded as very strong. The research is underway to come out with a kairomone based trapping system for the beetles.

B. Minor pests

Foliage feeders

Shoot tip caterpillars (Anarsia epotias M. and *Hypotima haligramma M.):* Two species of lepidopteran caterpillars are known to infest cashew shoot tips during flushing period and cause considerable damage. Larvae of *A. epotias* cause damage to shoot tips of cashew trees during active growth period (Plate 11.6). The pale yellowish green young caterpillars with black head web together the tender leaves and feed within it at the early stage. Later on, they bore in to the terminal shoots and tunnel inside up to 2-3 cm. A gummy substance oozes out from the infected tips and finally the attacked shoots dry up. The egg, larval and pupal period lasts for 3-4 days, 12-16 days and 7-10 days respectively and the life cycle is completed in 25 to 29 days (Remamony, 1965).

Similarly, the tiny, yellowish to greenish-brown larvae of *H. haligramma* also damage shoot tips by folding the fresh leaves and feed within. Tender shoot tips are bored occasionally up to 25 to 35 mm, leading to drying-up of shoot tips. This pest is regularly reported from the east coast tracts (Mohapatra *et al.*, 1998) and in Odisha it is noticed during July-November (Jena *et al.*, 1985). The larvae may also damage inflorescences subsequently. The injury is characterized by exudation of gummy substances from the injury

Plate 11.6 Shoot tip damage by *Anarsia epotias*

site. Later, the terminal shoots turn black and perish, which results in production of auxiliary shoots. In west coast, extent of damage up to13.0% in newly emerging post-monsoon flushes (in October) and 10.5% in pre-monsoon flushes (in May) have been reported (Pillai *et al.*, 1976) indicating the significance of this pest. Abiotic factors do not exert a significant influence on infestation and population of this particular pest (Mohapatra *et al.*, 1998).

Leaf miner: Leaf miner [(*Acrocercops syngramma* M) Plate 11.7] is one of the serious pests of cashew during post monsoon period all over the country. Reports of its occurrence are available for Goa (Sundararaju, 1984, Sundararaju and Bakthavatsalam, 1994), Odisha (Jena and Satapathy, 1988) and also Andaman Islands (Jacob and Belvadi, 1990). The mining injury by caterpillars occurs both in the tender leaves as well as tender shoots. Young plants are observed to be more prone to attack by this pest. The caterpillars mine and feed below the epidermal layer of the tender leaves causing extensive leaf blisters which later dry up causing distortion, browning and curling of the leaves. As the attacked leaf ages, the holes develop due to drying out of the damaged portion. In general, up to eight caterpillars present on a single leaf (Rai, 1984), but a maximum of 45 larvae were recorded in a single leaf during peak infestation at Puttur, Karnataka (Vanitha *et al.*, 2015). During the developmental period they are dull white in colour and turn pinkish before pupation. The adult is a silvery grey moth, lays eggs on tender leaves. The freshly hatched larvae and younger larvae are pale whitish green in colour, while full grown caterpillars measure about 5-7 mm in length, are reddish brown and feed by scraping the mesophyll below the epidermis. After full development, the larvae fall off to the soil where they pupate and emerge after 7-9 days (Pillai *et al.*, 1976). Abraham (1959) estimated around 26 per cent leaf miner damage in severely infested cashe leaves. Veried leaf damage levels were recorded in different states viz., Kerala (70-80%), Karnataka (60%), Andhra Pradesh (6-20%), Odisha (8.4%) and West Bengal (18-20%) respectively (Basu Choudhuri, 1962; Rai, 1984; Ayyana *et al.*, 1985; Jena *et al.*, 1985; Chatterjee, 1989).

Plate 11.7. Leaf miner damage

Leaf folder and leaf rollers: The light yellowish larvae of *Caloptilia tiselaea* M. (Gracillaridae: Lepidoptera) cause considerable damage to post-monsoon tender foliage of cashew. The incidence commences during the first fortnight of November and prevails up to the end of January and peak population is seen during the second fortnight of December. Higher leaf infestation is recorded in early cashew types than the mid and late cashew types (Mohapatra, 2007).

At Andhra Pradesh, *Dudua aprobola* M. (Tortricidae: Lepidoptera) and *Caloptilia tisilea* (Plate 11.8) are observed from second fortnight of August to first fortnight of March and maximum population is seen during November. Higher population and damage are observed in the plantation of 8-11 years age (Ayyana and Ramadevi, 1987). In Kerala, pink leaf roller, *Anigraea albomaculata* (Noctuidae: Lepidoptera) occurs on cashew (Pathummal Beevi *et al.*, 1993). The larvae damage tender leaves by making spindle shaped folds. Two to four terminal leaves are folded longitudinally one above the other and fastened with silken threads to form a tight tubular roll at the growing point. Maximum infestation is noticed during October-December and zero infestation during February- May. This pest is serious on young plants that produce continuous flushing because of which delayed or adverse effect on panicle emergence occurs. The larvae of *Sylepta auranticollis* Fabricius (Pyralidae: Lepidoptera) during their early stages roll the tender leaves and scrape the green matter, later they defoliate the entire leaves. Larvae of *Macalla albifusa* Hamps. (Pyralidae: Lepidoptera) join the leaves one above the other by silken threads and feed on them. The damaged portion gradually dries up. The larvae are found inside a tunnel formed of excretory matter and silk. Larvae are very active and wriggle out when disturbed.

Plate 11.8. Leaf folding by *Caloptilia tisilea*

Hairy caterpillars: Among the vast number of hairy caterpillars which damage cashew, two species *viz.*, *Metanastria hyrtaca* Cram (Lasiocampidae: Lepidoptera) and *Lymantria ampla* WLk Plate 11.8 (Lymantridae: Lepidoptera) cause severe sporadic defoliation in cashew. *L. ampla* is the correct name, where, *L. obfuscata* was erroneously used (Misra and Basu Choudhuri, 1974). The caterpillars defoliate the cashew trees completely leaving only bare branches. *M. hyrtaca* occur sporadically and attack isolated trees. Egg, larval, pupal and adult period are 9, 33-35, 12 and 1-6 days respectively (Nair *et al.*, 1974; Arjuna Rao *et al.*, 1977). The early instars of *M. hyrtaca* are gregarious feeders on tender foliage and the full grown caterpillars feed voraciously on mature leaves as well. They congregate on the trunk during day time and are active during night only. They feed voraciously on foliage during night. During day time they congregate in large numbers on the ground under dry leaves near the base of the tree, in crevices of bark or lower parts of well shaded branches

Plate 11.9. Leaf defoliation by *Lymantria*

and are capable of complete defoliation of young trees (Nair *et al.*, 1974).

The hairy caterpillars of *Euproctis* spp. (Lepidoptera: Lymantridae) *viz.*, *E. fraterna* Moore, *E. scintillans* Walker and *E. subnotata* scrape the green tissues when young and start defoliating the leaves and inflorescence branches and also feed on the shell of the nut in the tender green stage and tender apples (Rai, 1984; Sundararaju, 1984). Eggs of *E. fraterna* and *E. scintillans* are circular, flattened and creamy-yellow in colour, laid in groups on the lower leaf surface. Full grown larvae of *E. fraterna* are stout, dark reddish-brown and about 3 cm and the body is thickly covered with whitish hairs with a pair of dark tufts on either side of the head and one on the anal segment. While full grown larvae of *E. scintillans* are stout, dark-brown with tuft of fine hairs. A pale yellow strip runs down the back and on the first abdominal segment a thick tuft of blackish hairs is seen. Larval period lasts for 30 days and pupation takes place within leaf folds. Pupal period lasts for 8-12 days. The light brown moths of *Diacrisia obliqua* Walker (Lepidoptera: Arctiidae) lay 400- 1200 spherical, pale yellow eggs in small clusters that hatch in about 8-10 days. Larva is black and yellow with long, black and white hairs, and several yellow bands are seen on the body. It pupates after 4-5 weeks inside a loose silken cocoon and adult emerge after 1-2 weeks (Rai, 1984). While, *Estigmene lactinea* Cramer (Lepidoptera: Arctiidae) appear during the time of new flush and defoliate cashew. Eggs are laid in batches on the leaves or in soil. The caterpillars are active, dirty black and the body is suffused with black and yellow hairs arising from warts set in a ring around the middle of each segment. They pupate inside a silken cocoon and are dark reddish- brown.

Loopers and semilooers: The defoliating loopers (Geometridae) like *Oenospila flavifusata* Walker, *Thallasodes quadraria*, *Hyposidra talaca* (Walker) and *Pingasa ruginaria* Guenee are very common during the new flush period from August to January causing severe defoliation (Rai, 1984). Tiny reddish eggs of *Oenospila flavifuscata* (Plate 11.10 and 11.11) are laid on margin of tender leaves and they hatch in about 5 days. Young caterpillars have reddish tinged body, when grown become green in colour. Larval period lasts for about 15 days and they pupate within leaf folds. Pupal stage lasts for 10 days. Though they are sporadic in occurrence they do cause considerable damage. The eggs of *T. quadraria* are laid on the leaves that hatch in 3-5 days. The larvae are pinkish, slender and assume a characteristic pose oblique to the stem on the twigs and are mistaken for part of a twig or leaf petiole. Pupa attaches to the leaves and the pupal period lasts 6-8 days. The larvae of another looper, *P. ruginaria* besides leaves damage inflorescences also. *H. talaca* is recorded as an emerging pest in cashew (Chutia *et al.*, 2011) having wide host range including various forest trees, crops and weeds. Prolonged drought and inconsistent rainfall influences the range expansion of this pest and lack of

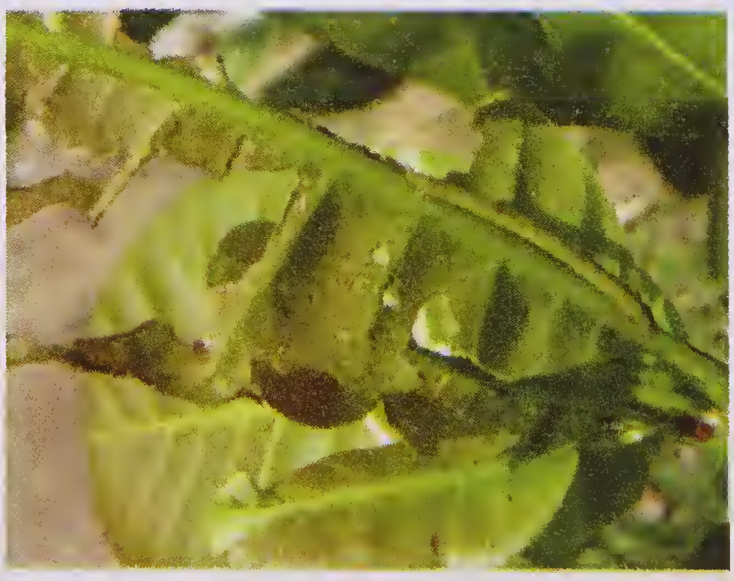

Plate 11.10 Larva of *Oenospila flavifusata* Walker on leaf

specialized natural enemies leads to build up of this pest in a short period of time (Sinu *et al.*, 2013).


Plate 11.11 Closeup of Larva of *Oenospila*

Leaf thrips: Occurrence of foliage thrips (Thysanoptera: Thripidae) *viz.*, *Selenothrips rubrocinctus* Giard, *Rhipiphorothrips cruentatus* Hood and *Retithrips syriacus* (Mayet) have been reported on cashew (Ananthakrishnan, 1984, Ayyanna *et al.*, 1985; Jena *et al.*, 1987) causing silvery leaves. The red banded thrips *S. rubrocinctus* (Plate 11.12), a tropical-subtropical species is very serious in nursery and young cashew plantations. It damages young leaves, shoots, inflorescence and flowers and is more active during summer months (Mutter and Bigger, 1962). The adults and immature stages of thrips colonise the lower surface of leaves. As a result of this rasping and sucking activity, the leaves become pale brown and slightly crinkled with roughening of the upper surface. They prefer young foliage and their feeding cause leaf distortion and leaf drop. Honeydew excretory products from red-banded thrips giving rise to black sooty mould. In severe cases, there will be shedding of leaves and stunting of tree growth (Pillai *et al.*, 1976). If infestation occurs on cashew seedlings, leaves wither and whole seedlings may dry up. The adults are dark brown and about 1-2 mm long. The nymphs are pale yellowish and have a red band around the middle of their body. Eggs are laid singly into the lower epidermis and covered with excrement. Nymphs hatch in 12 days, move freely carrying a drop of excrement at the anal end. The Nymphal, pre-pupal and pupal period lasts for 10, 1 and 2-3 days respectively (Jena, 1990).


Plate 11.12 Leaf damage by *Selenothrips*

Immature stages of *S. rubrocinctus* are abundant on the older leaves than on young leaves while adults are present both on young and old leaves (Cavalcante *et al.*, 1975). In Ivory Coast also, *S. rubrocinctus* is serious and egg, nymphal and adult period lasts for 10, 12 and 25 days respectively. The proportion of males to females is very low, hence parthenogenesis is likely to occur (Coulibaly, 1979). Nymphs and adults of *R. cruentatus* colonize the lower surface of leaves and suck the sap, as a result young infested leaves become silvery white initially, later turn into pale brown and crinkle with roughening of upper surface. In severe cases, shedding of leaves occur. Younger leaves are preferred by thrips for feeding. The nymphs are white when they hatch, but pale red markings develop soon. The female thrips are 1.2 to 1.5 mm long, blackish-brown in colour, with the legs and antennal segments yellow and the forewings pale with yellowish veins. Male thrips are similar to females in structure but their pronotum and abdomen is yellow in colour (Shanthi *et al.*, 2007).

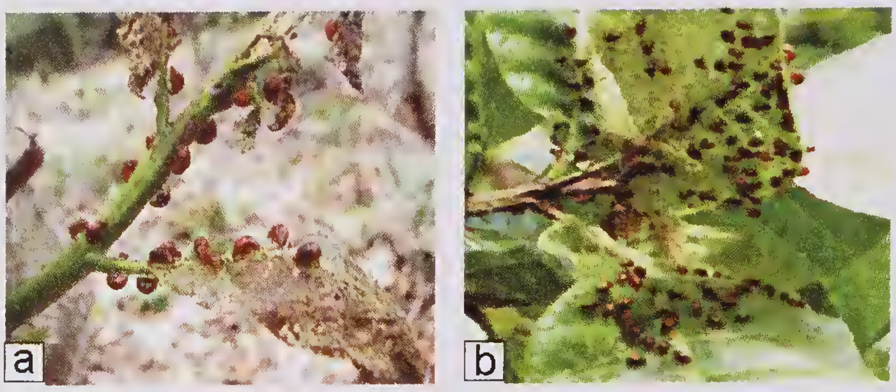

Plate 11.13 Monolepta longitarsus damage on a. tender

Leaf beetles and weevils: During rainy season (June-August), the chrysomelid leaf beetles and weevils defoliate cashew voraciously. The chrysomelid beetle, *Monolepta longitarsus* Jal., Plate 11.13, (Coleoptera: Chrysomelidae) is an important regular pest in the west coast regions during the south west monsoon. They appear abundantly especially in young trees and skeletonise the leaves which gradually dry up. Tender shoots in common and matured shoots in sporadic manner are attacked by the beetles that finally dry off (Vanitha *et al.*, 2015). When nursery seedlings are attacked the entire seedlings dry up. These beetles also damage tapioca (Rai, 1984), *Terminalia arjuna* and *T. paniculata* Roth (Sundararaju, 1984). *Deporaus marginatus* (Pascoae) (Attelabidae: Coleoptera) and *Monolepta orientalis* (Coleoptera: Chrysomelidae) also co-occur with *M. longitarsus* and cause severe defoliation during post monsoon period. An ash coloured chrysomelid *Neculla pollinaria* Baly (Coleoptera: Chrysomelidae) also attacks the post harvest flushes and also the upcoming tender shoots and buds. Mango and *Buchnania lanzon* are recorded as alternate hosts for this beetle (Sundararaju and Bakthavatsalam, 1994).

In Odisha, another beetle, *Microserica quadrinotata* Moscr (Melolonthidae: Coleoptera) occurs on cashew from June-October causing up to 30 per cent leaf damage during peak infestation on September (Jena *et al.*, 1985; 1986a). The adults skeletonise the leaf by scraping chlorophyll that turn red and finally dries up. The beetles also infest mango, neem, acacia, basal, Crotalaria and cucurbits. Similarly, an ashy weevil, *Peltotrachelus pubes* Faust. (Curculionidae: Coleoptera) feeds on the tender leaves causing up to 15 per cent leaf damage is also recorded in Odisha (Jena *et al.*, 1986b). Besides, leaf rolling weevil, *Arodepus marginatus* (Attelabidae), Curculionid weevils *viz.*, *Amblyrrhinus poricollis* Schoenherr, *Apion amplum* Faust, *Apoderus tranquebaricus* Fab., *Myllocerus discolour*, cetoniid beetle, *Oxycetonia versicolor* Fabricius and chrysomelid beetles *viz.*, *Basilepta flavicorne* Jac., *Hyperaxis albostriata* Mots and *Pagria costatipennis* Jac also defoliate cashew.

Other leaf feeders: Bombotelia jacosatrix Guenee (Noctuidae: Lepidoptera) is a leaf eating caterpillar that feed tender leaves from the margins. Early instars are gregarious and during the later stages they feed on the entire leaf, leaving behind only the midribs. Eggs are laid in rows on leaf margins of tender leaves; they hatch in 3-5 days. Larvae are greenish, striped with reddish-brown spots and larval period lasts for 11-18 days. Body segments have tubercles and have sparsely distributed pale-whitish hairs all over the body. Pupation takes place in a silken cocoon inside the leaf folds and adult emerges in 9-15 days.

Caterpillars of *Orthaga exvinacea* Hampson (Pyralidae: Lepidoptera) web together tender shoots and leaves live within the webs and feed on the leaves. Several caterpillars are found in a single webbed-up cluster of leaves. Presence of silken webs reinforced with pieces of plant parts on terminal portions and blossoms as well as dried up appearance are the symptoms of its infestation. Eggs are yellowish green that hatch in 4-5 days. Caterpillars are slender, pale-green with dark bands, completes its development with in 28-33 days. Pupation takes place inside the webs in silken cocoon. The pupa is reddish-brown and lasts for 11-14 days. The larvae of *Spodoptera litura* F., *Helicoverpa armigera* Hubner (Noctuidae: Lepidoptera) and bag worm, *Dappula tertia* Templeton (Psychidae: Lepidoptera) also defoliate cashew in certain pockets of India. Besides, the caterpillars of Tassar silk moth (*Antherea paphia* Linnaeus) and *Circula trifenestrata* Helfer (Saturniidae: Lepidoptera) are sometimes noticed on cashew that defoliates voraciously. The wild silk moth *C. trifenestrata* is a stout reddish brown caterpillar found in swarms during September-October causing severe defoliation. They feed voraciously for more than a month and pupate in golden yellow hairy and spiny silken cocoons which are found in masses inside group of leaves during November. The pupa undergoes diapause and emerges during September- October of subsequent year (Sundararaju, 1992).

Stem and bark feeders

Apart from Cashew stem and root borer, there are also other pests damaging cashew stem and bark. The caterpillars of *Inderbela tetraonis* Moore (Arbelidae: Lepidoptera) make a small residential hole on the wood normally where the branches fork and from there make superficial galleries inside which they feed on the tissues. The presence of winding galleries on the bark made of powdered bark, faecal pellets and silk webbed together indicates this pest attack. Feeding damage of cambial tissues of small branches by this larva results in drying up of those branches. The eggs are laid under loose bark that hatch in 8-10 days. Larve are pale brown with dark head move along the branches concealed under the gallery. Larval period lasts even up to 10-11 months while, pupal period lasts 15-25 days (Rai, 1984). Adults are stout, pale brown moth with wavy grey markings on the wings.

The adult beetles of *Paranaleptes reticulate* Thomson and *Stenias grisator* Fabricius (Cerambycidae: Coloeptera) girdle the cashew branches with their strong mandibles. Hence, xylem and phloem tissues are damaged; the branches above the ringed portion dry up. Adult *P. reticulata* beetle lays eggs in series of irregular incisions made in the dead wood during the dry season. Hatching grubs are yellowish, that tunnel into the dead wood of the branch and cause damage. Whereas, adults of *S. grisator* are stout greyish- brown beetles having elliptical greyish spots and an eye-shaped patch on the elytra. While, coleopteran grubs of *Xystocera globosa* Oliver (Cerambycidae), *Xylothrips flavipes* (Bostrichidae), *Belinota prasina* Thunberg and *Lampetis fastuosa* F. (Buprestidae), bore into the bark and sap wood of cashew causing damage. Besides, *Analeptes trifasciata* Fabricius (Cerambycidae), *Coptos aedificator* Fabricius (Cerambycidae), *Mecocorynus loripes* Chevrolet (Curculionidae) also cause bark and sap wood damage in cashew.

Inflorescence feeders

Leaf and blossom webber: Cashew shoots bearing fresh flushes and flowers are attacked by leaf and blossom webbing caterpillar, *Lamida* (*Macalla*) *moncusalis* Wlk. (Pyralidae: Lepidoptera) which is a major pest especially in east coast tracts of India. Symptoms of infestation are presence of webbing on terminal portions, with clumped appearance, and drying of webbed shoot/inflorescences Plate 11.14. Galleries of silken webs reinforced with plant scraps and castings, indicate the presence of caterpillars (Ayyanna *et al.*, 1985; Satapathy and Panigrahi, 1995; Sundararaju, 2007). The male moths are dark, fuscous and the females are green. Eggs are deposited ventrally on leaves and occasionally on tender shoots singly or in groups of six. The egg, larval, pre-pupal and adult stages last 4-7, 16-22, 9-15 and 3-6 days respectively (Murthy *et al.*, 1974, Rao *et al.*, 2002, Panda, 2013). *L. moncusalis* occurs sporadically and can cause damage between 25-60 per cent (Dharmaraju *et al.*, 1975). In Andhra Pradesh, maximum infestation occurs during second week of May (Subba Rao *et al.*, 2006), whereas in Karnataka, it occurs during January (Thirumalaraju *et al.*, 1991). During post monsoon period, the caterpillars feed on the terminal leaves of new shoots and blossoms after webbing them. Increase in temperature and fall in relative humidity is congenial for the pest outbreak (Ramadevi and Radhakrishnan, 1991). The tree species *viz.*, *Terminalia catappa* and *T. arjuna* are also hosts for this pest (Suresh *et al.*, 1994). Maximum temperature is positively correlated while morning relative humidity is negatively correlated with this pest population (Subba Rao *et al.*, 2006).

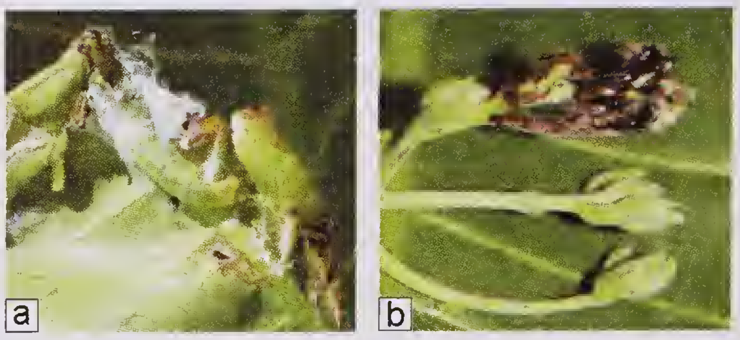

Plate 11.14. Damage by leaf and blossom webber larva

Flower thrips: Flower thrips such as *Rhynchothrips raoensis* G., (Phlaeothripidae), *Haplothrips ganglbaueri* (Schmutz) (Phlaeothripidae), *Thrips hawaiensis* (Morgan) (Thripidae), *H. ceylonicus* Schmutz (Thripidae), *Frankliniella schultzei* (Trybom) and *Scirtothrips dorsalis* H. (Thripidae) attack flowers, apples and nuts. Infestation causes shedding of flowers, immature fruit drop, formation of scabby as well as, malformed apples and nuts (Gowda *et al.*, 1979 and Rai, 1984). The occurrence, extent of damage and seasonal incidence of *R. roaensis* on cashew are studied (Abraham, 1958, Ayyanna *et al.*, 1985, Patnaik *et al.*, 1987, Thirumalaraju *et al.*, 1991), *S. dorsalis*, *H. ganglbaueri*, *T. hawaiiensis* (Ayyanna *et al.*, 1985), *H. ceylonicus* and *F. schultzei* (Patnaik *et al.*, 1987).

Scirtothrips dorsalis and *R. raoensis* are prevalent in the east coast regions of India, whereas in west coast region, *H. ceylonicus* and *F. schultzei* are prevalent (Patnaik *et al.*, 1987). Nymphs and adults of *S. dorsalis* feed on all parts of the inflorescence leading to dropping of flowers and small nuts, hence reduces the fruit set. Infestation on the developing nuts and apples results in formation of corky layers and malformation of nuts as well as apples. Up to 15-25 per cent fruit drop is noticed (Gowda *et al.*, 1979). Apart from cashew, it breeds on a number of annual crops, including *Calycopteris floribunda* Lamk. (Combretaceae) a common shrub in many cashew plantations (Sundararaju, 1984). In Karnataka, *S. dorsalis* (75.4%) is dominant than *R. raoensis* (24.6%). The initiation of population buildup of both the species occurs at the time of flower bud initiation in cashew *i.e.*, first fortnight of November reaches its peak during February and completely disappears after May. Cashew varieties that bear off-season flowers have continuous infestation of thrips. In Odisha, there is an increase in population of flower thrips from October and reaches its peak during first fortnight of December (Jena *et al.*, 1987).

Other inflorescence feeders: TMB is also a major pest that damages the inflorescence. Besides, adult chaffer beetle, *Popillia complanata* (Scarabaeidae: Coleoptera) feeds on unopened and opened flowers of cashew and can feed 10-18 flower buds or flowers in a day (Sreeramulu *et al.*, 1974). Young larvae of *Thylacoptila paurosema* Meyrick (Pyralidae: Lepidoptera) also damage flowers and buds. Other pests *viz.*, *Lypesthes* sp. (Chrysomelidae: Coleopetera), *Oxycetonia versicolor* (Cetonidae: Coleoptera), *T. odinae* (Aphididae: Hemiptera) and *F. virgata* (Pseudococcidae: Hemiptera) also damage inflorescence.

Apple and nut feeders

Apple and nut borer (ANB): The *Thylacoptila paurosema* attack tender apples and nuts. When apples are attacked they are sometimes completely hollowed and drop prematurely. Eggs are laid on the fruits and the incubation period is 3 to 5 days. The caterpillars are very active, dark pink in colour, measures 2 to 2.5 cm and the larval period lasts for 15 to 20 days. Larvae initially damage flowers by webbing the panicles and feed the unopened flower buds. Then they bore inside the tender nuts and developing apples resulting in shrivelling and premature fall. In the developed green nuts and apples, larvae tunnel near the junction of apple and nut and the boreholes are plugged with frass and excreta. Usually, these damaged apples and the nuts shrivel and fall prematurely. Damaged fruits can be easily located as they have frass hanging externally at fruit and nut joint (Plate 11.15). Variable degrees of damage by this species have been reported from different cashew-growing tracts of India and 10% damage was reported by Nair *et al.* (1979). This pest also damages stored cashew nuts (Rai, 1984).

Plate 11.15. ANB Initial damage symptom

The caterpillars of *Hyalospila leuconeurella* (Pyralidae: Lepidoptera) bore through the apple from one end to the other and remain inside the apple till the fruit drops. Attacked apples generally fall down from the trees. Nuts when attacked become severely deformed. The egg, larval and pupal period lasts for 4 to 5, 12 to 17 and 9 to 12 days respectively (Jena, 1990). The adult is dark-brown moth with a wing expanse of 16 mm. Females lay eggs in the groove near the junction of nut and apple. Freshly laid eggs are whitish in colour, turn dark red before hatching. Caterpillars are reddish with a light brown head. In a single apple, up to 6 caterpillars of different sizes are seen (Basu Choudhuri and Misra, 1973). In south India, *Anarsia epotias* Meyr. (Gelechiidae) and *Helicoverpa armigera* (Noctuidae) particularly in Andhra Pradesh are found as apple and nut feeders (Basu Choudhuri and Misra, 1973; Ramadevi and Ayyanna, 1988). The larva of *A. epotias* binds dry inflorescences to the side of the apples or nuts hanging adjacently and nibbles them continuously. The infestation is manifested by the presence of dry inflorescences touching cashew fruits. In the progressive stages of injury, the caterpillars even make galleries inside the nut. The female lays 50-60 eggs singly or in groups of 10-20. The egg period lasts for 3-4 days. Pupation takes place in larval tunnels of the attacked shoot, in crevices of the branches, twigs, at the cut end of branches or within the galleries in the dry apples. Pupal period is 7-10 days and the total life-cycle is completed within 27-29 days (Basu Choudhury and Misra, 1973).

Similarly, *Nephopteryx* sp. (Pyralidae: Lepidoptera) is common in Tamil Nadu and Andhra Pradesh (Ayyanna *et al.*, 1985, Dharmaraju *et al.*, 1975) attacking fruits at all stages of development causing up to 60 per cent of nut damage. The larvae scrape the epidermis of tender nuts and apples. The young larvae move to the point of attachment of nut and apple, scrap the epidermis and bore into apples and nuts. The entry hole is minute and plugged with the excreta. The infestation spoils the apples and nuts, larvae also feed on the kernel. The fruits shrivel and drop prematurely, while, the nuts do not develop and dry up. The larval period is 15-33 days. Full grown larvae are 2-2.5 cm in length, pink having short setae. In one fruit, 3-5 larvae are found (Rai, 1984). Pupation takes place in earthen cocoon and the pupal period lasts 8-10 days (Jena, 1990). Larvae of *Orthaga exvinacea, L. moncusalis* and *Euproctis* spp. besides leaves and shoot, also damage tender nuts and apples, however, they are considered to be external feeders. If proper management of lepidopteran flower and fruit pests of cashew is taken up, more than 60 per cent yield loss can be avoided (Sundararaju, 2007).

Hemipteran pests of apple and nuts: Both nymphs and adults of TMB suck sap from tender apples and nuts causing shrivelling. Aphids (*Toxoptera odinae* van der Goot), many species of thrips and mealy bugs (*Planococcus citrii* Risso, *Planococcus lilacinus* Cockrell and *Ferrisia virgata* Cockrell) damage immature apples and nuts by sucking their sap. Occasionally, the pentatomid bug, *Catacanthus incarnatus* Drury also damages young cashew apples (Davis, 1949, Bhat and Srikumar, 2013). A coreid bug, *Cletus rubridiventris* is recorded as a minor pest feeding on immature cashew apple (Sundararaju, 1984). Feeding by the coreid bug, *Paradasynus* sp. causes shrivelling and drying of tender nuts (Nair and Remamony, 1964).

Another coreid bug, *Pseudotheraptus devastans* damages both young and mature trees by sucking sap and juice from shoots, young apples and nuts. Points of stylet insertion develop necrotic lesions that appear as black, sunken, elongated spots on the epidermal tissue. Attacked apical meristems cease to grow and damaged young fruits abort. A mealy bug, *F. virgata* (Pseudococcidae) is observed to be destructive in many of the cashew orchards in Konkan region and Goa

Plate 11.16. Damage by *F. virgata*

(Plate 11.16). Though sporadic in nature, it occasionally causes considerable damage. Mealy bug colonies develop on young vegetative shoots, leaves, panicles and tender fruits. Damaged flowers wither and dry, while the fruits shrivel, underdevelop or sometimes dry up. Due to honey dew secretion by mealy bugs, sooty mould develops on the affected areas, and heavy infestation occurs in nursery particularly bud-wood orchards thus reducing graft quality (Godse *et al.*, 2003).

Dipteran and coleopteran pests of apples and nuts: Drosophila melanogaster Meigen (Drosophilidae: Diptera) is the very serious apple feeding fly during fruiting stages followed by *Bactocera* spp. in almost all cashew growing regions. Under coleopteran apple pests, *Carpophilus* sp. is found in India, while in Brazil, *Macrodactylus pumilio* Burm. (Scarabaeidae: Coleoptera) feeds on ripe apples (Ohler, 1979). Khan and Nagaraju (2005) observed beetles of *O. versicolor* attacking cashew apple in Kolar district of Karnataka during May having preference for uniformly yellow coloured fruits. In Andhra Pradesh, blister beetle, *Myllabris pustulata* Thunberg (Meloidae: Coleoptera) causes pronounced damage on cashew apples, an average of 3 to 4 adult beetles feed gregariously on an apple at a time and about 60-70 per cent of fruits are damaged. The initial feeding starts with scraping on the apple, followed by feeding on the pulp and later completely destroying the apple, consequently, the nuts drop to the soil. Adult beetles cause wounds on apple and also at junction of nut with apple, which may predispose secondary invasions of fruit flies or infection by microbes leading to rotting of apple (Sreedevi *et al.*, 2009).

Plate 11.17. Thrips damage

Thrips: Apart from flowers, thrips such as *Rhynchothrips raoensis* and *Scirtothrips dorsalis* also scrape on immature apples and nuts (Plate 11.17), results in the malformation of nuts and immature fruit drop (Sundararaju *et al.*, 2002). The incidence of TMB, along with flower thrips and fruit borers leads to fruit drop of 1.0 to 9.0% during the mustard stage, 6.4 per cent during the pea nut stage and 11.9 per cent fruit drop during later stages (Pillai and Abraham, 1974).

Non-insect pests of cashew

Mites: About 18 species of mites (Phylum: Arthropoda, Class: Arachnida, Sub class: Acari) have been reported on cashew in many of the cashew growing countries. Leaf mites *viz.*, *Calacarus decoratus* (Eriophyidae), *Mesalox abathus* Keifer (Eriophyidae) and *Vimola globosa* (Keifer) (Eriophyidae) are serious in Brazil causing bronzing of the leaves (Fletchmann, 2001). Similarly, flower mites *viz.*, *Calacarus citrifolii* (Eriophyidae), *Tenuipalpus anacardii* De Leon (Tenuipalpidae) and *Aceria rossettonis* Keifer (Eriophyidae) are seen on the underside of sepals of cashew flowers and the infested tissues become chlorotic, necrotic and the flower buds do not open (Ohler, 1979) and the symptoms on the inflorescences resembles anthracnose disease (Fletchmann, 2001). *Brevipalpus* *californicus* (Banks) (Tenuipalpidae), *Oligonychus coffeae*, *O. mangiferus* and *Eotetranychus falcatus* Meyer and Rodrigues (Tetranychidae) are prevalent in Mozambique (Ohler, 1979). *O. coffeae* colonizes upper surface of the leaves and also the inflorescence causing silvery blotches. Whereas, adults and juveniles of *O. mangiferus* congregate along the midrib and veins of cashew leaves and suck the sap causing depressions on the leaves. Severe attack leads to browning of the leaves.

Nematodes (Phyllum: Nematoda): Nematodes are recorded as cashew pests in many of the cashew growing countries, including India. High populations of *Criconemoides* sp. (Tylenchida: Criconematidae), *Xiphinema index* Thorne *et al.* (Dorylaimida: Longidoridae) and *Scutellonema* sp. (Tylenchida: Tylenchidae) are found in the rhizosphere of unthrifty cashew trees in Brazil. Among which, *X. index* is common causing "Xiphinematose". While, *Trophurus* sp. (Tylenchida: Tylenchidae) is reported from Jamaica (Ohler, 1979). In North Central Nigeria, ten genera of plant parasitic nematodes are found, in which, *Meloidogyne* sp., (Tylenchida: Meloidogynidae), *Helicotylenchus coffeae* (Tylenchida: Hoplolaimidae) and *Radopholus* sp. (Tylenchida: Pratylenchidae) are widespread. *Xiphinema* spp., *Scutellonema* spp. and *Criconemella* spp. are important nematodes in South-east Nigeria (Agu, 2006). In Liberia, *X. ifaculum* (Lamberti *et al.*, 1992) and in Costa Rica, *R. reniformis* (Lopez and Salazar, 1987) are reported. In India, *Caloosia longicaudata* (Caloosiidae), *Hemicriconemoides mangifera* (Tylenchida: Criconematidae), *Tylenchorhynchus mashhoodi* (Tylenchida: Belonolaimidae) and *Hemicycliophora attapadii* (Tylenchida: Criconematidae) are reported in cashew (Ray and Das, 1980; Rahaman *et al.*, 1996)). During 2012, twelve more species are found in association with cashew trees in Tripura (Bhattacharya *et al.*, 2012). In Nigeria, cashew seedlings that were inoculated with root-knot nematodes exhibited significant reduction in the height (Orisajo, 2012) and even death of cashew seedlings (Okeniyi *et al.*, 2013). Hence, nematodes can also be important pests of cashew.

Birds: During fruit ripening period several birds damage cashew apples. In Tamil Nadu, 14 species of birds (Thirumurty and Balashanmugam, 1987) and in Karnataka, eight species of birds damage cashew apples (Hosetti and Venkateshwaralu, 2001). Among the birds, crows are serious since they carry apples along with nuts and hence large number of nuts is lost. Similarly, koel, tree pie and myna are also important birds damaging apples. Though parakeets cause less damage in Tamil Nadu (Thirumurty and Balashanmugam, 1987) they are serious in Andaman (Jacob, 1988). The rose-ringed parakeet is reported to cause cashew fruit damage in Central America also (Ohler, 1979). Besides apples, germinating seeds are also being taken away by some birds. Birds usually carry a large number of nuts, hence are responsible for yield loss (Hosetti and Venkateshwaralu, 2001).

Other vertebrates: Damage to cashew trees by rats, squirrels, porcupines, jackals, primates and wild boars are documented. Rodents girdle trees and uproot nursery seedlings and planted saplings. During the fruiting season they damage nuts and apples. Occasionally rats cut open the stored nuts to eat the kernels (Abraham and Nair, 1981). Bats carry the fruits along with nuts, chew the pulp and drop the nuts. Large numbers of nuts can be collected under the trees on which they roost (Hosetti and Venkateshwaralu, 2001). Squirrels also eat the fruits and are troublesome when they destroy the seedlings (Basheer and Jayaraj, 1964). The monkeys are fond of ripe cashew apples and occasionally cause considerable damage which is more in plantations due to spoiling of tender nuts while plucking fruits. Porcupines damage young cashew seedlings by burrowing around the base and may dislodge the young trees. During the fruiting season they eat the apples along with the nuts. Wild boars, in cashew stem and root borer infested cashew trees, tear open and destroy the cashew bark to eat the grubs resulting serious damage. The jackals have a peculiar habit of gathering fallen fruits at night, feed only the apples and leave the nuts in a heap. Occasional raids of elephants and bisons cause debranching and bark peeling (Hosetti and Venkateshwaralu, 2001). The total loss due to vertebrate pests in cashew at Mudigere, Chikmagalur was 17% of apples and 21% of nuts (Chakravarthy, 1993). In Guinea and Guinea Bissau, squirrels cut the stems of young cashew plants. Pangolins and Marmosets are reported as cashew pests in West Africa and Brazil respectively (Ohler, 1979). In East Africa cattle damages young cashew plants in different regions (Clive and Caligra, 1999).

Pests of storage: Processed cashew kernels during storage are damaged by some insect pests. About twenty species of beetles, five species of caterpillars and some psocids and mites are reported to be infesting cashew nut kernels in storage. Among these, *Ephestia cautella* (Walker) (Pyralidae: Lepidoptera), *Corcyra cephalonica* Stainton (Gracillaridae: Lepidoptera), *Tribolium castaneum* (Herbst) (Tenebrionidae: Coleoptera) and *Necrobia rufipes* (De Geer, 1775) (Coleoptera; Cleridae) cause direct damage to the kernels while others contaminate them with their presence and excreta (Nair *et al.*, 1985, Vijay Singh, 1988a, 1988b; Vishnu Priya, 2011).

Shift in pest status

An insect population always fluctuates according to the dynamic condition of its environment. Several abiotic factors including soil types and biotic factors like natural enemies, age of the plant, nature of vegetation and food supply are believed to be the factors responsible for the change in a population. Knowledge on the seasonal abundance and trends in the population build up of a pest of a particular region has become important. The severity of pest problems has been changing in many of the crops with the developments in production and protection technologies in the scenario of climate change. In cashew also, shift of pest status may occur. At present, tea mosquito bug is a serious constraint mainly in Kerala and Karnataka of west coast regions and in Tamil Nadu in the east coast. Still now, cashew tracts of Andhra Pradesh, West Bengal and Odisha are less affected by this pest except for a few sporadic occurrences. Recently, the hot spot areas of TMB across the cashew tracts of the whole country have been demarcated (Gupta *et al.,* 2009) taking into consideration the optimum temperature during flushing and following phenological stages. It is forewarned that the pest may spread to new areas under current scenario of climate change and states like Andhra Pradesh, West Bengal and Orissa may come under severe TMB attack in near future. Like wise, the pests that are presently considered as minor pests of cashew especially shoot tip caterpillar, leaf miner, apple and nut borer, leaf and blossom webber, thrips may also become serious in future. Hence, monitoring the occurrence, damage potential and spread of these insects is essential.

Management strategies for minor pests

(a). *Cultural control:* Proper surveillance and regular monitoring of the pest situation has become essential to rationalize their management strategies so as to avoid the need for blanket insecticidal sprays. Removal of weeds in cashew plantations is necessary, since weeds especially *Terminalia paniculata*, *Chromolaena odorata* are not only competitors of cashew but also serve as host plants for many of the cashew pests. In young cashew plants, wherever possible, removal of different stages of pests like egg laden leaves or shoots, caterpillars, pupa or cocoons, grubs from the infested plants gradually reduces the pest population. Removal and destruction of mealy bug and aphid infested plant parts helps to minimize their infestation and spread. To manage bark eating caterpillar, removal of galleries plastered on tree trunk or pouring of kerosene during early stage of infestation is suggested.

(b). *Biological control:* Under unsprayed conditions, an array of predators *viz*., spiders, ants, reduviids, coccinellids, neuropterans, hemipteran bugs and praying mantises take care of many of the cashew pests. But so far, very little progress could be made in biological control options. However, some efforts can be resorted to for conservation and augmentation of the existing natural enemies in the cashew plantations. Cashew is attracted by lots of ants throughout the year and around 49 species of ants are recorded to occur in cashew plantations (Vanitha *et al.*, 2015). Among these ants, red ants (*Oecophylla smaragdina*) are the potential biocontrol agents in cashew plantations that feed on bugs, caterpillars, hoppers, moths etc. Red ant colonized old cashew trees are generally free from pests. Research works at Australia confirms the potential of red ants in controlling cashew pests including TMB and recently it is proved at Madakkathara centre of Kerala also. At present, ant technology is under implementation in cashew plantations of Australia and Vietnam.

Apart from predators, there are natural enemies that act as parasitoids on several cashew pests. Under west coast condition (coastal Karnataka), apple and nut borer is extensively parasitized by two larval parasitoids *viz. Panerotoma* sp., (Braconidae) and *Trathala* sp. (Ichneumonidae) and maximum of 46.2% to 50% parasitism was recorded during 2003-2005. Similarly, two larval parasitoids *viz. Chelonus* sp. and *Sympiesis* sp. are recorded on leaf miners and around 35% parasitism was reported. Recently, three eulophid parasitoids *viz., Chrysocharis* sp., *Aprostocetus* sp. and *Closterocerus* sp. are recorded as larval parasitoids of leaf miner in Puttur (Vanitha, 2015). Braconids such as *Aleiodes* spp; *Apanteles oblique*, the chalcidid, *Brachymeria poithetrialis* and the tachinids *Blepharipa* sp., *Carcolia* sp., *Exorista* sp. and *Palexorista* sp. are the parasitoids recorded on the hairy caterpillar, *Lymantria ampla*. *Perilampus microgastri* Ferr (Pyralidae) is a parasitoid recorded on *Metanastria hyrtaca* Cram. On shoot tip caterpillar, two larval parasitoids, *viz*., *Pristomerus* sp. and *Sympiesis* sp., have been recorded causing parasitism up to 25%. Under east coast condition, leaf and blossom webber is parasitized by braconids (*Apanteles* spp.), elasmid (*Elasmus johnstonii* F.) and tachinid (*Blepharella lateralis*) in Andhra Pradesh and Odisha and maximum of 50% parasitism was reported, while in Kerala, *Avga choaspis* (Braconidae) occurs as parasitoid on leaf and blossom webber along with *Apanteles* sp. In Kerala, on mealy bug *F. virgata*, besides *Blepyrus insularis,* up to 35% parasitism occurs due to *Aenasius advena* (Encyrtidae) (Beevi *et al.*, 1993).

Hence, indiscriminate spraying may be avoided as above pests are parasitized by a number of parasitoids. Under situation that warrants spraying, tree to tree spraying is to be advocated, instead of whole plot spraying to avoid environment pollution. Trees harbouring ant nests especially red ants should be spared of spraying to allow them to take care of pests naturally. These ants besides controlling pests, help to improve pollination also. Avoiding spraying on the non-target areas such as trunk, tree bases etc can help to protect some natural enemies.

(c). *Botanical control:* Botanical insecticides are good biological weapons that can be best integrated with insecticides. Neem (*Azhadirachta indica*) oil @ 3-5%, Karanj (*Pongamia pinnata*) oil @ 2%, Fish Oil Rosin Soap and neem seed kernel extract @ 1% are some of the botanical preparations effective against many of the foliage pests of cashew like leaf miners and leaf feeding caterpillars. While using botanicals, emulsifiers (soap water/bar soap 0.5% @ 5g/litre or teepol @ 0.1%) should be used in the spray fluid. Pongamia and Callophyllum extract @ 2% can be effective against many cashew pests.

(d). *Chemical control:* Generally, the plant protection measures taken up against tea mosquito bug usually take care of the infestation of most of foliage pests, hence spraying for other pests is required only under severe infestation. Insecticides recommended for cashew pest management include, monocrotophos 36 SL, quinolphos 20 EC, carbaryl 50 WP, lambda-cyhalothrin 5 EC, chlorpyriphos 20 EC, triazophos 40 EC, profenophos 50 EC, phosphamidon 40 SL, phosalone 35 EC and dimethoate 30 EC. Rotation of insecticides between sprays is advised to prevent development of resistance to any particular pesticide. Avoiding spraying of carbaryl and phosphomidon at the time of flowering has to be taken care, as these are highly toxic to honey bees.

- Spraying of monocrotophos (0.5%) or fenitrothion (0.05%) or lambda-cyhalothrin (0.003%) is effective for leaf miners, leaf beetles and shoot tip caterpillars.
- Spraying of carbaryl (0.1%) or lambda-cyhalothrin (0.003%) is effective for leaf and blossom webber, loopers, hairy caterpillars.
- Spraying of monocrotophos (0.5%) or lambda-cyhalothrin (0.003%) or dimethoate or quinolphos (0.05%) or carbaryl (0.1%) is effective for thrips.
- Spraying of carbaryl (0.1%) or quinolphos (0.05%) is found effective for apple and nut borers.

Spraying should be taken up before 9 AM or after 4 PM to save cashew pollinators. When the crop is at vegetative stage, hard chemicals like monocrotophos and phosphomidon can be used. Bearing crops should be sprayed with soft chemicals like dimethoate. Generally, chemicals play a pivotal role in pest management because of the short- term strategies and ease of operation. But on contrary, chemicals are to be used as last line of defense. By integrating available methods of pest management, without harming our environment it is feasible to realize good yield and profit from our cashew plantations.

Conclusion

A thorough knowledge about the pests is one of the prerequisites in evolving suitable control measures against any pest. Though several aspects of various cashew pests have been researched, understanding of the cashew ecosystem in general is limited, and studies on the pest monitoring techniques are not well developed. In cashew, aspects like tritrophic interactions between plants, pests and their natural enemies and the associated biodiversity need to be well researched. Determining the economic threshold levels for various key pests is essential in order to adopt sound integrated pest management techniques. Development of molecular markers for identification of pest resistant in cashew varieties may form an area of future research.

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12

Disease Management

CASHEW (*Anacardium occidentale* L.), an important cash crop in Africa, Asia and Latin America, is considered to be a native of lower Amazon and North-east coast of Brazil (Mitchell and Mori, 1987). It was introduced to India by Portuguese in 16th century. In India, Maharashtra is the largest producer of raw nuts. Other cashew growing states are Kerala, Karnataka, Goa, Tamil Nadu, Andhra Pradesh, Telangana, Odisha and West Bengal. As a foreign exchange earner, the production of cashew has to be looked upon more seriously. Among the various factors, which play detrimental role in cashew production, pests and diseases are of prime importance. In Brazil and African countries, cashew diseases have gained much importance and a lot of studies have been carried out by various workers. However, diseases are not a major problem as compared to insect pests in the cashew plantations of India. Hence, cashew pathology hasn't received much attention in India, and the research works on cashew diseases are meagre and scanty.

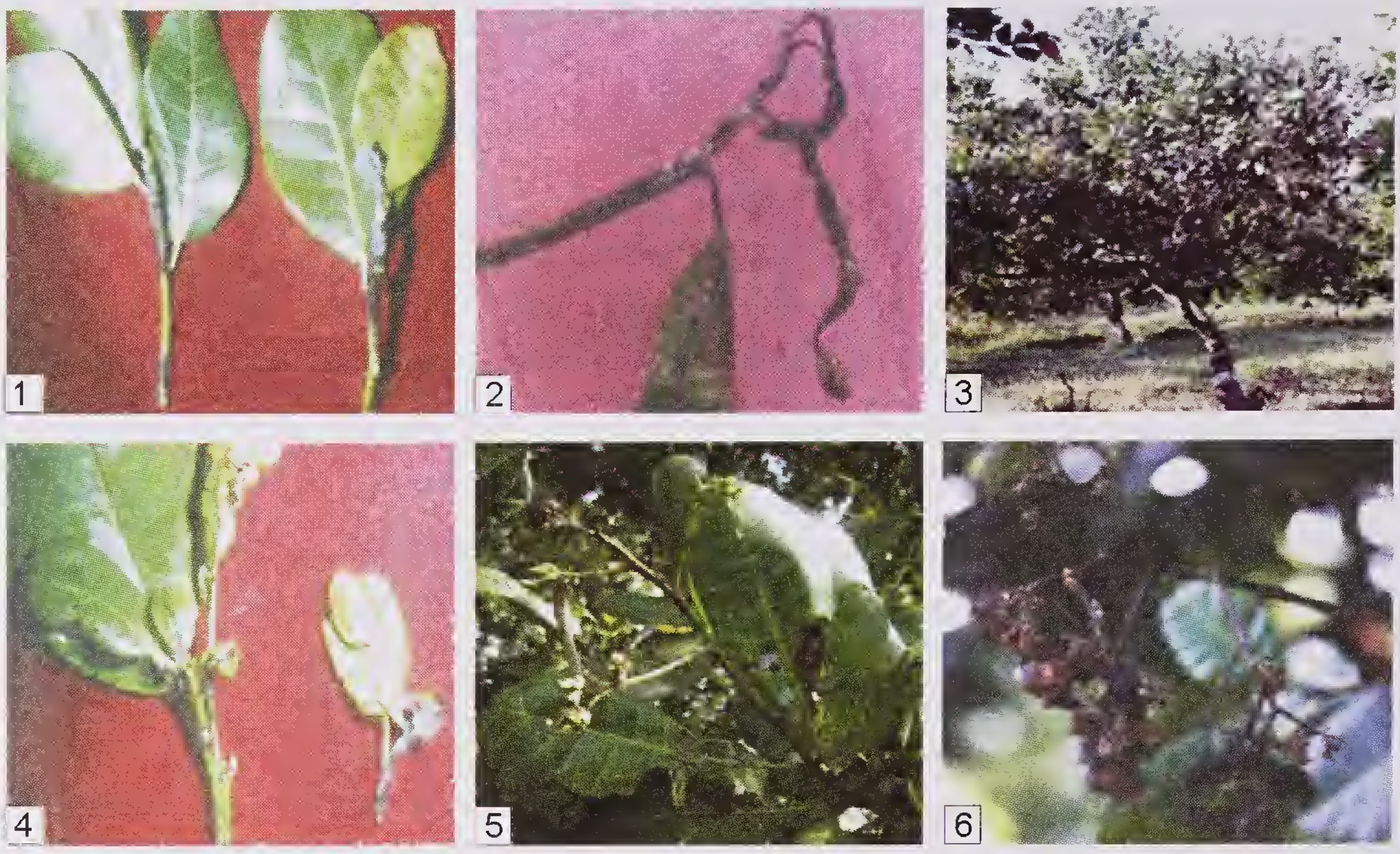
Diseases of cashew plants

Among diseases, anthracnose (die back and inflorescence blight) and powdery mildew are the most serious diseases. In addition, other diseases such as gummosis, black mould, pink disease, sooty mould, various leaf spots, red rust etc. are also reported.

Anthracnose

The most serious and dreaded disease affecting cashew plantation is anthracnose. In Brazil, this disease is known to cause severe economic loss to the crop and 40 to 45% crop losses have been reported from Nigeria. Anthracnose and inflorescence blight resulted in decline of cashew cultivation in Tanzania. There was an epidemic outbreak of this disease in Trichy (India) during 1965-66 and 30% incidence has been reported from Karnataka also. This malady has received much attention in Kerala with severe outbreak of anthracnose- tea mosquito bug complex in Kasaragod district during 1998-99, which resulted in 80-100% yield loss.

Symptom: Die back and inflorescence blight are the most common symptoms. Reddish brown lesions appear on young shoots, which enlarge, coalesce and result in dry up of shoots from tip downwards with a scorched appearance. Affected tender leaves become crinkled. Minute water soaked lesions are seen on main rachis and secondary rachis of inflorescence which later coalesce and lead to dry



Figs. 12.1–12.6: **1.** Anthracnose infected shoot; **2.** Anthracnose infected shoot; **3.** Die back due to Anthracnose; **4.** Anthracnose infected leaf; **5.** Inflorescence blight due to Anthracnose; **6.** Nuts damaged by Anthracnose

up of inflorescence. It becomes severe when rainfall coincides with flowering. Small black spots appear on apples. Later afffected nuts become mummified (Figs. 12.1, 12.2, 12.3, 12.4, 12.5 and 12.6).

Causal organism: The fungus, *Colletotrichum gloeosporioides* Penz. has been reported as the causal agent of anthracnose by various workers. The pathogenicity of *Lasiodiodiplodia theobromae* (Pat.) Griffan and Maubl, as the causal organism of twig die back and inflorescence blight has also been established in Nigeria, India and Brazil (Olunloyo and Esuruosa, 1975; CPCRI 1983; Panda *et al.*, 1986; Varma and Balasundaram, 1990; Cardoso *et al.*, 2000). In addition, co-association of inflorescence blight *Phomopsis anacardii* from India (CCRS, 1965), Malaysia (Lim and Singh, 1985), Tanzania (Intini, 1987) and Cuba (Miranda *et al.*, 2005) and with *Fusarium* sp. from India and Nigeria (CPCRI 1983; Bindu*et al.,* 1998; Adeniyi *et al.*, 2011) has been reported.

Tea mosquito bug (TMB) infestation and concomitant association of various fungi with die back and inflorescence blight are studied by various researchers. The primary cause for the entry and establishment of the pathogen is attributed to infestation of TMB (*Heliopeltis antonii*) and involvement of fungal pathogens accelerate and aggravate the anthracnose symptoms (Nambiar *et al.*, 1973; Pillai and Abraham, 1975; Intini and Sijaona, 1983; Varma and Balasundaram, 1990; Bindu *et al.*, 1998; Deepthy, 2003). The flower thrips are also observed to cause feeding injury for the entry of the fungus (Panda *et al.*, 1986). A study conducted at Kerala Agricultural University, Thrissur (Kerala) in1999 revealed that die back symptoms are developed on shoots only on inoculation of the pathogen, *C. gloeosporioides*, after 24h of TMB feeding or with pin prick injury. However, in case of inflorescence blight symptoms are produced without injury but symptom appearance is delayed. With injury the lesions appear 48h after inoculation with fungal spore suspension, whereas in case of no injury, it took seven days for symptom expression (Mathew, 2009).

Control: Anthracnose disease can be effectively controlled by spraying of fungicides. Preventive spray with 1% Bordeaux mixture was recommended for control of this disease (Singh *et al.*, 1967). Trials conducted in Brazil, revealed the effectiveness of copper oxychloride, copper hydroxide, zinc + manganese carbamate, captafol, benomyl, dithianon, anilazine, bitertanol, triademenol and triforine against disease (Menezes *et al.*, 1975; Freire and Rossetti, 1991; Nogueira *et al.*, 1993). In view of the reported involvement of both fungus and insect in causing the anthracnose disease, a combined application of fungicide and insecticide are suggested by various researchers for the control of anthracnose-TMB complex. Combined application of 0.1% ziram and 0.03% phosphomidon is reported to be effective against inflorescence blight (Nambiar *et al.*, 1973). Spray of mancozeb, dicrotophos and a foliar fertilizer mixture provided good control of the disease in Malaysia (Lim and Singh, 1985). Applications of 1% Bordeaux mixture with reldan 0.05% reduced floral shoot die back (Panda *et al.*, 1986). Spraying of benomyl (benlate 50WP) 1.5g a.i. L^{-1} and dimethoate (roger-40 EC) 1.0 g a.i. L^{-1} at pre-bloom and full bloom periods provided greater protection against inflorescence blight (Olunloyo, 1997).

In another study conducted at Kerala Agricultural University, Thrisur (Kerala) during 1999-2001 revealed that, combined spraying of copper oxychloride 50WP (2 $glitre^{-1}$) + quinalphos 25EC ($2mll^{-1}$) during flushing and mancozeb 75WP (2 gL^{-1})+ endosulfan 35 EC(1.5 mlL^{-1}) during flowering and carbaryl 50WP(2 gL^{-1}) during fruiting stages provided effective control of anthracnose-TMB complex (Kurian *et al.*, 2001). In consequences with the events arisen on using endosulfan in cashew plantations of Kasaragod district in Kerala. Further, recommendation was modified for this complex to copper oxychloride (2 $glitre^{-1}$) + monocrotophos 35EC (1.5 mll^{-1}) during flushing, mancozeb(2 gL^{-1})+ quinalphos 25EC (2 mlL^{-1}) at flowering and carbaryl (2 gL^{-1}) at fruiting stages (KAU, 2002). Subsequent to the ban of monocrotophos for the use in Kerala, a new recommendation is suggested replacing monocrotophos with lamdacyhalothrin 5EC (0.6 ml l^{-1}) at the flushing stage (KAU, 2011).

Pruning of the affected shoots and spraying with copper sulphate, benomyl or chlorothalonil + methylthiophanate provided good control of the disease in Brazil (Cardoso *et al.*, 2000). Azam-Ali and Judge, (2001) also reported that pruning of affected branches and spraying with 1% Bordeaux mixture or other copper fungicides provides control of die back. NPK fertilizer application as urea @ 60 kg/ha, single super phosphate @ 144 kg/ha and muriate of potash @ 24 kg/ha increased the yield and reduced the infection of inflorescence blight caused by *Lasiodiodiplodia theobromae* in Nigeria (Adejumo, 2010).

In-vitro screening of botanicals *viz.* garlic, *Chromolaena odorata* and *Piper guineense* against *L. theobromae* showed that, the extract of *P. guineense* significantly reduced the growth of the pathogen and compares favorably with benlate fungicide. Field spray of 5% and 10% *Ocimum gratissimum* extracts reduced the infection, but had no effect on nut yield. Conversely *P. Guineense* extract at 5% and 10% and combination of the extracts at 7.5% reduced disease incidence and gave higher yield than those treated with benlate @ 1.5 g a.i. l^{-1} (Adejumo and Otuonye, 2002).

The effect of plant defence activators such as, acibenzolar-S-methyl (ASM), 2-6-di chloro isonicotinic acid (DCINA) and salicylic acid (SA) and dibasic potassium phosphate (K_2HPO_4) against cashew anthracnose was studied by Lopez and Lucas (2002) and observed minimum disease incidence with 0.07mm of ASM and DCINA, followed by 15 mm salicylic acid with an interval of 48h between the spray and fungal inoculation.

Efficacy of different chemical salts such as, zinc sulphate, calcium sulphate, manganese sulphate and magnesium sulphate on *C. gloeosporioides* tested by Venkateswarlu and Murthy (2003) revealed maximum inhibition on the growth and sporulation of the pathogen with zinc sulphate followed by calcium sulphate. *In-vivo* experiment also, spray of 0.2% zinc sulphate recorded lowest disease intensity (23.64%) followed by calcium sulphate (27.27%).

Among various fungicides *viz.* copper oxychloride 50W.P (0.3%), carbendazim 50WP (0.1%), mancozeb 75WP(0.2%), chlorothalonil 75 WP (0.2%), propineb 70WP(0.2%) and tricure (0.5%) tested against *C. gloeosporioides*, chlorothalonil 0.2% reduced the incidence to 7.64% followed by copper oxychloride 0.3% (7.97%) and carbendazim 0.1% (8.17%) (Arasumalliah and Rangaswamy, 2008). Monthly spraying of a mixture of lindane 20EC (4 mlL^{-1}) and copper based fungicide, Champ D-P (4 gL^{-1}) for four months effectively reduced the infection of twig die back in Ibadan (Hammed and Adedeji, 2008).

In a varietal screening trial, genotypes 2sc Eruwa, 1Eruwa188/276, 1sc Iwo79/89 and Iwo 245/262 were found tolerant to inflorescence blight in Nigeria (Olunloyo, 1994). High genetic variability has been detected among a population of dwarf cashew clones, suggesting a great potential of selection for resistance. Out of 30 clones screened under natural infection, 19 showed resistance to anthracnose in Brazil (Cardoso *et al.*, 1999). Among the KAU varieties screened for TMB- *Collectotrichum* complex, Anakayam-1 showed high panicle and nut infection, whereas, Dhana showed less panicle and nut infection but high susceptibility to shoot infection (Deepthy, 2003). Of the 229 dwarf genotypes screened in Mosambique, none of the clones showed high level of resistance. However, dwarf clones 1.12PA, 12.8PA, 1.18PA and common genotypes NA-7, MB-77, 1.5R and MCH -2 are found tolerant to anthracnose (Uaciquete *et al.*, 2013).

Powdery mildew

Powdery mildew caused by *Oidium anacardii* Noack. is a serious disease in Brazil and African countries. The disease is first reported from Sao Paulo Brazil by Noack in 1898. Due to this disease, 50-70% crop loss has been reported from Tanzania (Sijaona and Shomari, 1987). In India, it is noticed in west coast regions of Maharashtra state (Phadnis and Eliah, 1968).

Symptom: The disease occurs as greyish white growth on leaves, young twigs and inflorescence. Infection will affect the fruit set resulting in small, crunched and cracked cashewnuts. Severe infection may lead to shrivelling and drying up of

Fig. 12.7. Powdery mildew

leaves and twigs. Uaciquete (2006) analysed the relationship of powdery mildew epidemic with temperature, relative humidity and dew and observed no direct correlation between the disease and the climatic factors (Fig. 12.7).

Control: Field sanitation by the removal of infected parts before flowering can delay disease development and reduce disease severity. Adoption of appropriate spacing and formation pruning during establishment followed by maintenance pruning can reduce the carryover of inoculum to next season (Maddison *et al.*, 1997).

Fungicidal trials conducted in Tanzania, revealed good control of disease and increased yield from 1.388, 3.592 and 3.643 kg nuts/tree with spraying of dinocap (Karathane) 0.25% a.i. (80g/hl) and wettable sulphur (spersul) 73% a.i. (200g/hl) respectively (Casulli, 1981). In Brazil, disease could be controlled by fortnightly dusting or spraying with sulphur products and benomyl (Cardosa *et al.*,1995; and Menezes, 1997). In Tanzania also successful control of the disease was obtained by five to six applications of sulphur dust during flowering period (Waller *et al.*, 1992). It is also observed that spraying of organic sulphur 30-50% is superior to sulphur dusting 20% (Smith *et al.*, 1997b). Spraying of inflorescence with triadimenol 250g a.i. L^{-1} reduced mildew infection to less than 9% in highly susceptible genotypes (Sijaona and Mansfield, 2001). Three sprays of triadimenol 250 EC (Bayfidan) and triademefon 25 WP (Bayleton) at 14 day interval starting at the onset of flowering showed effective control of the disease in Kenya. Systemic fungicides like triademenol, hexacanazole (50g a.i. L^{-1}) and penconazole (100g a.i. L^{-1}) have been effictive in Tanzania and Mosambique (Topper *et al.*, 1997 and Smith *et al.*, 1997).

A hyper-parasitic fungus, *Cicinnobolus cesatii* is found in association with *O.anacardii* (Casulli, 1979). In an *in vivo* screening of 72 isolates of bacteria and fungi isolated from cashew leaves and florets did not show inhibitory effect, but the commercial bioagents, *Bacillus subtilis, B. licheniformis* and *Candida saitoana* were antagonistic to the pathogen. The inhibitory effect of *B. licheniformis* was on par with triadimenol fungicide (Uaciquete, 2006).

Angular leaf spot

It is a widespread foliar disease in Brazil caused by *Septoria anacardii,* Freire. This fungus infects seedlings as well as adult plants. On seedlings, vein limited; angular, light brown lesions with dark brown margins are visible on both surfaces of the leaves. Severe infection may cause defoliation. On leaves of adult plants, lesions are black, angular with a chlorotic halo and formed pycnidia in necrotic tissue which are depressed (Freire, 1997). Spraying of protective and systemic fungicides have successfully controlled the disease and 11 dwarf clones are found resistant to this disease in Brazil (Cardoso *et al.*, 1999).

Pink disease

Pink disease caused by *Corticium salmonicolor* (*Pellicularias almonicolor*) has been noticed in India, Nigeria and Vietnam and it is prevalent during rainy season. White silky thread of mycelium develops on the branches which later turns pink (Figs. 12.8, 12.9 and 12.10). In advanced stage, the bark splits and peel off and the affected shoots dry up from the tip (Nambiar and Brahma 1979; Asogwe *et al.*, 2008). Scraping off the infected tissues or pruning the affected branches and application of Bordeaux paste may control the disease. Prophylactic spray of 1% Bordeaux mixture is recommended to control the disease (Mathew, 2005).

Fig. 12.8–12.10: **8.** Pink disease (White mycelial strand); **9.** Pink disease (Pink mycelia strand); **10.** Pink disease (Die back symptom)

Gummosis

Gummosis is one of the important diseases of cashew in semi-arid north-eastern Brazil which is caused by *Lasiodiplodia theobromae* (Pat.) Griffon and Maubi (Friere,1991b). Association of *Certatocystis* sp. (Vietnam) and *Phytophthora nicotiane* (India) with this disease are also reported. As a weak parasite, *L. theobromae* is mainly associated with wound or stress weakened plants. As an opportunistic pathogen the fungus seldom infects well managed plantations (Fig.12.11).

Symptom: Gummosis symptoms are characterised by swollen cankers in the trunk or woody branches which may crack and ooze a resin like gum. Gum exudation is the most visible symptom after yellowing and leaf drop. The infected tissues under the gum are dark and lesions may reach deep woody tissues completely blocking the sap flow (Freire *et al.*, 2002).

Fig. 12.11. Gummosis

Control: In a field trial with nine fungicides, a bactericide and a micronutrient against the gummosis caused by *P. nicotiane*, application of Bordeaux paste showed best result with 81% recovery of affected trees (Mishra *et al.*, 1993). The disease can be effectively controlled by cutting of the infected part and fungicidal pasting at the cut ends. On trunk, chisel out the infected tissues and apply protective or systemic fungicidal paste (Friere and Cardoso, 1995). The infected part of the trunk treated with copper oxychloride suspension and benomyl (1.5g L^{-1}) showed a progressive decline of the disease and benomyl reduced the disease significantly either alone or combined with copper oxychloride (Cardoso *et al.*,1998). Chakraborti (2008) reported that two-time application of Bordeaux mixture 5% or copper oxychloride @ 3g a.i. L^{-1} on tree trunk and chlorpyriphos @ 30ml a.i. L^{-1} of water in vertical tunnels in ground around termatorium and soil drenching of the insecticide, after the removal of gummosis affected area and termite galleries were effective against gummosis-termite complex in cashew plantation.

In Brazil, 28 dwarf genotypes screened against the disease, most of them were susceptible and the clones CAPC – 42 BRS – 226 showed resistance while commonly cultivating clone CP – 76 was highly susceptible to this disease (Cardoso *et al.*, 2006 and Cardoso *et al.*, 2010).

Black mould

Black mould is most important foliar disease of cashew in Brazil. The disease epidemic has caused a nut yield loss of 33% (Cardoso *et al.*, 2000). Damage is more severe on dwarf cashew clones and CP-76 is highly susceptible. The disease is caused by the obligate parasitic fungus *Pilgeriella anacardii* Arx and Miller which infects only cashew plants.

Fig. 12.12. Black mould

Symptom: Initial symptoms are chlorotic spots on the upper surface of leaves which later spread to lower surface and the pathogen forms black colonies giving velvet like appearance. Severely infected leaves become shrivelled and fall prematurely. Symptoms are seen on old mature leaves and young leaves are not susceptible to the pathogen (Fig.12.12-12.13).

Fig. 12.13. Black mould

Control: The effective control of black mould by copper oxychloride (3g l^{-1}) has been reported by Freire (1991a). Spraying of protective and curative fungicide can control this disease (Cardoso *et al.*, 1995). Two applications of plant activator, acibenzolar-S-methyl (ASM) at 30 days' interval are sufficient to reduce the disease incidence (Viana *et al.*, 2012). Few clones of the Brazilian Enterprise for Agricultural Research have shown resistance to this disease (Cardoso *et al.*, 1999). A fungus, *Acremonium,* is found parasitizing this pathogen (Freire, 1999).

Leaf spot and leaf blight

A number of leaf spot diseases have been reported from all cashew growing areas but none of these diseases are so serious (Fig. 12. 14). Different fungi are associated with leaf spot diseases in different places. They are *Colletotrichum gloeosporioides, Pestalotia* sp., *P. paeoniae, P. dichaeta, P. anacardii, Phomopsis anacardii, Phyllosticta brasiliensis, Corynespor ahansfordii, Phomatospora anacardicola, Septoria anacardii, Cryptosporiosis* sp. etc. (Abraham and Padmakumar, 1980; Naik *et al.*, 1986; Menezes, 1997; Freire *et al.*, 2002; Joshi, 2005; Mathew, 2005; Miranda *et al.*, 2005; Sijaona *et al.*, 2006). Control of leaf spot can be effectively obtained by spraying with any protective or curative fungicides.

Fig. 12.14. Pestalotia leaf spot

Brown root rot

Brown root rot caused by *Phellinus noxius* is a major constraint in cashew plantation in Bali, Indonesia. Symptoms of the disease are yellowing of leaves, defoliation and wilting, leading to the death of the plant. Brown mycelia encrustation on collar and main roots of the diseased plants. *Lannea coromandelica* tree is also found to be a collateral host of this pathogen (Supriadi *et al.*, 2004).

Bacterial leaf and fruit spot

A bacterial disease caused by *Xanthomona scampestris* pv. *mangiferaeindicae* is observed on early dwarf clone in Brazil. Initial symptoms consist of angular water soaked dark to black spots on the leaf and at the mid rib vein, surrounding the leaf veins. Eventually lesions extend from the mid-rib to the secondary veins, delineating the vein system of the leaves. In young green fruits, symptom appears as large dark oily spots surrounded by conspicuous water soaked areas. This bacterial pathogen has been reported on cashew in India under the former name of *Pseudomonas mangiferae* (Viana *et al.*, 2007).

Shoot rot and leaf fall

Shoot rot and leaf fall caused by *Phytophthora nicotianae* var. *nicotianae* is noticed in Kerala during south west monsoon period (Thankamma, 1974). The disease is characterised by black linear lesions on the stem with gum exudation. The lesions later enlarge in size resulting in the collapse of the affected shoots and shrivelling of older leaves. Lesions first appear on the mid-rib of mature leaves which later spread to the main lateral veins and leaf blade. Leaf and stem infection results in extensive defoliation.

Sudden death disease

The sudden death of cashew trees is noticed in Tanganyika in 1951. The affected trees developed rapid yellowing of leaves, which then russet as if scorched by fire. The fungus isolated from affected tree is identified as *Cytonaema* sp. which was later found similar to *Valsa eugeniae*. Management of the disease is difficult and the diseased trees should be destroyed by burning to prevent the spread (Wallace and Wallace, 1955).

Red rust

A parasitic alga, *Cephaleuros virescence*, is reported to infect cashew in Sri Lanka, Southern Tanzania, Brazil and India. The algae penetrate through epidermis into parenchymatous tissue killing larger parts of the foliage.

Cashew leaf and nut blight

A new disease of leaf and nut blight is reported in Southern Tanzania. Angular lesions, dark tan with dark reddish brown margin are formed on leaves. Lesion subsequently enlarge and coalesce causing blighting and defoliation. Older lesions become papery, silver-grey in colour and develop shot holes. At the time of fruit set infection of young nuts cause blackening and abscission. Infection of older nuts result in yield losses. The disease is caused by the fungus, *Cryptosporiopsis* sp. (Sijaona *et al.*, 2006).

Bacterial wilt

This disease was observed in Indonesia in1991. Symptoms include root rot, leaf fall and eventual death of the affected tree. The bacterium isolated from the roots of diseased tree has been identified as *Pseudomonas solanacearum* race I biovar III (Shiomi *et al.*, 1991).

Nursery diseases

Cashew seedlings are prone to many diseases seedling die back caused by *C. gloeosporioides*is more serious. Damping off, foot and root rot, seedling blight, leaf blight are the other diseases in cashew nursery. Bindu (1996) studied the role of fungus in aggravating the shoot die back when inoculated on the grafts infested by tea mosquito bug. The secondary association of the fungus is responsible for the initiation and spread of die back of young cashew grafts. Study of Deepthy (2003) on TMB- *Colletotrichum* complex revealed that, plants infected with TMB alone caused slight damage and regained the growth and recovered later. But the plants inoculated with TMB and *Colletotrichum* combination, could not regain the growth. Inoculation of fungus without injury did not cause symptoms on shoots which indicates that fungus gain entry through the wound caused by TMB feeding.

In host range studies of anthracnose in cashew nurseries, 15 plants including weeds are found to be the collateral hosts of *C. gloeosporioides*. Among the five plant species, cashew showed highest susceptibility followed by mango, citrus, *Annona* and *Punica*. The weeds, *Aristolochia bracteata, Achyranthes aspera, Argemone mexicana, Corchorus trilocularis, Cleome viscosa, Daturas tramonium, Parthenium hysterophorus, Leucas aspera, Tribulus terrestris* and *Tridax procumbens* are also susceptible to this pathogen with disease index of 13.24-70% (Venkateswarlu and Murthy, 2003). Since these weeds act as the collateral

Figs 12.15–12.23: **15.** Pre- emergence damping off; **16.** Post-emergence damping off; **17.** Seedling blight; **18.** Seedling blight; **19.** Seedling root rot; **20.** Seedling die back; **21.** *Colletotrichum* leaf blight; **22.** *Pestalotia* leaf blight; **23.** *Phytophthora* leaf blight

host of the pathogen, weed management is also necessary in nursery to prevent the spread of the disease.

Spraying of 1% Bordeaux mixture is effective in preventing the progression and spread of die back symptoms (Bindu *et al.*,1998). Weekly spraying with copper oxychloride (3g l^{-1}) or with benomyl (1g l^{-1}) can efficiently control the disease (Freire, 2002). Combination spray of carbendazim (1g l^{-1}) or copper oxychloride (2g l^{-1}) with quinalphos 0.05% are most effective against TMB- *Colletotrichum* complex in cashew nursery (Deepthy and Kurien, 2004). Combined application of insecticide lindane 20EC 4 ml L^{-1} and copper based fungicide Champ D-P (4g L^{-1}) provided control of seedlings die back in Ibadan (Hammed and Adedeji, 2008).

Grafted cashew seedlings are also affected by *Lasiodilodia theobromae* during the healing of graft union and this infection can be controlled by periodically cleaning the knives with 1% sodium hypochlorite solution or by immersing the scion in 1% benomyl solution for 15min (Almeida *et al.*, 1979) (Figs. 12.15– 12.23).

Damping off

Damping off, root rot, seedling blight are the soil borne diseases occur in ill drained conditions. This disease is reported from India in 1962 from Vengurla, Maharashtra and also noticed in Kerala and Andhra Pradesh. *Phytophthora palmivora* and *Pythium* sp. are found associated with both pre-emergence and post-emergence damping off (Kumara Raj and Bhide, 1962; CPCRI 1986; Mathew, 2007). Symptoms consist of rotting of seed nut before emerging out of soil and appearance of water soaked lesions at the collar region result in girdling of the stem and such seedlings topple over or rot. Soil drenching with 1% Bordeaux mixture reduced the infection (CPCRI, 1986).

Root rot

It is a common disease in cashew nurseries in Nigeria, Brazil, Vietnam and India. Different species of *Pythium viz. P. ultimum* (Nigeria) *P. splendens* (Brazil) and *P. aphanidermatum* (Kerala, India) are found to be the main pathogens. Association of *Phytophthora* sp. and *Sclerotium rolfsii* is noticed in Brazil. Primary symptoms are yellowing of lower leaves and conspicuous stunting and rotting of the root system followed by wilting and drying up of plants (Olunloyo, 1976; Freire, 2002; Mathew, 2007).Better drainage in nursery bags, suitable level of irrigation and shading are sufficient to keep the disease under control (Fierie, 1996; Friere, 2002). Soil application of dexon @ 113.6 kg/ha and metalaxyl provided successful control of *Pythium* and *Phytophthora* in Nigeria and Brazil (Olunloyo 1976; Freire, 1996).

Seedling blight

Different fungi such as *Pythium* sp., *Phytophthora* sp., *Cylindrocladium scoparium, Fusarium* sp. and *Aspergillus niger* are reported as the causal organism of seedling blight (Freire, 1996; Mathew, 2005; Govindan and Sathiarajan, 1990). Characteristic symptoms of infection are rotting of the collar region, wilting and withering of seedlings.

A study conducted at Kerala Agricultural University, Thrisur in 2001 revealed that use of solarised potting mixture can effectively control all soil borne diseases in nursery. It also reduced the saprophytic nematode population and weed growth in polybags. In addition, the use of *Trichoderma harzianum* @ 2g/bag, AM fungi, *Glomus fasiculatum* @ 10g/bag at the time of sowing and soil drenching with mancozeb or copper oxychloride @ 2 g l^{-1} before sowing are also effective in reducing infection and the disease incidence in the treatments varied from 1.22 – 2.66% against 12% in control (Mathew, 2007). In another study, soil application of *Trichoderma viride* @ 3g/poly bag filled with potting mixture and soil drenching with 1% Bordeaux mixture at the time of sowing and after grafting, reduced the soil borne diseases in nursery. Application of *Trichoderma* at the time of sowing itself enhanced the growth of root stock seedlings as well as cashew grafts. But the soil drenching of 1% Bordeaux mixture affected the germination of seed and also retarded the growth of seedlings and grafts (Mathew, 2009).

Application of biofertilizers *viz. Azospirillum* sp., *Azotobacter chroococcum, Glomus fasiculatum* @ 10g/polybag at the time of sowing increased germination (91.33- 96.67%) over that of control (85.67%). It also increased the seedling vigour and reduced fungal disease incidence (6.33-10.67%) significantly as compared to

29% in control (Kumar *et al.*, 1998). Solarised potting mixture with *Trichoderma harzianum* has got profound effect on growth and vigour of cashew seedlings. Use of *Trichoderma* enhanced early germination, but soil drenching with copper oxychloride (2g L^{-1}) delayed germination of cashew seeds, however it showed cent per cent germination (Joseph *et al.*, 2002).

Leaf spots

In all cashew growing countries, leaf spot diseases caused by various fungi are a serious problem in nurseries. Among these, leaf spots caused by *Colletotrichum gloeosporioides* and *Pestalotia* sp. are the most common and serious ones.Leaf spot caused by *C. gloeosporioides* appears as light brown spots with reddish brown margin, which later coalesces and lead to blighting symptom. Spraying with copper oxychloride (3gl^{-1}) or benomyl (1gl^{-1}) can effectively control the disease (Freire *et al.,* 2002).

Pestalotia sp. shows irregular brick red necrotic lesion on leaf lamina mainly along the midrib, which enlarge and cause leaf blighting. Leaf spots caused by *Cylindrocladium scoparium* and *Septoria anacardii* are also reported on cashew. Leaf blight caused by *Phytophthora heveae/P. nicotiana*e is observed in cashew seedlings during rainy season. This disease can devastate nursery if proper control measures are not adopted. Initial symptom appears as water soaked lesions which lead to rotting, yellowing and defoliation of leaves.

Spraying with metalaxyl (1gl^{-1}) controls the infection (Freire, 2002). Spraying of 1% Bordeaux mixture/copper oxychloride/mancozeb/zineb @ 2gL^{-1} can effectively control all leaf infection in cashew nursery. Spraying of carbendazim 1gl^{-1} is also effective against *Colletotrichum* and *Pestalotia* leaf blights (Mathew, 2007). Cashew shell extract has got tremendous effect in suppressing the growth of pathogenic fungi like *Fusarium* sp., *Rhizoctonia bataticola, Sclerotium rolfsii. Pellicularia filamentosa, Phomopsis* sp. especially *P. palmivora* which showed 70% inhibition (Joy *et al.*, 2002). Thus, use of cashew shell extract as a potential antifungal botanical can be exploited in ecofriendly disease management practices.

Diseases of nuts and kernels in storage

Various fungi are found associated with kernel deterioration. According to Brazilian exporters, fungal kernel deterioration can cause loss as high as 20 million dollars yearly (Freire *et al.,* 2002). The most common fungi are *Aspergillus* and *Pencillium* spp.Eusurosa (1974) reported occurrence of *Aspergillus* sp., *Rhizopus nigricans*, *Fusarium* spp. and *Gliocladium* spp. causing kernel rot in Nigeria. In Brazil, a kernel rot caused by *Pencillium digitatum* is first recorded by Ponte *et al.* (1975). *A. flavus, Oedocephalum bergii* and *Neurospora* spp. are also detected in cashew kernels in Brazil (Andrade *et al.,* 1990). Olunloya (1978) observed invasion of *A. tamarii, Pencillium citrinum* and *L. theobromae*. Studies conducted in Brazil have demonstrated that, the fungi associated with kernel infection are endophytic to cashew plants or can invade ovaries through flower or introduced into the young kernels by insects (Freire,1999). In India, the presence of *Cladosporium* sp., *A. niger, Fusarium* sp., *Pencillium* sp. and *Rhizopus* sp. associated with kernel rot in immature and mature nuts were confirmed by Nambiar

(1978). A comprehensive study of fungi occurring in kernels has been provided by Pitt *et al.* (1993) in Thailand. Presence of some fungal metabolites including traces of aflatoxin G2 is reported in Brazilian cashew kernels (Freire *et al.,* 1999). The fungicidal property of mango and bitter leaf extracts against the storage fungi of cashew nut such as *Trichodermaviride, Cephalosporium sp.* and *A. niger* is reported by Sulemian and Ogundane (2010).

Future thrusts

Diseases such as anthracnose, powdery mildew, black mold, angular leaf spot, gummosis or inflorescence blight/floral shoot and twig die back, root rot and damping off etc., are considered as major yield limiting factors of cashew. Management of the diseases through chemicals, cultural practices and host plant resistance has been documented especially in Brazil and African countries. However, in India, an intensive research on diagnositic and management of cashew diseases has not been carried out. Emergence of new disease or outbreak of existing disease is unavoidable in changing climatic scenario. Hence, emphasis should be given on periodical documentation of diseases of cashew so as to develop disease forecasting models and to devise sustainable management strategies or options. In India, intensive research is required for standardizing such integrated methods particularly for development of resistance varieties/hybrids. Being a prime export commodity, it is essential to workout MRL for the major chemicals used in cashew production and it has to be continuously monitored.

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13

Post-harvest Management of Cashewnut

CASHEW processing is deemed to be sunrise sector of the Indian economy owing to its exponential growth since its inception and socio economic impact, specifically on employment, income generation and gender equity. Industrialized agriculture and food production rely on efficient utilization of energy to carry out the desired operations and obtain high processing output through mechanization towards safe storage of agricultural products and conversion processes that create new forms of food. Cashew (*Anacardium occidentale* L.) is one of the horticultural crops and is often referred to as 'wonder nut' having potential to provide source of livelihood for the cashew growers, create employment opportunities and generate foreign exchange through exports. Cashew kernels are a high value commodity with sales growing steadily at an annual rate of seven per cent, with every expectation that the market will remain strong in future too. The cashew industry ranks third in the world production of edible nuts with world production during last fiscal at about 2.8 million tonnes of raw nuts and an estimated value in excess of US $ 4.19 billion (FAO, 2012).

Traditionally, various processing operations were performed manually by the skilled personnel in India, the world's largest producer of cashew kernels. Although, various mechanized equipments were developed globally for different operations in the line of processing during 60's, it could not attract Indian processors primarily due to twin reasons *i.e.*, availability of adequate work force, possessing required skill to extract whole kernels which fetched premium price at consumer level and also due to lower performance of the processing machines. Cashew business expanded tremendously over a period of time, providing more opportunity for the new entrepreneurs to plunge in to this business. Spurt in the cashew value chain and employment creation in other sectors led to non-availability of skilled work force in this system and presently these industries are gradually progressing towards mechanization. This chapter encompasses post harvest management of cashewnut, opportunities for rural based microenterprise and by-product utilization. Besides, thrust areas have been identified to strengthen cashew value chain to anchor India's premier position in the global arena.

Harvesting and collection of nuts

Cashewnut is a seasonal crop and is harvested from March to May in the east and west coast and certain plain regions of India. Raw cashewnuts are harvested after natural drop or thrashed by sticks or shaking trees. Mechanization of harvesting cashewnuts is yet to be practised not only in India, but also in cashew growing countries in the world. Investigations conducted in the farms of Sindudurg district of Maharashtra (Dalvi *et al.,* 1992) clearly indicates that about 72% of the farms follow harvesting the nuts by thrashing with stick and collection method. Certainly, this would increase the proportion of immature nuts while reaching the processing sector for value addition. Only 16% of farms follow the collection of nuts after natural drop. Obviously, these methods increase the immature nuts and leads to inferior quality final produce. Harvesting by thrashing or climbing also results in dropping of young flowers and ultimately reduces the production. Besides, the nuts have to be harvested at right stage. The colour of the nuts changes from brownish green at fruit set to light green at ¼th growth apple stage and thereafter turns grey irrespective of varieties. This is the right time to harvest the nuts. The different harvesting period of cashew in the world ensures the supply of nuts around the year. This helps to have control on imported nut price and the Indian processors are assisted by not carrying long term stock. The peak season of cashew production in India,Vietnam and West Africa is from March to June while Brazil from July to February and East Africa from October to December.

Cashewnut processing

Processing of cashewnut can be defined as changing or altering the raw cashewnut by the application of various unit operations and utilization of machinery to recover the edible kernel and cashewnut shell liquid. Various stages in the line of processing are conditioning, shelling, drying, peeling, grading and packaging (Fig. 13.1). Increasing popularity of cashew during 1920's prompted development of processes designed to extract the kernel. The CNSL in the pericarp is initially burnt due to its caustic properties to eliminate chances of contaminating kernels and to minimize the risk of injury to the fingers while manually extracting kernels.

Discovery of commercial value and the versatility of Cashew nut shell liquid (CNSL) for industrial uses encouraged adoption of methods to recover it by sophisticated oil bath process of roasting the nuts in the medium of CNSL itself. In steam conditioning technology, raw cashewnuts are subjected to alternative wetting and cooling after exposing to steam. This process loosens the edible kernel inside shell due to differential moisture diffusion process and enables its extraction in whole form through mechanical means and considered to be cost effective system.

Drying raw cashewnuts

Depending on the variety, maturity and environmental factors, whole nut moisture content varies from 16% to 21% d.b and required to be reduced to equilibrium moisture content of 8% d.b which is considered to be safer level to enhance its shelflife in the ware houses. Accounting, the presence of 33% of oil i.e. CNSL in the shell and 47% fat in the edible kernel, it is computed that the permissble moisture content for cashew kernel is around 8.07% d.b (Ohler, 1979). Besides, investigation onmoisture sorption isotherm of raw cashewnuts, clearly indicated that 50.4% of total moisture is free moisture i.e. 8.12% and removal of this free moisture ensures protection of raw cashewnuts against microorganisms.

	Process	Options	Objectives
Preparation for kernel extraction	**Stage 1 Drying raw cashewnuts**	Sun or Solar drying	Raw cashewnuts are dried under sun preferably on concrete floor to reduce the moisture to safer level of 8 % d.b for long term storage
	Stage 2 Cleaning and calibration cashewnuts	Rotary sieve grader	Raw cashewnuts are segregated in to 5-6 grades based on effective width to ensure uniform processing
	Stage 3 Conditioning of raw cashewnuts	Drum roasting; Steaming; Oil bath roasting	Thermal or alternative wetting and cooling process to loosen the adhering kernel and make it amenable for extraction process.
Shelling	**Stage 4 Shelling of conditioned cashewnuts**	Manual cracking; Semi-mechanized shellers Automated shelling machine	Separations of kernel in whole form and without affected by CNSL
Drying	**Stage 5 Drying of unpeeled cashew kernels**	Convective dryers; Steam assisted dryers	Diffusion of moisture to ease peeling of kernel testa
Peeling	**Stage 6 Peeling of dried unpeeled cashew kernels**	Manual peeling; Mechanical peeling	Removal of testa to make kernel edible
Grading	**Stage 7 Grading of cashew kernels**	Manual grading; Colour sorter; Mechanical size grader	Classification according to grade specification
Packaging	**Stage 8 Packaging of cashew kernels**	Vita packaging system; Moulded Vacuum Packaging system	Either for long term storage or long distance transport maintaining its quality

Fig 13.1. Stages in cashewnut processing

Therefore it is strongly recommended to bring down the moisture to safe level of 8% for long term storage (Anonymous, 2013).

Cashew being a seasonal crop, available only from March to May every year, therefore it is essential to reduce the moisture to prolong its shelf life so as to operate processing units throughout the year. Therefore, a moisture loss i.e. driage of 8-12% takes place depending on the size of the nut, maturity and drying time. Undried nuts lead to fungal spoilage due to adhering fleshy portion of cashew apple, resulting in poor quality of kernels. Fungi such as *Gonatobotryum* sp., *Helminthosporium* sp., *Corynespora* sp., *Alternaria* sp., *Verticillium* sp. and many species of *Aspergillus* have been isolated from stored cashewnuts (Joseph, 1981).


Fig. 13.2 Sundrying of raw cashewnut

In view of the occurrence of fungi, drying of the raw nuts before storage is essential. Therefore, freshly harvested nuts required to be dried under sun for 48 to 72 h depending on the prevailing environmental condition to reduce its moisture to safer level.

Raw cashewnuts could be exposed to sun by uniformly spreading in thin layer on either semi-finished floor or over polythene sheets and the quantity of nuts to be dried shall not exceed 20 kg m^{-2} (Fig 13.2). Uniform drying can be achieved by constantly turning nuts over to prevent partial drying or non-uniform heating. Alternatively, raw nuts can be dried in electrically or bio fuel operated cross-flow dryers. Time required to dry raw cashewnuts at air temperature of 65ÚC inside commercial dryer is in the range of 7 to 10 h whereas drying time under sun is found to be in the range of 33 to 40 h (Balasubramanian and Sandeep, 2011). Irrespective of drying methods, moisture content of raw nuts should be brought down to 8% d.b for safe storage. It is reported that higher kernel to shell weight ratio is proportional to moisture content and moisture content of whole nut and kernel could be predicted from that of shell (Okwelogu and Mackay, 1969).

Storage of raw cashewnuts

Owing to the availability of harvested nuts for limited period, it needs to be stored in a protected environment after proper drying to supply to processing industries for sufficient length of time. Normally, jute or sisal bags of 80 kg capacity is used for storing the dried nuts. At any cause, nuts should not be heaped or stored in silos to avoid humid environment in storage chamber. Besides, storing in woven high density polyethylene (HDPE) bags are also not recommended for raw nuts. Raw cashewnuts filled bags are stacked one over the other in ware houses maintaining sufficient gap between two rows. More over, it is necessary to provide proper wooden dunnage to prevent damage to the cashew nut in bags to avoid direct contact of bags to the warehouse floor (Fig. 13.3). Ceratin factors viz., sufficient ventillation, low humidity environment, free of stored product pests, insulation against rain water seepage into the ware house or dampness etc., ensures quality of nuts


Fig. 13.3 Storage of raw cashewnut

and its shellife. Research report on environment conditions in the store house indicated that nut stored at 27°C at a relative humidity (RH) of 70% maintained a moisture content of 9.2% d.b for a longer period and nuts exposed to higher RH (>75%) lead to mould infection within few weeks (Okwelogu and Mackay, 1969). Therefore, it is evident that RH of the storage godown plays an important role in prolonging shelflife of raw cashewnuts under godown condictions. Nagaraj and Prabhu (1996), revealed that raw cashewnuts with moisture content of 5 to 6% d.b can be stored for a period of 12 months without affecting processing and biochemical quality, provided the ambient temperature is maintained in the range of 25 to 30°C . Recent studies on effect of maturity on the processing quality have clearly indicated that shelling percentage, peeling outturn, whole kernel recovery increases while kernel rejects decreases with maturity.Application of insecticides or pesticides is prohibited to improve shelf life of raw cashewnuts in warehouses.

Nut conditioning

Extraction of whole cashew kernel from just harvested nuts is highly difficlut as the testa surrounding the kernel adhere tightly with the inner surface of the shell. Prior thermal or steam treatment ensures loosening of kernels inside the shell and make it amenable for manual or mechanical means. Mode of conditioning raw cashewnuts which aids in extraction of whole kernel during shelling operation are briefed below.

Open pan method

In this method of roasting, nuts are spread in a thin layer over circular dish like pan structure made out of mild steel and placed over earthern furnace. While heating the pan, nuts are stirred constantly to prevent scorching. During the process, nuts exudes oil from the pericarp and get ignited, producing flame and smoke. After appropriate time, flame sholud be dowsed off by sprinkling water and rubbed with wood ash to absorb oil. Later, charred, swollen and brittle nuts from pan are transferred for manual cracking to extract edible kernel. Valuable CNSL oil is lost and there is no assurance of uniform roasting.Now this method is obselete and seldomly followed in the rural areas of many cashew growing countries in one or other form.

Drum roasting method

Presently drum roasting mode of roasting raw cashewnuts is quite prevalent in processing industries located in Kerala, Tamilnadu, Andhra Pradesh, Odisha, West Bengal and North-East states, primarily to obtain edible kernel with enhanced flavour. It is a continuous roasting process, consisting of an inclined drum resting on rollers at both ends to facilitate rotational motion. The whole assebmly

Fig. 13.4 Drum roasting process

is erected on a furnace in such a way that the drum is heated throughout its length uniformly. Nut feeding and rotation of the drum are manually controlled. It is coupled with chimney at the top end to carry off objectionable fumes produced during roasting of raw cashewnuts. Nuts fed at the top end of the drum, slides downwards due to mild slope provided to the drum and continuous rotational motion. While moving across the drum, nuts catches fire due to the presence of oil in the shell layers and reaches outlet in a burning condition.

Water is sprinkled to quench off the fire and mixed with ash to absorb oil (Fig. 13.4). The degree of roasting or recovery of white whole kernels depends on size, feed rate, moisture content of the raw cashewnuts and rotational speed of the drum. Roasted nuts are, then, transferred to shelling or cracking section. It is essential to shell the nuts in brittle condition to avoid breakage of kernels, otherwise it absorb moisture, if prolonged for shelling and lead to higher breakage (Anonymous, 2013). In view of certain demerits of the system such as scorched tips of cashew kernels, loss of valuable by-product and exposing workers to acrid fumes i.e. emission of obnoxious smoke polluting the atmosphere, drum raosting processing is gradually vanishing from India.

Oil bath method

Conditioning raw cashewnuts by oil bath method was evolved after understanding the increased demand of cashew nut shell liquid (CNSL). Unlike other mode of conditioning, raw nuts are to be soaked in water prior to roasting. Silos are used for the purpose of infusing required moisture ranging from 15 to 25% d.b. (Ratnam, 1969). This pre-treatment prevents scorching of kernels, while passing through hot CNSL for roasting. Soaked nuts are submerged into the bath of hot CNSL mainatained at a temeperature of 190 to 195°C by a continuous chain conveyor. While moving from inlet to the discharge end of oil tank, nuts are exposed to hot oil, thereby oozing out CNSL from the shell structure increasing volume to the CNSL tank. Residual oil adhereing to the surface of the nuts is removed by centrifuge to ease material handling. Quality of kernel extracted depends on machine parameters *viz.,* temperature of CNSL, speed of chain conveyor and feed rate and material parameters *viz.*, size, moisture and origin of the nuts.

Steam boiling method

In this method, nuts are exposed to steam at regulated pressure comparatively at low temperature to infue moisture in to the shell, but not sufficient to bring out the shell liquid (Fig. 13.5). This process reported to loosen the kernel and make its removal easy. Care should be taken to control the steam pressure in such a way that pigment from testa should not be transferred to discolour the surface of

Fig. 13.5 Steam boiling of raw cashewnuts

the edible kernel. Therefore, steam pressure and duration of exposure are the decisive factors during steaming operation which are influenced by size, dryness and storage time (Balasubramanian[1] 2000). After steaming, the nuts are air-cured by spreading out on the floor in the ambient environment. This process ultimately harden the shell and make it amenable for subsequent kernel extraction process.

Shelling

Shelling is the process by which roasted or steamed nuts are cracked or deshelled by manual or mechanical means to etarct kernel in whole form. High dexrity is required for manual cracking of drum roasted nuts using mallets or deshelling steamed and air cured nuts using hand cum pedal operated gadget (Fig. 13.7 and 13.8). Workers acquire the skill through practice and outturn is expected to be in the range of 92-95% of the whole kernels with operational capacity of 1.75 to 2.5 kg h^{-1} of kernels. It is a standard practice to smear ash or clay or oil to prevent the contact of CNSL on their hands during operation (Balasubramanian[2], 2000). In the hand cum pedal operated gadget, nuts are fed one by one between pair of knife each shaped to the contour of the two halves of the nut. When the pedal is pressed, nut is held tightly between the blades and lifting the lever split open the shell in to two halves releasing the kernel without damage. In order to reduce the drudgery experienced by the operators, a radial arm type cashew kernel extracting machine is developed at Directorate of Cashew Research, Karnataka, India (Balasubramanian, 2010). Due to the avaialbility of high skilled labourers, India has enjoyed virtual monopoly in the past. But now-a-days, scarcity of labourer in the cashew processing system led to deployment of mechanized shelling machine.

Fig. 13.7 Manual shelling of drum roasted nuts

Fig. 13.8 Shelling of steam tretaed nuts

Kernel drying

The shelled kernel is completely wrapped up by a brown layer called testa and to facilitate its removal i.e. peeling, drying is essential. Invariably, kernel moisture ranges between 6 and 8% d.b before exposing to controlled environment for moisture diffusion process. While drying, surface layer 'testa' looses its moisture faster than edible kernel and aids in manual or mechanical peeling. Generally, drying of unpeeled kernel takesplace in 'Borma' a brick construction with thermal insulation wherein externally generated hot air is circulated inside the drying chamber. Kernels are spread on a tray with wire mesh bottom and loaded in the mobile trolleys. These trolleys, in turn, are moved inside chamber for drying. In order to overcome differential rate of drying at top and bottom location, it is a standard practice to change the position of the trays to ensure uniform drying (Balasubramanian, 2001). Recently introduced steam assisted dryer ensures quality of the end product in terms of surface colour and falvour. Moreover, it is comparatively efficient and economical dryer, utilizing dry air derived from super heated steam through radiator assembly.

Humidification

Dried cashew kernels are subjected to humidification process depending on the prevailing environment conditions. If the ambient condition too warm and low RH, kernel breakage is expectedly more during the subsequent operation i.e. peeling. In order to extract kernels in whole form, dried kernels are exposed in humid environment i.e. humdifying chamber for a short time to infuse desired moisture content in to the unpeeled kernel.

Fig. 13.10 Manual peeling of cashew kernels

Peeling

Dislodging the skin or testa surrounding the edible kernel by manual or mechanical means is called peeling (Fig. 13.10). During manual peeling process, specially designed stainless steel kninfe is used to scrap off the testa adhereing to the kernel. In India, labourers engaged in peeling has the capability to peel ranging from 4 to 12 kg head^{-1} day^{-1}with peeling efficiency or whole kernel recovery up to 82%. Preliminary grading of peeled kernels i.e. 8-10 grades is segregated at this stage itself. Wages are fixed on the basis of whole kernel recovery as it serves as a control for careful work (Balasubramanian[3], 2000). In the wake of labour scarcity, automated peeling machines are introduced in the large scale processing industries. These machines showed better performance and works on the basic principle of shearing and impact.

Grading

Manual grading is predominatly followed in Indian cashew processing system and primarily three factors *viz.* wholesomeness, size and surface colour are considered for segregation according to grade designations or standards developed by Bureau of Indian Standards (IS 7750:1975). High degree of cleaniness is maintained in this section and clean containers i.e. plastic or alumininum are used. Grading standards varies from country to country, but in India it mainly refers to number of kernels per pound which is equivalent to 0.454 kg. For example, WW320 designates

Fig 13.11 Grading of cashew kernels and whole kernels

320 numbers of white whole kernels in a pound (lbs) weight. Number of kernels in the largest whole kernel grade 'W180' is in the range of 265 to 395/kg and the smallest whole kernel grade 'W500' in the range of 1,000 to 1,100/kg. Thus, lower the number, bigger the size and higher the price per unit weight (Fig. 13.11). Broken kernels are either butts or splits depending on whether they are broken across or along the cleavage and size grading is based on sieve in which it passes through. Electrically operated and electronically controlled mechanical graders are now available wherein size, surface colour, defectiveness, partially peeled, surface smoothness/shrivelness are considered for grading the kernels for greater volume with high accuracy.

Conditioning of cashew kernels

Permissible moisture in the graded cashew kernel is 5% d.b by weight at the port of importation (CEPCI, 2013). While a moisture level above 5% at the time of final packing is not preferred as the same may cause fungi and aid infestation, low moisture level below 2% is undesirable as it causes breakage of kernel during processing and shipment. Processors by and large control the final moisture level of kernel before final packing up to 3-5% by weight. Cashew kernel are humidified to increase moisture percentage to the required level or hot air treated to reduce the excess moisture to maintain desired final moisture level before final packing.

Packaging

Presently, there are two major packaging techniques followed for cashew kernels. They are (i) Vita packing, and (ii) Mouded vacuum packaging. In the begining, simple tin containers were used to pack cashew kernels followed by vacumising the container using hand pump. Vita packing was introduced during fifties to overcome the inherent problem of cashew kernels packaging by flushing with inert gas to prevent incidence of rancidity and insect infestation. Vita packing is the process of vacuumising and injecting inert gas viz. Carbon-di-oxide (CO_2)

Fig. 13.12. Vita packaging machine

Fig 13.13. Moulded vacuum packaging machine

or Nitrogen (N_2) into the cashew kernel filled tins (Fig 13.12). The gas infused tins are hand-soldered hermetically using lead free solder. Such tins are packed in a carton (2 nos.) and strapped and stencil marked for shipment. Tin containers of 25 lbs equivalent to 11.32 kg, are used for packing and tested for leakage by immersing in a pool of water. Due to stringent quality standards for cashew kernels followed by the importing countries and finding difficult to dispose off bulky tin containers, now-a-days, this packaging system is followed only for domestic supply of cashew kernels. As an alternative, Moulded Vacuum Packaging (MVP) developed by M/s Vanleer private limited, South Africa, is now preferred by many countries as it produces consistent rectangular blocks ranging in size from 500g to 25kg of cashew kernels comparatively at lower cost (Fig. 13.13). Major advantages of MVP system are easy to transport, hande, display, stock count etc. Moreover, vacuum barrier bag and the cardboard box are totally recyclable, rectangular shape of primary packs ensures minimum movement during transport and handling ensuring maximum protection to kernels.

By-product utilization

Owing to its caustic properties, the CNSL in the pericarp, traditionally, it is burnt first to eliminate the chances of contaminating the kernels and minimize the risk of injury to the fingers of shelling workers. Although, the shelling process remains essentially the same until today in the Indian cashew processing industry located in certain regions, the discovery of commercial value and the versatility of CNSL for industrial uses encouraged adoption of methods to salvage the oil. Cashew nut shell liquid (CNSL) is a dark brown viscous liquid present inside a soft honey comb structure of the cashew nut shell and is a byproduct obtained during the processing of cashew nuts. Physical, chemical and thermal properties are presented in Table 13.1.

Table 13.1 Properties of cashewnut shell liquid

I Gross Calorific Value	5056 kcal kg^{-1}
II Proximate analysis (% weight)	
(a) Moisture	8.85
(b) Volatile matter	68.03
(c) Ash 2	
(d) Fixed Carbon	21.12
IIIUltimate Analysis	
(a) Carbon	46.08
(b) Hydrogen	3.88
(c) Nitrogen	0.21
(d) Sulphur	Nil
(e) Moisture	8.85
(f) Ash: 2.00	2
(g) Oxygen	38.98
IVBulk density	0.4430 g cm^{-3}
V Ash Chemical composition (% by weight)	
(a) Silica (Si02)	61.83
(b) Iron Oxide (as Fe_20_3)	3.99
(c) Aluminium Oxide	1.99
(d) Calcium Oxide (as CaO)	25.64
(e) Magnesium Oxide (as MgO)	1.88
(f) Sodium Oxide (as Na_20)	0.65
(g) Potassium (as P_20_5)	Traces
(h) Sulphate (as P_20_5)	Traces
(i) Phosphate (as P_20_5)	Traces
VI Ash Fusion Characteristics	
(a) Initial deformation temperature (T_1)	840
(b) Hemispherical temperature (T_2)	920
(c) Fusion temperature (T_3)	1010

Mode of extraction of CNSL

The traditional method of extracting CNSL is by roasting the nuts over an open fire. This removes the CNSL by charring/degradation thereby wasting the liquid which is a valuable source of natural phenols. There are three main methods generally used in extracting cashew nut shell liquid from cashew nuts *viz.*, thermal, mechanical and solvent extraction. Solvent extraction in turn can be carried out by cold extraction, hot extraction by different solvent using Soxlet extractor, Ultrasonication and super critical carbondioxide extraction. Cashew nut shell liquid was also extracted using vacuum pyrolysis. CNSL is classified into Technical CNSL and natural CNSL depending upon the type of extraction. Technical CNSL is rich in Cardanol, also known as Decarboxylated CNSL, where as Natural CNSL is rich in Anacardic acid.

Roasting method

This is the traditional method of removing CNSL (Acland, 1975) and it involves roasting the nuts in drum or bath. The roasting process not only removes the corrosive CNSL, but also makes the shell brittle, thereby aiding the cracking or shelling process. This method causes the loss of CNSL and to extract the retained CNSL, the nuts are roasted in baths at a temperature of 190-195°C. Vents in the equipment dispel the unpleasant fumes. This method recovers 85–90% of the liquid.

Hot oil bath method

By and large, this is the most common method of commercial extraction of CNSL in practice other than India. In order to extract CNSL from raw cashewnut, pre-conditioned nuts are passed through a bath of hot CNSL itself, during which the outer part of the shell bursts open and releases CNSL. This method could extract CNSL to the tune of 6-12% by weight of nut. In the case of cashewnut shells, CNSL is extracted by conduction heat generated by steam for 2-3 minutes. This method yields CNSL of around 7-12% by weight.

Screw press method

The raw cashew nut shells are transferred to the hydraulic or screw press and then exert high pressure in order to release CNSL from shells. Performance of extracting CNSL by means of tapered compression screw revealed that 21% of CNSL by weight with purity of 86% could be achieved at a screw speed of 13 rpm and feeding rate of 95 kg h^{-1}. The CNSL obtained by this process contained 42% cardol, 47% anacardic acid and 3% Cardanol (Francisco *et al.*, 2011)

Solvent extraction

Comparatively higher quantity of CNSL can be extracted by this method. The oil remains in the residue is less than 1% by weight. If anacardic acid of high percentage is required, cold extraction using solvent extraction found to be the possible feasible solution. Moreover, the CNSL obtained by cold solvent extraction preserves the original properties of the liquid. Anacardic acid percentage in steam roasted shells is less compared to raw cashew nut shells suggesting decarboxylation during the separation of kernel from the shells by steam roasting.

In cold extraction process, pentane, hexane, diethyl ether, carbon tetrachloride, light petroleum, acetone, methanol and toluene can be used as a solvent (Shoba and Ravinderanath,1991). The broken shells are placed in Erlenmeyer flask and covered with the pentane and after 12 h, the extract is filtered off and the shells are again covered with solvent. Five such extracts are combined and evaporated on rotary evaporator under reduced pressure, below 30°C. The solute to total solvent ratio is maintained at 1:10. The CNSL obtained consisted of 10% cardol, 50% cardanol and 30% anacardic acid. Quality and quantity of CNSL extraction depends on type of solvent, solute to solvent ratio, extraction temperature, agitation speed and size of cashew shell. Solvent extraction has a serious problem of elimination of polluting organic solvent from the extract.

Extraction using supercritical carbon dioxide

Recently, carbon dioxide near critical and supercritical states (scCO_2) has drawn much attention as solvent, especially in food and pharmaceutical industries. This is particularly for the interest of avoiding the use of organic solvents that are economically and environmentally unfriendly, besides the difficulties of completely eliminating organic solvents from the desired end products (Smith *et al.*, 2003). The first mechanism of extraction of CNSL by supercritical CO_2 is the permeation and diffusion of the carbon dioxide into the matrix and subsequent diffusion of CNSL into the bulk phase. The second mechanism is that the CO_2 penetrates into the natural matrix and partially dissolves into the oil phase. This causes the oil to swell and its viscosity to become gradually reduced. This allows the oil to flow out of the honeycombed matrix and then diffuse into the bulk phase.

Supercritical extraction is carried out at a pressure of 250 bar and a temperature of 40°C with carbon dioxide of 5 kg h^{-1} for 16 h. It was reported that the extraction rate found to be maximum between 5 to 10 h, though the yield is only 60% of that obtainable and the product is nearly colourless. In another method, the shells are contacted with high pressure carbon dioxide at elevated pressures of 30 MPa for an hour and the pressure is released before separation process begun. Extraction yields of CNSL to the tune of 10 times those obtained by supercritical fluid extraction method indicating temperature has different effects on the solubility depending on the pressure. The extraction mechanism of pressure profile method seems to occur by (*i*) penetration of the CO_2 through the shell material, (*ii*) dissolution of the CO_2 into the CNSL, (*iii*) expansion and rupture of the shell matrix due to depressurization that increases mass transfer and phase contact area.

Vacuum pyrolysis

Pyrolysis is generally used to describe processes in which preferred products are liquid oils especially those with desirable chemical composition and physical attributes for liquid fuels, fuel supplements and chemical feedstock. The liquid pyrolysis fuels apart from being energy rich are easier to handle, store and transport in combustion application and can be upgraded to obtain light hydrocarbons for transport fuel. In the method described, CNSL on removal of oil at 150°C is termed as Bio-oil CO_1 and this is pyrlosed for study of product distribution in a packed bed vacuum pyrolysis unit. The reaction conditions are maintained at initial reactor vacuum pressure of 5 kPa and at various maximum temperatures between 400°–600°C, with an increment of 50°C for each experiment (Subarao, 2011). The total condensable collected in the condensing train is termed as total liquid. Among the total liquid, first three fractions, which are directly combustible without any further treatment, are termed as bio-oil CO_2. The total liquid percentage varies from 37% (400°C) to a maximum of 42% (500°–550 °C) and dropping to 36% (at 600°C). However, the liquid to oil ratio was reported to be independent of maximum temperature of pyrolysis in the temperature range of 400°C to 550°C. The calorific value of Bio-oil CO1 is 33 MJ kg^{-1} while that of Bio-oil CO_2 is 40 MJ kg^{-1} which is unusually high like petroleum fuels.

Densification and gasification

Fuel briquette are prepared using pulverized cashew shell cake derived from steam boiling process and saw dust mixture in the ratio of 1:1 using ram type briquette making machine. Cashew shell obtained from drum roasting process partially burnt shell can be carbonized completely by retort process and converted in to carbonized briquette (Pillow type) for value addition to cashew byproduct.

An updraft gasifier is developed for a feed stock of 14 kg of Cashew shell cake (CSC) at a time for the generation of thermal power up to 12 kW. The gasifier is tested for 70 h continuously and the biomass consumption is found to be 8-10 kg h^{-1} (Balasubramanian, 2012). Various parameters viz., Quantity of feed stock, air velocity and moisture content of CSC influencing the flame temperature and period of thermal energy generation is studied. The flame temperature varied from 387 to 528°C with average mean value of 487°C. Periodical maintenance could avoid the problem of tar generation in the gas conduit with the progressive run of the gasifier

Current scenario of Micro-enterprises in processing

Market oriented production often goes through several level of processing and carried out at or near the source of raw material so that more product value can be retained locally. Although the focus of cashewnut processing is taking the dimension of multiple product development an attempt to improve opportunities for processing at rural area i.e. production catchments is imperative (Balasubramanian, 2008). Unlike other crops, price structure is not followed for cashew based on quality standards.

The consumption of kernels at domestic level showed an increasing trend over the last decade. Domestic consumption recorded an all time high of 2.59 lakh tonnes i.e. 72.6% of total kernel production in India and it is a prime factor for promoting micro level cashew processing in this country. Besides, cashew market data reveals that kernel demand in India is unexpectedly growing at the rate of 8.75% per annum. Share of domestic production in exported kernels also declined from 45.5% in 1991-92 to 33.3% in 2013-14, accounting a sharp fall of 27%. It is evident that this changing scenario in domestic consumption favour micro level processor to continue in the value chain of cashew.

Processing of cashew in micro level normally confined to use locally available raw materials and small machinery giving emphasis on integration of rural man power. It requires less power and infrastructure and can operate as everything under one roof. It is a simple and low cost technology for processing either at farm or in the proximity of production catchment. Technological design maintains a balance between human energy and machine energy to strengthen work opportunities and asset-based creation in the event of modernization. The major emphasis is given on integration of the rural manpower at farm or household in to overall system.

Appropriate technology is not only the technology relevant to the needs for whom it is designed. It is socially appropriate, economically accessible and can be used and maintained in the local environment without causing damage. Down sized scale cashewnut processing is a household technology package tailored to escalate the economic status of farm sector. The feasibility of small-scale cashew processing units reveals that the net value addition per unit at farm level is worked out to be ₹ 65,700 and the value addition per unit weight of raw cashew nut is around ₹ 38. The economics for the unit having utilization capacity of 3 TPA is found out as ₹ 32,983 per month (Table 13.2). Besides, about 450 man-days per unit is generated during season.

Table 13.2. Economic feasibility and cost economics of micro level cashewnut processing

Feasibility	Units	Cost Economics	Units
Number of cashew trees (Average No.)	100	Processing capacity/day (kg)	40
Raw cashew nut production @ 6 kg/tree (Average)	600	Quantity of processing/year (kg)	3,000
Receipt from RCN @ ₹ 110/kg (₹)	66,000	Market price/kg (moisture loss-3%)	112
Shelling % (KPR)	25	Raw material cost (₹)	3,36,000
Receipt after processing (Wholes: Broken ration is 4:1) (₹)	88,248	Labour cost (₹)	12,500
Receipt through Cashew shell @ ₹ 5/kg	2,250	Electricity, fuel and other expenses (₹)	2,500
Total income (₹)	90,498	Total processing cost (₹)	3,51,000
Net value addition (₹)	24,498	Sales (₹)	4,52,500
Unit weight benefit (₹)	151	Profit (₹)	1,01,500
Value addition per unit weight (₹)	41	Profit/month (₹)	33,850

Procuring raw cashew is the largest component of the operating costs in cashew processing sector, a slight increase in cashew price adversely affects the entire economics of cashew processing. Traders and middlemen dominate the market for raw cashewnuts and kernels. The individual farmers are in a disadvantageous position as they are forced to sell the produce at a price determined by the traders/ lease holders. Farmers are not interested to use the regulated markets due to taxes/ cess and as such quality based pricing system is not developed. Establishing supply chain for raw cashewnuts and developing quality standards could address this issue.

The small-scale cashew nut processing technology followed in Sindhudurg district is developed in consideration of resources and need. The growth of micro level units (<3000 nos.) having processing capacity between 2 to 12 tonnes per season i.e. 3 months, indicates the technology adoption in this region. The financial support by the Government of Maharashtra and Khadi and Village Industry Commission (KVIC) for processing machineries is the key factors for the promotion of this sector in this region. Access to the supporting services brings success to the technology adoption. Certain organizations *viz.*, Hedgewar Prakalp and Ratnagiri Zilla Khadi Sangh are acting as an effective instrument to impart training skills. Training is conducted as vocational level through "learning by doing" to become proficient and confident in application of technology at work. Training program focuses on improving group activity, technical skill development, market support, value addition of low-grade kernels and cashew apple utilization (Balsubramanian, 2008). The comparative advantages over large-scale industries, integration of rural man power and socio-economic improvement of farmer cum processor indicate that these micro enterprise is quiet successful and highly contribute to the rural development.

Cashew, the multifaceted commercial crop has made significant contribution to the agriculture as well as socio economic scenario of Kerala state. Micro enterprises in cashew processing under Kudumbashree in Kasaragod district registered under independent society category. Twelve micro-cashew processing units and a centralized grading and packaging unit are started as cluster under 'Safalam Cashew Processors' with financial support from Kudumbashree, banking sector and respective panchayats of the district. Cashew processing machinery and raw materials have been provided to 12-units functioning at different Panchayats. Comprehensive training program on primary processing offered by Directorate of Cashew Research, Puttur, Karnataka acted as an effective instrument to impart skills to all the employees of the 'Safalam cashew processors group'. Steam boiling is the pretreatment technique being followed owing to easy operation and less floor space requirement. Eight women personnel employed in the unit operates the processing unit. The financial support by the Government of Kerala for processing machineries and the systematic training offered by Directorate of Cashew Research, Puttur facilitated towards the promotion of this sector in this region. The marketing channels established helps to sale the produce for better price. Value addition to unit weight of raw cashew nut is around Rs 11 and the economic return for the unit having utilization capacity of 5 tonne/season is found out as ₹ 9,577 per month (Balasubramanian, D. 2010).

SWOT analysis of cashewnut processing

SWOT analysis on cashewnut processing system existing in India suggest that the institutional support at national and state level for research and development, network on procurement of raw cashewnuts, favourable export policies, additional revenue through CNSL, man power availability to work up to break even point in a mechanized sector, experienced personnel in checking the quality of raw nuts and appreciative sales strategy especially growing domestic kernel market are the major strengths. While under utilization of man power, government policy of minimum wages during non-working days, lower efficiency at various stages of operation, improper utilization of cashew apple in product diversification and non-availability of raw nuts at standard prices are considered to be the weakness of the processing. Various opportunities favouring Indian cashew processing system are increased trend in global consumption, increased nutritional awareness among the consumers and attraction of valued added kernels in the international market. The threats to Indian cashew industry are establishment of increased processing facility in raw nut exporting countries, declining quality of raw nuts, introduction of cost effective and low investment technology, non-availability of raw nuts throughout the year and high speculation in raw nut prices.

Future thrusts

Global consumption of cashew kernels is growing at the rate of 8% annualy, confirming a strong market and assuring stake holders in the cashew value chain a lucrative business. Although sustainable productive capacity remains a challenge, India continues to distinguish itself in the market by producing high quality kernels through a labor assisted mechanization. Overall, privately-owned firms dominate processing in India and traders serve as important middlemen between farmers and factories. In order to promote production and processing, government policies need to support rural based small scale industries. Way ahead for small scale processor is that development organizations can be instrumental in bridging the gap between the small-scale processor and the producer or buyer. Ofcourse, world cashew market in terms of price, quality and volume is controlled by intermediaries. Stringent procedural standards should be developed and implemented to maintain quality and control highly speculative market price, favouring peasants and consumers.

Rising problem of labour shortage, mechanization has to be inducted in the existing system gradually and cautiously. There is substantial potential to exploit value added products, cashew by-products, CNSL for industrial and medicinal purposes and the juice for conversion in to bio-ethanol and in this regard, secondary processing should be encouraged. A paradigm shift in the cashewnut processing industry into modern, efficient and economically viable and sustainable cashew industry that competes effectively in the international market of cashew is in progress. While India has a legacy of leadership in the global cashew industry, it is clear that it must continuously reassess its comparative advantages in order to remain competitive. If it manages to increase domestic production, better agricultural extension services, induct measured mechanization and explore alternative markets, including fair trade and organic, it has the potential to lead the industry for many more years.

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14

Processing and Utilization of Cashew Apple

CASHEW is a major commercial horticultural crop of India, ranking second in agricultural export. The crop is now grown for its nut, which is considered as the only economic produce from the crop. However, another valuable produce from cashew *i.e.*, cashew apple, is totally neglected without any economical utilization, may be due to the attractive value for the nut. The scenario is same in most of the cashew growing countries, except few exceptions. The production of cashew apple in India alone is estimated to be around 60 lakh tonne per annum, considering that cashew apple weighs 8 to 10 times that of the nut, which is almost completely wasted now, without any commercial exploitation, leading to huge economic loss to the farmers and the nation.

Cashew apple, having medicinal properties and highly nutritious is a valuable source of sugars, minerals and vitamins. It is comparable with many of the tropical fruits in its nutritive value but superior in the contents of vitamin C and riboflavin (Jose Mathew and Mini, 2008a). The ripe apple is very juicy, spongy, somewhat fibrous, having a unique smell, and has a very thin skin that gets easily bruised. By effective utilization of cashew apple on commercial scale, the farmers can be assured of increased income, in addition to the income from nut, which definitely will encourage them to take up cashew cultivation with renewed interest. This chapter discusses the possibilities for the economical utilization of cashew apple including the techniques for overcoming the limitations associated with the apple, its offseason storage, development of value added products and attempts for their commercialization.

Processing of cashew apple

Limitations in cashew apple processing: The utility of cashew apple is limited because of its high susceptibility to physical injury, the apples being easily susceptible due to very thin skin. This leads to microbial spoilage by yeast and fungi during harvest, transportation and storage. More than 63 per cent of cashew apple collected at ripe stage exhibits moderate to heavy damage. The storability of cashew apple is thus very poor and complete spoilage can occur within hours after harvest.

The presence of astringent and acrid principles in cashew apple is a major draw back of the fruit for the commercial processing and utilization. They produce a rough, unpleasant and biting sensation on the tongue and throat. The astringency of cashew apple is determined to a large extent by the tannin content, a phenolic compound, and its content varies from 0.06 to 0.22 g/100 g. The presence of tannin interferes with the taste of the apple and the processed products from it. Removal of tannin is therefore a must before preparation of products.

The seasonal production of cashew apple is one of the greatest handicaps for the processing industry. Fragmented and scattered nature of cashew plantations also creates problem in collection and utilization of cashew apple. Since cashew apple is soft and delicate, when stacked in thick layers, lower ones burst because of weight and loose juice, causing problems in transportation. The system of collection of cashew nuts from fallen fruits after considerable delay also limits the availability of quality cashew apple for processing purposes.

Offseason storage of cashew apple: Concerted research efforts at different research institutions have now led to the development of several effective technologies for the storage of cashew apple juice and pulp for off season processing and removal of astringency. The Cashew Research Station, Madakkathara, under Kerala Agricultural University has developed the following technologies for the off season storage of juice, pulp and green pieces of cashew apple.

Studies conducted at Madakkathara have led to the development of very effective technologies for the storage of cashew apple juice and pulp for offseason processing. Juice, after clarification with 2.5 g KMS (potassium metasulfite), 5.0 g citric acid and 5.0 g sago per litre, can be stored in well sterilized, air tight, food grade plastic barrels even up to one year. In respect of pulp, steam de- tanned cashew apple, make into pulp, mix with 2.5 g KMS and 5 g citric acid with every kg of pulp and store in air tight glass bottles. The de-tanned green mature fruit pieces can be stored in glass bottles for pickle preparation after adding 200 g salt per kg of piece in alternate layers.

Removal of astringency: The presence of tannin interferes with the taste of the apple and the processed products from it. Removal of tannin is a must before preparation of products. Clarification (removal of tannin) can be done by using gelatin, calcium hydroxide, pectin and polyvinyl pyrrolidone (PVP), but excess gelatin imparts a disagreeable odour and high dose of calcium hydroxide turns the cashew apple juice reddish black giving a bitter taste. Steaming of cashew apple for 5 to 15 minutes and subsequent washing or treatment of the fruit for four to five minutes in boiling solution of common salt (2%) or sulphuric acid (0.2 N), followed by washing in water can remove the undesirable tannin. Madakkathara station has developed the following effective, low cost and organic technologies for the removal of tannin from juice and ripe and mature apples (Mathew *et al.,* 2010) and it is being employed commercially.

Clarification of juice: Add powdered and cooked sago @ 5g/litre of juice, keep for 12 hours and decant the upper layer of clear juice

De-tanning of whole ripe cashew apple: Dipping in 5% salt solution for 3 days, changing water every day.

De- tanning from green mature cashew apple pieces: Immersing the cut pieces in 8% salt solution for three days, with the change of salt solution daily.

Selection of cashew apple for processing

Cashew apple suited for processing should have medium to large fruit size with more than 70% juice containing more than 11% sugar and 0.39- 0.42% acidity.

Though the yellow colored apple is preferred in some regions because of its sweetness, more or less sweet or astringent apples have been found in all colour groups. Harvest of cashew at full ripe stage and separation of the nut with minimum damage to the apple are essential for effective utilization of the apples. Crisp, firm, tight and full colour developed apples are to be collected and used for processing purpose. The physical and chemical properties of apple are optimum during 44 to 46 days after fruit set and at this stage, apple becomes suitable for processing and it falls to ground along with the attached nut. This period seems to be the best time for collecting apples without spoilage. The apples are to be collected every day when it falls to the ground and if the apples are left ungathered for some time, rotting of cashew apples takes place. Once damaged, the apples may ferment and deteriorate rapidly. Additional losses may also occur when apples are taken away by birds and animals. After harvesting, fruits are to be sorted to select the best quality ones. The selected fruits are washed with water.

Utilization of cashew apple

Large number of technologies, that are economical and effective, have been developed for the production of various value added products from cashew apple with high consumer acceptance. They broadly include fresh apple beverages (including blended beverages), fermented beverages, pulp products, confectioneries, culinary products and products for agricultural uses.

Consumption as fresh fruit: Cashew apple is eaten as fresh fruit either whole apples or they are cut into small pieces, mixed with table salt. Quality for fresh consumption is related to low astringency and acidity, sweetness, firmness, size and pear shape. The market requirements for appearance are to be taken into consideration. Cashew apple must be cosmetically perfect without misshaping or physical signs of injury to be sold as fresh fruit. A study was conducted at Madakkathara to identify the best varieties for fresh consumption. Based on the organoleptic and quality analysis of 16 varieties, it was found that Dhana, MDK 1, VRI 3, Amrutha and KGN-1 were the best varieties to use as table fruit (Sobhana *et al.*, 2011a). Poduval and Tarai (2007) reported that V6, V4, M-33/3, Dhana, Kanaka and Madakkathara, are the best varieties for their cashew apple qualities in the red and leterite zone of west Bengal. A niche market for cashew apple for direct consumption can be located at least in major towns. Attempted was made for selling of fresh cashew apples, along with nuts, in pouches through university sales counter at Mannuthy, Kerala and there was good response for the sale.

Fresh apple beverages: Clarified and cloudy juice, juice concentrate, syrup, squash and ready- to- serve are some of the nutritious and refreshing beverages that can be made from the unfermented juice of cashew apple by adding varying concentrations of sugar, citric acid and preservative. The Kerala Agricultural University has standardized the technique for the preparation of juice, syrup and ready to serve drink. The Cashew Research Station, Madakkathara is manufacturing cashew apple syrup, a ready to serve (RTS) "Cashew apple drink" and carbonated cashew apple drink (Cashew apple soda) on a commercial scale and selling through the sales outlets of the university.

In Brazil, concentrated juice from cashew apple ranks first in sales among the tropical juices. It has contributed to human nutrition, particularly the poor people, by supplying low cost vitamin C. Vitamin C content in cashew apple juice averages to about 200 mg/100 g juice, which is nearly four times higher than other traditional fruit juices such as orange. Cajuda, cajuuina, cajuvita and cajuaperativo are different cashew drinks in South Brazil. Cashew apple juice can also be blended with other fruit juices like lime, pineapple, orange, grape, watermelon and apple juices to produce mixed or composite beverages with improved consumer acceptance. Sobhana *et al.* (2011 b, c) reported that cashew apple juice blended with suitable vegetables like gooseberry and carrot and fruit juices like pineapple, passion fruit have better acceptability and nutrient quality.

Fermented beverages: Cashew apple can be utilized for the manufacture of the fermented products like wine, vinegar, liquor and alcohol. Cashew apple vinegar can be prepared by alcoholic and subsequent acetic fermentation of juice, which is perhaps the oldest known fermentation product. The Cashew Research Station, Madakkathara has standardized the technique for the preparation of vinegar and is manufacturing it on a commercial scale.

Cashew liquor is not made by blending of spirits, as done in case of foreign liquor, but distilled exclusively from the pure juice of cashew apple without addition of any extraneous matter. Use of good ripe apples is very important; as unripe or overripe apples would affect the quality of final product. One litre of 60-62% ethyl alcohol can be obtained from eight litres of cashew apple juice. Kerala Agricultural University has standardized the method of producing four different grades of liquor from cashew apple.

Cashew apples are utilized widely in Goa for the preparation of the liquor, *feni,* by distillation mostly through crude country methods on cottage industry basis in almost all plantations. Apples which have fully ripened and fallen on the ground are collected, crushed for extraction of juice and the extracted juice is fermented and distilled without the addition of any foreign ingredients to obtain feni. Feni is primarily considered as country liquor and it has a strong fruity flavour, peculiar taste, strong aroma and astringent smell. It has been registered as the first geographical indication (GI) product from cashew (Elsy *et al.,* 2009).

Cashew wine is a product of fermentation of hexose sugar of cashew apple juice by intact yeast cells to form ethyl alcohol and carbon dioxide. Kerala Agricultural University has developed methods for producing four grades of wine such as soft, medium, hard and sweet, based on the alcohol percentage and sweetness. Fermentation, filtration and ageing are done on detanned cashew apple juice. All grades of wine preparation, except soft wine, involve one more step of adding sugar. Sensory evaluation showed that the performance was in the order of sweet, medium, hard and soft wines. Wine can also be distilled to produce brandy. Cashew apple mixed with sugar and lukewarm water in 1:1:1 ratio along with starter solution, spices and preservatives produced quality wine which was comparable with grape wine (Mini *et al.,* 2012). Cashew apple wine can be mixed with fresh juices of orange, pineapple, tomato, grape and cashew apple as well as tender coconut water to produce wine coolers to serve as good health drink as they contain both wine with its medicinal properties and fruit juices with high amount of nutrients and minerals.

Cashew apple pulp products: Jam is the most important pulp product of cashew. It can be prepared by boiling the cashew fruit pulp with a sufficient quantity of sugar and a pinch of citric acid to a reasonably thick consistency, firm enough to hold fruit tissues in position. Mixed fruit jam can also be prepared by mixing cashew apple pulp with equal quantity of banana pulp or pineapple pulp. Mini *et al.* (2007) reported that cashew apple can be mixed with pineapple, mango or combination of mango, pineapple and apple in 50:50 ratio for preparation of jam for increased acceptability. The Madakkathara Centre is commercially producing Cashew apple- Mango mixed jam named as *Cashewman.*

Fruit bar having 80^0 brix can be prepared by heating layers of fruit pulp mixed with pectin, sugar, glucose and potassium metabisulphate to 90^0 C and drying to 15% moisture. Different layers of cashew apple paste mixed with 1% citric acid are sun dried and cut into required size after placing one on top of the other to form leather. The layers, after smearing sugar syrup and pressed together, can be eaten like fruit wafers.

Confectionery and bakery products: Candied fruit is prepared from cashew apple by impregnating with cane sugar with subsequent draining and drying. One kilogram of cashew apple on processing gives 745 g candies. The Madakkathara Centre is commercially producing cashew apple candy. The syrup left over from the candying process can be used for sweetening chutneys, in vinegar making or for candying another batch of fruits. Cashew apple can also be utilized for the preparation of tutty fruity. Cashew apple (1 kg) on processing gives 715 g tutty fruity. The whole fruit can also be processed in to nutritious toffee, a feasible dessert item with extended shelf life. Toffee could provide 7.5g of protein and 442 k calories per 100 g. Cashew apple juice can be used for preparing frozen deserts and dairy confectionery items by optimization of juice concentration and spray drying. The only constraint here is the large capital investment required for spray drier equipment.

Dehydrated powder is used to prepare dehydrated cashew apple products. Clarified juice is prepared from steam blanched, sulphur dioxide treated fruits and spray dried for preparation of cashew apple powder with juice. The pulp or the residue of apple can also be dried, powdered and sieved for use as cashew apple powder without juice. 10 to 30% dehydrated cashew apple powder can be used in various value added products like wheat laddu, masala biscuits, sweet and masala doughnuts, sponge cake, steamed kabadu, tomato cashew apple powder soup, powder koftas, chocolates, sweet and hot bread products and cashew apple blended chocolates. The recipe for cashew apple chocolate with improved appearance, flavour, taste, sweetness and overall acceptability was reported by Sobhana *et al.* (2011d). Nutri-Cashew, a ready mix has been prepared using cashew apple powder for the elderly as high fibre fruit (drink) food mix for instant use.

A ready- to- serve beverage mix, fruit–milk or lassi mix has been prepared from clarified juice by homogenization, spray drying and mixing with milk/lassi powder. 10% to 15% clear and cool cashew juice mixed with skim milk powder can be spray dried for the production of cashew milk powder and can be utilized for the preparation of products like milk shakes, ice creams and ice candy. The Cashew Research Station, Madakkathara has standardized the technique for the preparation of chocolate from cashew apple powder and is manufacturing it on a commercial scale.

Culinary uses: Several traditional culinary preparations are in vogue in cashew growing areas using both unripe and ripe fruits. Sliced raw green fruit can be used to prepare pickle using chilli powder, gingelly oil, fenugreek powder, asafoetida, turmeric powder, garlic, mustard powder, a pinch of sodium benzoate and salt to taste.

Chutney can be prepared from sliced cashew apple using sugar, onion, ginger, spices like cumin seed, pepper, cardamom, cinnamon and coriander powder, salt and vinegar. Dried pulp prepared from semi- boiled apples is preserved for off-season and used for culinary uses particularly for the preparation of chutney.

Canned products: Cashew apple is peeled after treating with boiling NaOH solution followed by subsequent treatment in boiling solution of 0.2 N H_2SO_4. The treated fruits can be steamed and hot sugar syrup can be poured over the fruits for preparation of canned apple. Canned curried vegetables from raw green fruit of cashew in combination with potatoes (1:1) or potatoes and tomatoes (2:1) with or without tamarind are also reported

Medicinal uses: Several preparations from cashew apple have been extensively used traditionally for several ailments. Cashew apple is used as a curative against scurvy and stomach ailments like dysentery and diarrhoea. It is used as a tonic to mothers in confinement. It is a medicine for women after parturition. Cashew apple juice, without removal of tannin, is prescribed as a remedy for sore throat and chronic dysentery in Cuba and Brazil. Fresh or distilled, it is a potent diuretic, possessing anti scorbutic properties, and is useful for kidney troubles, and in advanced cases of cholera. It is given for uterine complaints and dropsy. The brandy is applied to relieve the pain of rheumatism and neuralgia. The cashew *feni* is used to cure various aliments of infants and aged.

Cashew apple liquor is used for medicinal purposes for aliments like worms, sickness, cold, body ache, fever or flue, toothache, fresh wounds and cuts, cramps due to chilling weather, muscular pain, irregular movement of bowels, low blood pressure, loss of sleep for aged people and cholera. Cashew apple juice kept in sunlight for a fortnight can be preserved for 2 to 3 years, which would have effect in treating fever and diarrhoea of both human beings and domestic animals. It is believed that cashew apple juice induces sleepiness when given along with medicines for patients affected by fever, thus helping in fast recovery.

Use in nutraceuticals: Ascorbic acid, fibre, carotenoid pigments, minerals and host of other chemicals, which are of significance to human health, are contained in cashew apple. Cashew apple powder lipids are rich in unsaturated fatty acids, the major ones detected being palmitoleic and oleic acids. Crude fibre content of dried cashew apple powder has been found to vary from 1.99 to 4.7% (NRCC, 2005). Vitamin C, an antioxidant present in cashew apple was analyzed and it showed variation from 40.1 to 177.8 mg/100g. A valuable by- product that can be obtained from cashew apple waste is pectin. Pectin is used in manufacturing jams, jellies, marmalades, preserves etc. It is useful as thickening, texturizing and emulsifying agent and finds numerous applications in pharmaceutical preparations and cosmetics. Pectin has been isolated from cashew apple powder, the yield of which varies from 1.6 to 2.03%. The cashew apple pomace or the fruit waste has been identified as the ideal medium for pectinase enzyme production for *Aspergillus foetidus* 115 through solid state fermentation.

Agricultural uses

Considerable amount of cashew apple residue is obtained as waste when bulk quantities of cashew apple is utilized for the manufacture of soft drinks or fermented beverages on a commercial scale. Nutrient status of cashew apple residue on dry weight basis are: total ash 1.6%, total tannin 5.2%, ether extractives 4.6%, calcium 20.6 mg/100g, phosphorous 152.7 mg/100g, proteins 8.8%, crude fibre 8.4% and iron 35.0 mg/100g. The cashew apple/cashew apple residue has the following uses in agricultural/livestock production.

Vermicompost: The cashew apple waste, which is highly perishable and seasonal, can be converted to value added products with good manurial value without creating problems for disposal. Apple residue could be effectively utilized for the production of vermi-compost of 1.69% N, 0.44% P and 0.58% K using *Eudrilus euginae*. The pH of the compost from cashew apple is 8.9 and hence could be used as a good ameliorant for acidic soils.

Animal feeds: The ripened cashew apple or its residue could be utilized for the preparation of cattle feed, pig feed and poultry feed. Cashew apple is a promising feed source for diary cows in Vietnam. Cashew apple or its residue could be preserved for long term use as cow feed by anaerobic ensiling with poultry litter. Cashew peel (7.6% protein, 12.3% fat and 59.2% carbohydrate) is a good poultry feed. Apples are also dried and preserved as cattle feed for rainy season. Daily feeding of 3-4 kg fresh apples along with normal feed to cow is found useful. However, cattle will have stomach problem causing diarrhoea, when fed excess quantity.

Cashew apple pomace, which is available after extracting juice from cashew apple and is rich in fibre, could be blended with cereals (ragi, rice and wheat) and pulses (green gram) up to 10% with out affecting the quality, in terms of *in vitro* digestibility of both proteins and carbohydrates. Cashew apple pomace based blends could be stored up to one year without affecting quality (Bhat *et al.*, 2009). Cashew apple residue after fermentation could be blended up to 20% to prepare animal or poultry feed, with out any adverse effect on milk yield (Nagaraja and Balasubramanian, 2007). Swain *et al.* (2007) reported that cashew apple waste could replace up to 20% maize on w/w basis in the diet of Vanaraja growing chicks for better economics without affecting the overall economics.

Pest management: It is observed that cashew apple extraction is an effective insecticide against red palm weevil (*Rhynchophorus ferruginous* Olive) in coconut. Cashew apple and gum extract, in combined form or alone, acts as an effective repellent against leaf feeding pests of vegetables. The cashew apple is dried and powdered into meal which can be used as bait for catching crustaceans.

Industrial uses

Bio-fuel: Utilization of non food crops such as cashew apple as a source for bio fuel production has great significance in today's world where we are facing huge energy crisis. Use of cashew apple particularly avoids food security problems when food crops were used for bio fuel production.

The potentials to utilize cashew apple for production of alcohol to be used as a bio-fuel are immense. Fresh cashew apple contains 9.5 to 10% carbohydrates, in addition to varying quantities of fats, minerals and vitamins. It is estimated that cashew apple can yield 8 to 10% of ethanol. Every kilogram of raw nut generates apple equivalent to produce 500 to 600 ml of ethanol of about 70% purity. This indicates that there is a huge potential of generating ethanol from cashew apple. As such, the use of cashew apple for ethanol production assumes greater significance.

If the cashew apple can be productively used it will not only provide a rich source of environment friendly bio-fuel, but also will revolutionize the economics of the cashew producing industry. The technology for extraction of ethanol from cashew apple has been standardized by CEPC Laboratory, Kollam, India and the same can be utilized for bio-ethanol production. However, further research is needed to evolve an efficient technology for getting a better recovery of ethanol from cashew apple. At present the residue obtained after extracting juice for feni preparation is used as fuel in liquor industry in Goa.

Biogas: Ripened fruits can be used as raw material for biogas plant.

Cashew apple processing technologies developed for commercialization

Cashew apple processing unit has been established at Cashew Research Station, Madakkathara, Thrissur under Kerala Agricultural University during 1997 for the manufacture of unfermented cashew apple products. It is the first ever unit established in India for cashew apple processing. The unit is successfully running for the last fifteen years and is currently undertaking commercial production of various cashew apple products *viz.,* cashew apple syrup, cashew apple drink, cashew apple soda, mixed cashew apple - mango jam, cashew apple pickle, cashew apple candy, cashew apple chocolate and cashew apple vinegar.

Cashew apple syrup, drink and soda: Selected cashew apples are cleaned thoroughly, juice extracted and clarifying agent, preservative and citric acid are added immediately. The clarified juice is siphoned out and this serves as the raw material for the preparation of syrup and drink. Sugar and citric acid are added to the clarified juice in required quantity to produce syrup and drink as per demand. Cashew apple soda was prepared by using syrup and carbonated chilled water. 75 psi carbonation is carried out in 150 ml water along with 50 ml syrup for the preparation of soda.

The nutrients, vitamin C and riboflavin, which are high in cashew apple, are preserved in these beverages also. Cashew apple syrup contains 276 mg vitamin C and drink contains 140 mg vitamin C/100 g. These are natural products and price is fixed comparatively less as compared to other common fruit drinks. Taste is better if served chilled. Syrup has a storage life of one year.

Cashew apple drink is an RTS (Ready – to -Serve) beverage. Drink is marketed both in glass bottles and in attractive food grade pouches. Pasteurized drink in glass bottles has a storage life of three months under ambient storage conditions.

Cashew Apple Drink and Cashew Apple Soda has also been launched in the open market during 2011 with very good sale.

Cashew apple-mango mixed jam: The ripe apples are collected from the plantation, selected, cleaned and soaked in salt solution for three days to remove tannin. Apples are again washed in water, cooked, made into pulp and is mixed with equal quantity of mango pulp. Pulp is mixed with sugar and citric acid to prepare jam. Vitamin C content of the product is 18 g/100g.

Cashew apple candy: It is a sweet product and quality apples with good shape are selected for candy preparation. As in jam preparation, tannin is removed from apples, cooked, pierced using fork and dipped in sugar solution. Concentration of sugar solution is gradually increased so as to reach 70^0 brix. After two weeks of soaking, sugar solution is drained out and candy is dried in shade. It takes about 2-3 weeks for making the final product. About 745 g candy can be obtained from one kilogram of cashew apple. Vitamin C content of the product is 28.4 mg/100g.

Cashew apple pickle: Mature but unripe cashew apples are collected directly from plantations carefully without disturbing the flowers and tender nuts. After cleaning, the fruits are cut into small pieces and astringency is removed by immersing in salt water. After removing from salt water, it is again washed and pickle is prepared using oil, chilly powder, fenugreek powder, turmeric powder, ginger and garlic paste.

Cashew apple vinegar: Cashew apple vinegar is prepared from cashew apple juice by adding sago, sugar and yeast along with mother vinegar.

Cashew apple chocolate: Cashew apple chocolate is prepared from cashew apple powder by adding milk powder, sugar and butter.

Economics and marketing of cashew apple products

Economics of processing of cashew apple for syrup production has been worked out (Mini *et al.*, 2006). By processing one tonne of cashew apple, a net profit of ₹ 10,368/- can be obtained. Considering that the average yield of nuts in India is ₹ 8,00 kg/ha, a production of 6.4 t/ha of cashew apple can be anticipated. A production of about 2 t/ha of good cashew apple can be ensured, taking 30% of the total production as good for processing. Thus the additional income from a hectare of cashew orchard from the processing of cashew apple worked out to ₹ 20,736/-, if a farmer or farmers' groups can venture into this endeavour. The income can be further enhanced by processing cashew apple for high value products like alcohol and wine. Compared to other fruits, the advantage of cashew apple is that it is available free of cost and hence the price of cashew apple can be fixed by about 20% less than that of conventional fruit drinks like mango and pineapple.

Processing of cashew apple is an economically viable enterprise in cashew growing tracts. Women Self Help Groups can very well take up this enterprise, thereby effectively contributing to the cause of women empowerment. Being natural and mostly organic, with medicinal and superior nutritive qualities, the products are well accepted by consumers. If legal permission is available for production of fermented products like liquor and wine, it can substantially enhance the income from cashew apple processing many folds. The increasing preferences for natural products, over synthetics, are to be given emphasis while marketing cashew apple products. Higher content of vitamin C and medicinal properties of cashew apple are added advantages to be popularized for the marketing of cashew apple products.

The production of cashewnut in the country is 6.13 lakh tonnes (2009-10). On an average, cashew apple weighs 8 – 10 times that of cashew nut. At that rate, the total production of cashew apple in the country is estimated to be around 60 lakh tonnes. At least a minimum of 30% of the total quantity can be economically utilized for production of value added products, working out to 18 lakh tonnes. Based on study, a net profit of ₹ 10,368/- can be obtained by the processing of one tonne of cashew apple. Thus the total national income that can be obtained through cashew apple processing is estimated to be around ₹ 1,800 crores. This is a significant contribution to national economy. Cashew apple processing can promote considerable economic activity in cashew growing areas, leading to substantial employment generation and added income to farmers, making cashew cultivation more attractive.

Transfer of technology programmes

Cashew Research Station, Madakkathara of Kerala Agricultural University is conducting intensive transfer of technology programmes at national and international levels to promote the economic utilization of cashew apple. It is running a frontline model cashew apple processing unit to acquaint the entrepreneurs on different aspects of commercial cashew apple processing unit, including the infrastructural and marketing requirements. The model unit is running on a commercial basis for the production of eight cashew apple products and has clearly demonstrated the profitability of cashew apple processing. This success story is to be replicated elsewhere in major cashew growing areas, which will give additional revenue to farmers and can generate considerable employment for unemployed youth and women. It is a good sign that few cashew apple processing units have started functioning in the state of Kerala, India

The constant transfer of technology initiatives by the Madakkathara Centre has resulted in the establishment of several units by private entrepreneurs and Self Help Groups. The first ever cashew apple processing unit in private sector has been established at Iritty, Kannur, Kerala under the trade name 'TOMCO PRODUCTS' and they are marketing cashew apple syrup. Three Self Help Groups have started cashew apple processing units at Payyavoor (Kannur district), Kelakam and Neendakara (Kollam district) during 2008-09.

The research, development and transfer of technology initiatives of Madakkathara Centre, supported by funding from State Horticulture Mission and *Rashtriya Krishi Vikas Yojana*, has started yielding results, with the establishment of several cashew apple processing units. The successes of these units largely depend upon the support of the state and central governments. Being a processed product, cashew apple products are also charged Valued Added Tax @ 12.5% at present. This is a major impediment in selling the cashew apple products at attractive prices. Extending financial support for establishing cashew apple processing units under National and State Horticulture Mission and Rashtriya

Krishi Vikas Yojana and declaring tax exemption for cashew apple products can encourage entrepreneurs to start new units.

Conclusion

Economic utilization of cashew apple has not progressed to the desired level in spite of excellent qualities of cashew apple and the availability of technologies for its processing to various value added products. The successful running of the commercial cashew apple processing unit for the last fifteen years at Madakkathara under Kerala Agricultural University clearly demonstrates the economic viability of cashew apple processing. However, the financial and policy support of the state and central governments are vital in promoting the economic utilization of cashew apple. Additional income from cashew apple processing will make cashew cultivation more attractive to farmers, there by enabling the country to achieve self sufficiency in raw nut production which is the need of the hour to support cashew industry as well.

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15

Nutritional and Nutraceutical Properties

CASHEW (*Anacardium occidentale*) is a versatile tree nut. The cashew kernel is a unique combination of fats, proteins, carbohydrates, minerals and vitamins. Cashew kernel contains 47% fat, but 82% of this fat is unsaturated fatty acid. The unsaturated fat content of cashew kernel not only eliminates the possibility of increasing cholesterol, but also balances or reduces the cholesterol level in the blood. Cashew kernel also contains 21% proteins and 22% carbohydrates and the right combination of amino acids, minerals and vitamins and therefore nutritionally, it stands on par with milk, eggs and meat. As cashew kernel has a very low content of carbohydrates, almost as low as 1% soluble sugar, it gives a sweet taste without excess calories. Consumption of cashew kernels does not lead to obesity and helps to control diabetes. Thus, it is a good appetizer, an excellent nerve tonic, a stimulant and a body builder (Nayar, 1998).

At present cashew is consumed as a snack food in all over world. There is, however, good scope for promoting cashew as a food ingredient as it blends well with every food preparation style. The kernels are eaten either fresh or roasted and salted and also contain a milky juice which is used in puddings. They are relished as garnish in sweets and desserts. Cashew kernels, along with almonds and other dry fruits are being used in various rice dishes such as Hyderabadi-biriyani, rice-pulao etc. and in curry (*kaaju*-shahi-paneer) preparations in Indian, Pakistani and Middle-East regions. Crushed cashew kernels with almonds, pistachio are often sprinkled over desserts.The cashew kernels are widely used in confectionery, as an ingredient to biscuits, sweets and cakes.

Lower grade kernels are processed in to cashew flour which has high protein content and is easily digested (Johnson, 1982). The kernels contain 35-40% oil. Lower grade kernels are processed into kernel oil (Caribbean oil) which is a high quality edible oil that has been favourably compared to olive oil. The oil obtained from cashew kernel rejects could find use in cosmetic industry after refinement. Kernel residue after extraction of kernel oil is used to produce cashew kernel butter which is almost similar to peanut butter. Butter could be extracted from cashew kernel and pertinent technology is developed by Central Food Technological Research Institute (CFTRI), Mysore, India (Van Eijnatten, 1991). There is a possibility of developing sugar, honey and salt coated baby bits, which are organoleptically acceptable. Baby bits are the lowest grade kernels marketed commercially. Sweetened and flavored milk could be prepared from cashew kernel baby bits. Cashew spread can also be prepared from kernel baby bits. Comparative investigation on various types of spreads revealed that sweetened and Vanillin flavored cashew spread is most preferred to salted spread (Bhaskara Rao and Swamy, 2002).

Nutritional properties

Cashew kernels: Nuts are complex food matrices containing diverse nutrients and other chemical constituents that may favorably influence human health (Joan Sabate *et al.*, 2006). Cashew kernel contains proteins (21%), carbohydrates (22%), fat (47%) and fairly good amount of minerals and vitamins. Besides protein, fat, and carbohydrate, it contains a number of inorganic elements like sodium, potassium, calcium, mangenium, phosphrous, iron, copper, zinc, manganese, selenium and chlorine.Cashew kernel is an ideal supplement in the diet of children, pregnant women and lactating mothers. It could be an alternate source of proteins and carbohydrates. The carbohydrates present in cashew are composed of sugars, starch and dietary fibre. Cashew kernel proteins are comparable with milk protein casein in terms of protein efficiency ratio (Nagaraja, 2008). The protein efficiency ration (PER) of cashew kernel protein is 3.2. It has been reported that the risk of developing diabetics is comparatively low even if cashew is consumed continuously. It is attributed to the low content of sugar and presence of complex

Table: 15.1. Nutritive value of different nuts (Nutrient comparison chart for one serving/one ounce of tree nuts)

Nuts	Almond	Brazil	Cashew	Hazelnut	Macademia	Pecan	Pistachio	Walnut
Calories (K Cals)	163	186	157	178	204	196	159	185
Protein (g)	6.0	4.1	5.2	4.2	2.2	2.6	5.8	4.3
Total fat (g)	14.0	18.8	12.4	17.2	21.5	20.4	12.9	18.5
Saturated fat (g)	1.1	4.3	2.2	1.3	3.4	1.8	1.6	1.7
Polyunsaturated fat (g)	3.4	5.8	2.2	2.2	0.4	6.1	3.9	13.4
Monounsaturated fat (g)	8.8	7.0	6.7	12.9	16.7	11.6	6.8	2.5
Carbohydrates (g)	6.1	3.5	8.6	4.7	3.9	3.9	7.8	3.9
Dietary fiber (g)	3.5	2.1	0.9	2.7	2.4	2.7	2.9	1.9
Potassium (mg)	200	187	187	193	104	116	291	125
Magnesium (mg)	76	107	83	46	37	34	34	45
Calcium (mg)	75	45	10	32	2.4	20	30	28
Iron (mg)	1.1	0.7	1.9	1.3	1.1	0.7	1.1	0.8
Zinc (mg)	0.9	1.2	1.6	0.7	0.4	1.3	0.6	0.9
Copper (mg)	0.3	0.5	0.6	0.5	0.2	0.3	0.4	0.5
Vitamin B_6 (mg)	0	0	0.1	0.2	0.1	0.1	0.5	0.2
Vitamin E (mg)	7.7	1.6	1.9	4.3	0.1	7.6	7.3	6.7
Folate (mg)	14	6	7	32	3	6	14	28
Riboflavin (mg)	0.3	0	0	0	0	0	0	0
Niacin (mg)	1	0.1	0.3	0.5	0.7	0.3	0.4	0.3
α-tocopherol (mg)	7.4	1.6	0.3	4.3	0.2	0.4	0.7	0.2

Table 15.2. Contribution from 100 g cashew kernels to the daily diet requirement of an adult

Particulars	Requirement for daily diet of a normal adult	Contribution by 100 g of cashew kernels
Calories	3000-3500	600
Proteins	60-75 g	21g
Carbohydrates	375g	22g
Fats	68g	47g
Phosphorus	1.44g	0.45g
Calcium	0.68g	0.05g
Iron	0.015g	0.5g
Vitamin A	4000 I.U.	3221 I.U.
Vitamin B	400 I.U.	111 I.U.
Vitamin E	46mg	—

(Abdul Salam, 2010)

Table. 15.3 Chemical composition of cashew apple juice and bagasse.

Composition	Value
Cashew apple juice	
Total soluble solid (% w/v)	7.4-14.5
Reducing sugar (% w/v)	9.04-10.4
Glucose (% w/v)	3.85-4.63
Fructose (% w/v)	3.90-4.52
Sucrose (% w/v)	0.042-0.051
Total acidity (% as malic acid)	0.29-1.1
Malic acid (% w/v)	0.4
Citric acid (% w/v)	0.42-0.64
Ascorbic acid (mg/100 ml)	104-293.5
pH	3.5-4.6
Total tannins (mg/100 g)	0.6
Condensed tannins (mg/100 g)	0.2
Carotene (mg/100 g)	0.03-0.74
Cashew apple bagasse	
Cellulose (%)	19.21-24.3
Hemicellulose (%)	12.05-12.5
Lignin (%)	22.5-38.11
Protein (%)	14.2
Non-fiber carbohydrate (%)	11.3

(Trakul Prommajak *et al.*, 2014)

carbohydrates (Jose Mathew and Sobhana, 2013). As per in USDA National Nutrient Database-2010; the nutritional value of different nuts is given in Table 15.1.

Besides, cashew kernel contains about 1.3% dietary fibre and it provides more energy compared to animal food (147-272 K cals/100 g) and fish (234 K cals/ 100 g). Cashew kernel provides an energy of 611 K cals/100 g and this is very much comparable with that of almond (612 K cals/100 g) (Nagaraja, 2008).Daily diet requirement of a normal adult and contribution from 100 g of cashew kernels is given in the Table 15.2.

Cashew apple: The pseudo fruit which is otherwise called cashew apple is a juicy fibrous fruit which is quite nutritious (Table 15.3). Cashew apple is very rich in ascorbic acid (240 mg/100 g) which is almost six times that of citrus fruits (40 mg/100 g) (Nagaraja, 2008). Also, cashew apple is a good source fibre and contains free soluble sugars most of which are reducing sugars. On a dry weight basis, the crude fibre content varies from 15 to 18%. Consumption of cashew apple could help in overcoming the Vitamin C deficiency and also constipation (Nagaraja, 2007). Cashew apple fruit has medicinal properties. It is used for curing scurvy and diarrhoea, and it is effective in preventing cholera. Hence, preparation of value added products from cashew apple is one of the important areas of concern for food technologist, industrialist and growers (Suganya and Dharshini, 2011). In Goa state, liquor named "Fenni", made from cashew apple, has been as "home doctor" for several centuries (Augustin, 1984).

The vitamin and mineral content of cashew apple is higher when compared with other common tropical fruits

(Table 15.4). Vitamin B_2 content of cashew apple is about 5-fold when compared with pineapple and grapes. The vitamin C content of cashew apple is 5 to 10 fold more than pine apple, banana, orange and grapes (Nagaraja, 2007).

Table: 15.4 Vitamin and mineral content of various tropical fruits (mg/100g)

Constituent	Cashew apple yellow	Cashew apple red	Pine apple	Avocado	Banana	Lime	Grape	Mandarin	Orange
Thiamine	-	-	90	120	90	10	40	70	90
Riboflavin	99	124	20	150	60	Traces	20	30	30
Vitamin C	240	186	24	16	10	45	40	31	49
Calcium	41	41	16	10	8	14	-	33	33
Phosphorus	11	11	11	38	28	10	-	23	23
Iron	3	3	0.3	0.3	0.6	0.1	-	0.4	0.1

`(Nagaraja, 2002)

Nutraceutical properties

Nutritional therapy and Phyto-therapy have emerged as new concepts of health aid in recent years. Strong recommendations for consumption of nutraceutical from plant origin have become progressively popular to improve health, and to prevent and treat diseases. Dr Stephen De Felice coined the term "Nutraceutical" from "Nutrition" and "Pharmaceutical" in 1989. Nutraceuticals are "naturally derived bioactive compounds that are found in foods, dietary supplements and herbal products, and have health promoting, disease preventing and medicinal properties." Evidences suggest that a diet high in fruits and vegetables may decrease the risk of chronic diseases, due to low fat content and high levels of fiber and antioxidant substances, such as ascorbic acid and polyphenols (WHO, 2003). Plant derived nutraceuticals/functional foods have received considerable attention because of their presumed safety and potential nutritional and therapeutic effects. Phytochemicals, as plant components with discrete bio-activities towards animal biochemistry and metabolism are being widely examined for their ability to provide health benefits; such phytochemicals include terpenoids, phenolics, alkaloids and fiber. Research supporting beneficial roles for phytochemicals against cancers, coronary heart disease, diabetes, high blood pressure, inflammation, microbial, viral and parasitic infections, psychotic diseases, spasmodic conditions, ulcers, etc is based on chemical mechanisms using *in-vitro* and cell culture systems, various disease states in animals and epidemiology of humans.

Nut: Cashew kernel is a complete capsule with high nutritional and nutraceutical properties. Because of high fat content (47%) which is quite rich in unsaturated fatty acids,cashew is considered as 'fatty food' and is listed in several occasions under foods to be avoided along with meat, fish and poultry but the fat quality of cashew nut is quite good than that of fat from the animal sources. The quality of fat depends upon its fatty acid profile. Fat source is considered best if the mono unsaturated fatty acids are more than poly unsaturated fatty acids and saturated fatty acids content. In addition, the levels of saturated fat and poly unsaturated fat need to be nearly equal. In cashew nuts, the ratio of mono saturated fat to saturated fat is about 4:1 while the ratio of unsaturated to saturated fatty acid is 5.9. There is also a balanced ratio between the saturated fat and the polyunsaturated fat, approximately 1:1 (Jose Mathew and Sobhana, 2013).

The cashew kernel contains right proportion of saturated, mono unsaturated and poly unsaturated fatty acids. The major fatty acids present in cashew kernel fat is oleic acid (73.4%) followed by linoleic acid (11.9%). Stearic acid is the major saturated fatty acid present (11.9%) (Table 15.5). Cashew kernel is free from cholesterol and contains sizeable quantity of mono unsaturated fatty acid (oleic acid) which is now believed to be as efficient as unsaturated fatty acids in lowering the blood cholesterol. The principal polyunsaturated fatty acid found in cashew is Omega-6, which is vital for the health. Fats from animal sources are composed of saturated fatty acids, which increase the level of low density lipoprotein (LDLs) in blood. Choking of the arteries is mainly due to LDLs in the blood resulting in to cardiac failure. The research has proved beyond doubt that the fat in cashew is composed mainly of unsaturated fatty acids (> 80%) which raises the levels of high density lipoproteins (HDLs) and reduces levels of LDLs, thus lowering the risk of heart diseases (Olife *et al.*, 2013). The linoleic acid (18:2) presents in cashew kernel helps in lowering serum LDL and elevating HDL.

Cashew kernel does not contain any anti-nutritional factors however allergic reactions to cashew kernel globulins have been reported from USA. Similarly, proteinase inhibitors have been detected in cashew kernel from Brazil. These proteinase inhibitors have not been detected in Indian cashew kernel. Cashew kernel proteins contain all essential amino acids (38.78%). The major basic amino

Table 15.5 Fatty acid composition of kernel oil of different tree nuts (% of total fatty acids)

Constituents	Almond	Hazel nuts	Walnuts	Macadamia nuts	Cashew
Lauric (12:0)	-	-	-	0.62	-
Myristic (14:0)	0.2	2.2	-	0.75	-
Palmitic (16:0)	8.9	3.1	7	6.15	0.9
Palmitoleic (16:1)	4.0	-	-	19.11	-
Stearic (18:0)	62.5	1.6	3	1.64	11.24
Oleic (18:1)	24.4	88.1	30	67.24	73.73
Linoleic 18:2)	-	2.9	57	1.34	7.67
Linolenic (18:3)	-	-	2	-	-
Arachidic (20:0)	-	-	-	3.30	-
Lignoceric (24:0)	-	-	-	-	0.15
Unsaturated	86.9	91.0	89.0	87.69	81.4
Saturated	13.1	6.9	10.0	12.46	12.29
Unsaturated/ Saturated	6.63	13.19	8.9	7.04	6.2
Mono unsaturated/ Poly unsaturated	2.6	30.4	0.51	64.4	9.6

(Nagaraja, 2008)

Table 15.6. Amino-acid composition of cashew kernel protein

Amino Acid	Values (%)
Glutamic acid	28.00
Leucine	11.93
Isoleucine	-
Alanine	3.18
Phenylalanine	4.35
Tyrosine	3.20
Arginine	10.30
Glycine	5.33
Histidine	1.81
Lysine	3.32
Methionine	1.30
Cystine	1.02
Threonine	2.78
Valine	4.53
Tryptophan	-
Aspartic acid	10.78
Proline	-
Serine	5.76

(Nagaraja, 2007)

Table 15.7. Mineral content of cashew kernel (%)

Calcium (Ca)	0.04
Phosphorus (P)	0.88
Sodium (Na)	0.005
Potassium (K)	0.57
Magnesium (Mg)	0.28
Irone (Fe)	0.008
Copper (Cu)	0.002
Zinc (Zn)	0.004
Manganese (Mn)	0.002

acids (Table 15.6) such as leucine and arginine are present to an extent of 22.23%.

Cashew kernel is rich in various minerals particularly potassium and phosphrous (Table 15.7). For instance, 100 g of edible cashew provide 2.82 mg of vitamin B, 37 mg of calcium, 292 mg of magnesium, 593 mg of phosphorus, and 660 mg of potassium (Sathe, 1994). Potassium is known to be essential for upkeep of human kidney. Selenium present in cashew kernel could help in protecting against, lung, liver, skin, brain and gastro intestinal cancer. Furthermore, the US Food and Drug Administration recommend the consumption of 1.5 oz (42 g) per day of most tree nuts which may reduce the risk of heart disease (Alasavarand Shahidi, 2009). The experiment carried out on human feeding trials has investigated the effect of nut consumption on blood lipids and other biological indexes of heart diseases (Kris-Etherton *et al.,* 1999; Mukuddem-Petersen *et al.,* 2005). Epidemiological studies have associated the frequency of cashew nut intake with reduced risk of some chronic diseases, such as coronary heart diseases (Hu and Stampfer, 1999; Sabate *et al.,* 2001), diabetes (Jiang *et al.,* 2002) and cancers of the prostate (Mills *et al.*, 1989) and colorectum (Yeh *et al.,* 2006). Cashew kernel oil contains vitamin E, which is a naturally occurring antioxidant (210 mg/100 g).

Cashew apple: Cashew apple is quite rich in crude fibre, phenols, tannin and flavonols could serve as natural antioxidants which play a major role in destroying free radicals. The use of cashew apple fibre for human consumption opens up new perspectives, as it is a natural source of phenolic compounds and antioxidant activity (Bronizi *et al.*, 2007), and also has appreciable amounts of vitamin C (Uchoa *et al.*, 2008). Christiane Queiroz *et al.* (2011) quantified ascorbic acid, total polyphenols and proanthocyanidins of fresh-cut cashew apple. Cashew apple presented 163 mg of ascorbic acid per 100 g of fresh weight (FW). Soluble and hydrolysable polyphenols contents were 12.79 mg GAE/100 g FW and 18.53 mg

GAE/100 g FW and proanthocyanidins were 9.27 mg/100 g FW. Ascorbic acid is important for the human physiology, and it has a role in the production and maintenance of collagen, wound healing, and the reduction in susceptibility to infections, also in the formation of bones and teeth, iron absorption and prevention of scurvy (Maia *et al.*, 2007). Ana Cristina Silva de Lima *et al.,* (2014) reported that ascorbic acid levels in cashew apple juice as 49.30 and 12.90 mg per 100 g native and after *in-vitro* simulated gastrointestinal digestion, respectively and found bioaccessible percentage after *in-vitro* simulated gastrointestinal digestion of ascorbic acid of the cashew apple juice as 26.2%. They further reported that bioaccessible percentage of zinc, ascorbic acid and total extractable polyphenols are higher in cashew apple juice which attributed to the low level of tannins and phytates found in fruit juices, hence recommended consumption of cashew apple juice. The cashew apple pulp is rich in ascorbic acid, phenolic compounds, minerals and carotenoids, to utilize this fruit as functional food.

Wojdylo *et al.* (2009) reported that phenolic compounds are metabolites that have the ability to neutralize reactive species, helping to protect the body against oxidative stress and have antioxidant activity. Ana Cristina Silva de Lima *et al.,* (2014) found out average content of total extractable polyphenols for cashew apple juice and cashew apple fibre as 338.60 and 566.10 mg GAE per 100 g and 130.60 and 105.03 mg GAE per 100 g after digestion, respectively. Bioaccessible levels of total extractable polyphenols were 39.0% and 18.6% for cashew apple juice and cashew apple fibre, respectively. Edy Sousa de Brito *et al.* (2007) identified and quantified flavonoids in cashew apple by Liquid chromatography. One anthocyanin and thirteen glycosylated flavonols were detected in a methanol–water extract.

Copper is an essential element for plants and animals, its importance lying in the fact that it is present in more than 13 enzymes that are involved in energy production, in the prevention of anemia and bone disease, in reducing cell damage and also required for foetal and infant development. In addition, copper is required for other functions, such as the maintenance of tissue and skin and hair pigmentation (Altundagand Tuzen, 2011). Thus, its intake is essential and the recommended daily intake is 2 mg (based on a 2000 calorie intake) (FDA, 2013). Ana Cristina Silva de Lima *et al.,* (2014) determined the average values for copper in cashew apple juice and cashew apple fibre were 2.10 and 12.20 mg per litre, respectively. Despite the fact that cashew apple juice has a lower copper content than cashew apple fibre, the bioaccessibility of the juice was almost four times higher than that observed in the cashew apple fibre.

Iron's main function in the body is its presence in the formation of red blood cells, and its deficiency causes anaemia, reducing the number of red blood cells and, thereby, decreasing oxygenation (Lehninger *et. al.*, 2011). The recommended daily intake of iron is 18 mg (based on a 2000 calorie intake) (FDA, 2013). Ana Cristina Silva de Lima *et al.,* (2014) also reported the values for iron obtained before and after *in-vitro* simulated gastrointestinal digestion were 1.82 and 0.17 mg per liter for the cashew apple juice, and 21.60 and 0.20 mg per liter for cashew apple fibre, respectively. Soares *et al.* (2004) observed iron content of 1.27 mg per liter in cashew apple juice. The bioaccessibility of iron after digestion of cashew apple juice was 11.50% and of cashew apple fibre was 1.2%. Khouzam *et al.*, (2011) in a study of bioaccessibility of essential elements in fruits and vegetables, reported bioaccessible percentages of iron ranging from 6.7% to 12.7%, values close to those found for the cashew apple juice.

Zinc is required for the operation of over 300 different enzymes and plays a vital role in a number of biological processes. The deficiency of this mineral in humans causes growth retardation, abnormal bone formation. The recommended daily intake of zinc based on a 2000 calorie intake is 15 mg (FDA, 2013). Ana Cristina Silva de Lima *et al.,* (2014) obtained values for zinc in cashew apple juice and cashew apple fibre were 4.70 and 7.14 U mg per liter, and after *in- vitro* simulated gastrointestinal digestion were 0.14 and 0.12 mg per liter, respectively. In the present study, they found cashew apple juice and cashew apple fibre having bioaccessible fraction of zinc was lower than 5%. According to Soares *et al.* (2004), the amount of total mineral in fruit juices, reported an average of 0.12 mg per liter of zinc in the cashew apple juice concentrate.

Cashew apple juice has been reported to have antitumor (Cavalcante *et al.,* 2005), antimicrobial (Kubo *et al.*, 2003), urease inhibitory (Kubo *et al.*, 1999) and lipoxygenase activity (Ha and Kubo, 2005). Three anacardic acids have been isolated from cashew apple as cytotoxic agents against BT-20 breast carcinoma cells from the cashew apple juice (Kobo *et al.*, 1993) Bicalho *et al.*, 2000 reported that chemically, the cashew apple contains volatile compounds such as resorcinolic acid, anacardic acids and carotenoids (a-carotene, b-carotene and b-cryptoxanthin). Cavalcante *et al.* (2003) measured protection of DNA damage from ROS and showed that fresh cashew apple juice has higher antioxidant capacities than the processed juice.

Himejima and Kobo (1991) studied antimicrobial activity of flavour compounds in cashew apple. They reported that the flavor compounds of the cashew apple, such as (E)-2-hexenal showed activity against all of the 14 microorganisms tested. Anacardic acids possesses antimicrobial activity against methicillin-resistant Staphylococcus aureus, Streptococcus mutans and anti-Helicobacter pylori (Kubo *et al.*, 2003; Green *et al.*, 2007). Diets containing antioxidants and branch chain amino acids are also reported to have potential effects on fat utilization. Cashew apple juice comprises many nutritional components including vitamin C and branched chain amino acids. Piyapong Prasertsri (2013) reported that cashew apple juice supplementation enhanced fat oxidation during exercise.

Stem and Leaf: Several studies have evaluated the biological effects and pharmaceutical potential of cashew tree extracts and parts. For instance, pre-treatment with 200 mg/kg of the methanol extract of cashew stem bark completely protected against lipopolysaccharide-induced septic shock in Swiss mice (Olajide *et al.,* 2004). A mixture of condensed and hydrolysable tannins from the bark of cashew. showed anti-inflammatory activity (Mota *et al.*, 1985).Antimutagenicity and antigenotoxicity studies performed with methanolic extracts of the cashew stem bark reinforced the potential therapeutic properties of this plant (Barcelos *et al.*, 2007 a, b). Hydroethanolic extract from cashew leaves, which are rich in polyphenols, inhibited gastric lesions induced by HCl/ethanol in female rats (Konan and Bacchi, 2007b).

Cashew nut shell: Cashew nut shell liquid (CNSL) is used in industrial applications such as food preservatives, paints, cements and for gasoline stabilization. As such, it is an important commercial product in several tropical countries (Paramashivappa *et al.*, 2001; Trevisan *et al.*, 2006; Narasimhan *et al.*, 2008). CNSL is a cheap and renewable by-product obtained during cashew nut processing (Paramashivappa *et al.*, 2001; Rodrigues *et al.*, 2006). As a unique, natural source of unsaturated long-chain phenols, CNSL is being used in insecticidal, fungicidal and medicinal applications. For instance, in the hypoxanthine/xanthine oxidase assay, CNSL is a potent scavenger of reactive oxygen species (ROS) (Trevisan *et al.*, 2006). Anacardic acids have been described as the main active compound in CNSL, and evidence suggests that the phytyl side-chain, along with the phenolic ring system (as salicylic acid), drives its great antioxidant capacity (Trevisan *et al.*, 2006). Anacardic acids in the cashew nut shell liquid are biologically active as gastroprotectors, inhibitors of the activity of various deleterious enzymes, antitumor agents and antioxidants.It is also reported gastroprotection and inhibition of enzymes such as lipoxygenase (Ha and Kubo, 2005), tyrosinase (Kubo *et al.*, 1999), cyclooxygenase) and histone acetyltransferases (Sun *et al.*, 2006; Dekker and Haisma, 2009) are some of the important functional properties of Anacardic acid. Sung *et al.* (2008) have demonstrated that AAS modulate the nuclear factor-B signaling pathway through a variety of stimuli and suggested that Anacardic acids could be a therapeutic option for cancer prevention or treatment.

Safety standard

Cashew, being a delicious snack food and an export oriented nut crop, it is important to take up all the precautionary measures so that no trace of any insecticide is detected in the kernels. Cashew suffers greatly due to pest menace wherever the crop is grown. Tea mosquito bug (TMB) and Cashew Stem and Root Borer (CSRB) are the two major pests that cause substantial yield reduction. For the management of TMB, insecticides like endosulfan and carbaryl were used since long but now not in use, however lambda cyholothrin is presently recommended for management of TMB. In order to determine residue levels in the cashew kernels, raw nuts were collected at regular intervals after spray and analysed. Results indicated that, residues of carbaryl were not traced in the kernels in all the samples collected from Tamil Nadu, Maharashtra, Karnataka and Orissa. Similarly, endosulfan residue was not detected from the sample obtained from Tamil Nadu,Karnataka and Orissa (Bhat and Raviprasad, 2006). However, traces of endosulfan (0.003 to 0.007ppm) were detected in the two samples only collected from Maharashtra. The cashew kernels obtained from the Experimental plots at DCR, Shantigodu Farm treated with lambda cyhalothirn (0.003%) were also analysed for the residues in collaboration with Cashew Export Promotion Council of India (CEPCI), Quality Control Laboratory, Kollam (Kerala) but no insecticide residue was detected at detection limit of 100 ppb (DCR Annual Report: 2005-06). The MRL permissible in kernel is not available for cashew. It is available in the case of macadamia nuts which varied from 0.1 ppm (European countries) to 0.2 ppm (United States) (Codex, 2004 and European Union, 2004). The level of residues detected is much lower than these limits and hence kernels are safe for consumption. Besides, the cashew apple samples were collected at regular intervals after spray of lambda cyhalothirn (0.003%), where the residue level fell below the Maximum residue limit of 0.2 ppm within 15 days of treatment (DCR Annual report: 2010-11).

Similarly, the cashew kernels obtained from the trees treated with lindane and chlorpyriphos in Tamil Nadu, Orissa, Maharashtra and Karnataka for the management of Cashew Stem and Root Borers at recommended concentration and double the recommended concentration were analyzed and it was also found free from residues of these insecticides (Bhat and Raviprasad, 2008). In general, adoption of plant protection measures for management of pests is very low among the cashew farmers. Therefore, there is minimum risk of insecticidal residues in the kernels.

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16

Marketing and Export

PROPER MARKETING SYSTEM always ensures better profit margin to the stakeholders. The return from cashew cultivation not only depends upon input and output factors but also quality of raw nut produced. Management of quality standards in rawnut was not an important factor earlier as it is now. The requirement specified in the quality standards are based on trade practices established by trade groups or associations. The general requirement is that the raw cashewnut shall be ripe nuts of *Anacardium occidentale* L. grown in the locality/region and shall (*i*) have the shape, colour and other characteristics of the variety (*ii*) be well dried and matured, (*iii*) be completely free from moulds, disease, decay, insect attack etc. Until a few years ago quality was a simpler concept and that of raw nuts was not an important factor. Competition was also not as severe then and customer expectation was not very high as it is now.

Raw cashew nuts are a seasonal commodity and the trading season is from March to May. Growers usually supply the primary or village markets where small traders collect and supply the urban markets. The cashew trade is seldom handled by exclusive traders. Usually, those traders who collect other plantation products also trade cashewnut. Due to the highly competitive nature of the cashew trade, growers have few marketing problems. When large quantities are collected by middlemen, the processors enter in the marketing chain and make wholesale purchases. Grades and standards for cashew are yet to be introduced in India. Quality is generally determined by appearance and cutting tests that traders employ prior to purchase. The raw cashew nut market involves a large amount of capital where nearly 80 per cent of the produce is transacted within 35 days. The current value of Indian production is estimated at around ₹ 10,000 million. This capital is made available by industry for procurement and processing operations.

The cultivation and marketing of cashew nut involve a considerable amount of manpower and hence play a vital role in the economic activities in India. The problems associated with its cultivation, domestic and export marketing do not permit the growers to reap optimum return and traders do not get reasonable profit. In India, large numbers of middlemen are involved in domestic and export marketing of cashew nut. As there is no organized domestic and export market for cashew nuts, many a time the growers are at the mercy of unscrupulous village traders. Further in the recent past, the export price of cashew nut is widely fluctuated due to changes in foreign market. Therefore, a scientific study to explore the ways and means to identify the problems connected with the production and marketing of cashewnut in order to enlighten the people concerned about the inherent strength, weakness, opportunity and threat becomes relevant and socially significant. Massive area expansion programme and rejuvenation of old cashew orchards of seedling origin, coupled with supply of quality planting material may have the potential to alter the cashew production, processing and EXIM scenario of the whole country.

The policy initiatives towards promotion of cashew growers cooperatives (for procurement of raw nuts, supply of inputs, credit and infrastructure, small scale processing, value addition and marketing), and cashew apple processing will definitely widen the perspective of cashew growers (Senthil and Mahesh, 2013). As such, there are no grower's cooperatives or organizations for cashew marketing. In Kerala, however, the government has been involved in the procurement process and supply to large-scale processors. This adversely affected the cashew trade and has now been replaced by a free market policy. In addition to the local production of nearly 7 lakh tonnes, India also imports a considerable quantity of raw nuts from African and South-East Asian countries to satisfy the national processing capacity of about 12 to 14 lakh tonnes established in the country.

This crop is subjected to wide price fluctuation in the domestic as well as in international market. There is a need to exploit the full potentiality of this crop. Therefore, farmers have apprehensions for the cultivation of this crop with long-term investments. India held a virtual monopoly position in the production and export trade of cashew prior to eighties. However, since eighties India is losing its monopoly to other new entrants like Vietnam, Brazil and Tanzania. International market for cashew becomes increasingly competitive exerting threat to India's export prospects. Further, the export market is exposed to increased risk because of trade liberalization and complex and continuously changing market environment. Therefore, it is imperative for us to study the market opportunities and to plan for appropriate export marketing strategy and policy so as to strengthen the production and export trade in cashew. Apart from this, in the world market, at present, we are facing stiff competition from Vietnam, Brazil and other tree nuts (Anon., 2015).

Prerequisites for better marketing

Ensuring maturity standard of raw cashewnut: Cashew fruit consist of two parts namely cashew nut (actual fruit) and cashew apple (pseudo fruit). Cashew nut develops first and the pseudo fruit develops later. It takes 60 days for both the nut and the pseudo fruit to develop completely since anthesis. Development of cashew apple and nut has been studied by number of workers in different cashew varieties (Antarkarand Joshi, 1987; Mohan Kumar *et al.*, 1984; Sumrit Feungehan *et al.,* 1989; Augustin and Unnithan, 1981; Rao *et al.,* 1962). According to a report specific gravity could be considered as physical index of maturity of nut in cashew varieties of V-1, 2, 3, 4 and 5 (Antarkarand Joshi, 1987; Mohan Kumar *et al.* 1984). Augustin and Unnithan (1981) have reported that the growth of nut is faster during early stage of development than that of fruit. Changes in the composition of cashew nut and apple during development have been looked into by various workers. Hariharan *etal.* (1985) reported decrease in amino acid content in kernel with increased maturity. Cashew kernel lipid, free amino acids and CNSL have been shown to increase with increased maturity. Similarly cashew kernel phenols have been shown to decrease with maturity. Changes in the kernel sugars and starch were not uniform (Anon, 1998).

Studies conducted at NRC Cashew on effect of maturity on the processing quality have clearly indicated that shelling percentage, peeling outturn, per cent wholes recovered increases while per cent kernel rejects decreases with maturity, Table 16.1 (Nagaraja, 2000).

Table 16.1 Effect of maturity on processing quality

DAA	Shelling (%)	Peeling out turn (%)	% Wholes recovered	% Kernel reject
40	12.3	3.2	87.5	68.0
45	23.1	17.1	80.9	28.8
50	28.7	-	-	Nil
55	27.9	27.1	78.4	Nil
Fully mature	29.9	24.6	84.5	1.8

Harvesting of nuts: Cashew puts forth indeterminate inflorescence which takes 60 to 120 days to complete flowering resulting in continuous fruit set and maturity within a panicle. Therefore, to get fully matured nuts, only fallen nuts are to be collected from ground. This method of harvesting not only helps in getting fully matured quality nuts but also in getting higher yield by weight per tree and fetches better market price as compared to existing practice of harvesting of nuts from tree before they mature by shaking or any other means, wherein potential hermaphrodite flowers and immature fruits at different stages drops off resulting in loss of yield and quality.

Fully mature nuts will have brown colour. In view of pilferage of nuts, cashew growers have a tendency of plucking the nuts before the pseudo fruit develops completely. This results in harvesting immature nuts which affects the quality of the kernels. Fully mature apples are plucked from the tree with the help of a long pole with a sickle tied to it at one end. When the cashew apple is fully ripe, with a simple tap on the fruit the fruit drops off. Shaking the branches for harvesting the nuts is practiced. Although this results in dropping of fully mature nuts, this also leads to dropping of immature nuts. As such this practice of harvesting nuts should be avoided. The best method of harvesting the nuts is to wait till it falls and collect the fallen nuts. This damages the pseudo fruit. If one intends to utilize cashew apple, one has to pluck the fruit from the tree without causing any damage to the fruit.

Drying of raw nuts: Drying seeks to reduce the moisture content to facilitate storage without rapid deterioration. Drying is done for 2 to 3 days only, moisture loss at this stage ranges between 8 and 10% depending on the time of harvest. However, excess drying at high temperature (above 40^0C) may lead to reduced kernel quality. Since the raw nut processing is an activity spread over different months, it is necessary to store the nuts over 6 to 12 months before processing. To prevent damage of kernels during storage, the moisture content of the raw nut is to be kept below certain critical level. Sun-drying of raw nuts for 2-3 days may bring down the moisture content to safer level (9-12%). Well-dried nuts when pressed with hand produce a shrilling noise indicating that they can be safely stored.

Some farmers proceed to one or two dryings for immediate sales. A few farmers store the raw nuts for off-loading during the Ganapathi festival (last week of August or first week of September) and therefore do dry the nuts three or four times. But, most of the farmers do not dry the produce at all. The reasons given are first, a fear of weight loss (estimated to be 10-12%); second, because of the small size of their lot (which will be mixed up with other lots) and consequent lack of negotiation power, they will get no extra price advantage from it. In addition, the infrastructure needed (drying yards) for drying is lacking among the farmers.

Moreover, many of them are not aware of the drying technology (i.e. number of turnings of the heap, testing the extent of drying by observations or cutting, etc).While small scale industries (SSIs) are aware of the quality of nuts in terms of moisture percentage, micro entrepreneurs do not know about these quality parameters. Moisture meter are available, but as the moisture varies from area to area, it is difficult to calibrate them that satisfy both, the buyers (processors) and the sellers (farmers/traders). Further, both farmers and petty traders often mix the dried and the un-dried cashew nuts pulled from different places when selling them in bulk. This is well known by the bigger traders, and as a result farmers loose on the price advantage of dried cashew nut. The lot purchased by processors is therefore a heterogeneous mixture of various sizes. Processors do not feel that segregated lots of cashew nuts are necessary anyway, since the cutters will not accept to cut small nuts, as their wage level (related to the weight of cashew processed) would decrease.

Raw nuts at the time of harvest will have moisture content ranging between 16 to 25%. Sun dried nut will have a moisture content of 9 to 11 per cent (Nagaraja, 2000). If the nuts are not dried and stored, it leads to fungal spoilage resulting in poor quality of kernels. Fungi such as *Gonatobotryum, Helminthosporium* sp., *Corynespora* sp., *Alternaria* sp., *Verticillium* sp. and many species of *Aspergillus* have been isolated from stored cashew nuts (Joseph, 1981). In view of the occurrence of fungi, drying of the raw nuts before storage becomes absolutely essential. Maximum permissible moisture content of raw cashew nuts is 8.7 to 9.1% (Ohler, 1979). Okwelogu and Mackay (1969) have reported that high whole nut or kernel moisture percentages are closely associated with high shell moisture contents and for nuts whose moisture content is in equilibrium with the ambient relative humidity, the moisture content of whole nut and kernel could be predicted from that of shell with more than 99% accuracy. A higher kernel shell weight ratio has been shown to be inversely proportional to moisture content.

Storage of raw nuts: Cashew nut is a seasonal crop and is available between March to end of May. For processing during off-season, it is therefore required to store the raw cashew that is not processed during that period. To ensure a longer life of the stored cashew, the moisture content in cashew nut has to be minimized. To minimize damage, it is necessary to store nuts in moisture proof store houses.

Usually dried raw nuts are packed in gunny bags, which can hold 40-80 kg nuts. It is not advisable to store the gunny bags on the floor as it may absorb moisture from the floor and cause damage. It is desirable to keep the bags on racks keeping a minimum distance of 30 cm from the ground and walls of the store. A single layer of sand bags are used to spread on the floor, to avoid direct contact with ground surface. The store should be dry and free from insects, birds, squirrels, rats etc. Storage in well ventilated warehouse is also a pre-requisite for good quality kernels.

Okwelogu and Mackay (1969) studied the effect of storage temperature and relative humidity and they reported that nut stored at 27°C at a relative humidity of 70% had a moisture content of 9.2%. Nuts exposed to higher relative humidity of more than 75% comes down heavily with mould infection within few weeks. Therefore, relative humidity of the storage godown plays an important role. Under high relative humidity, nuts pick up moisture from the atmosphere till they attain equilibrium. The storage of raw nuts with a moisture content of 5 to 6% for a period of 12 months at ambient temperature (25 to 30°C) did not affect either processing or biochemical quality (Nagaraja, 1996; Nagaraja and GiridharPrabhu, 1996).

Insect such as *Corcyra cephalonicas, Oryza ephilussurinamensis* Fab. *and Triboliumcastaneum* L. have shown to infest cashew kernels during storage at RH ranging between 40 and 90% (Vijay Singh and Pant, 1986). Kernel rejects of 2 to 3% obtained during processing of cashew by steam roasting method has been shown to be influenced by immature nuts and floaters (Nagaraja and Giridhar Prabhu, 1996). However, storage period up to 16 months initial moisture content of rawnuts ranging from 5 to 14%, time delay up to six months in drying the freshly harvested nuts, grading the nuts before processing, processing with and without steam roasting, time varying from 5 to 20 min have been shown to have no effect on percent kernel rejects obtained during processing (Nagaraja and Giridhar Prabhu, 1996).

Precautions during pre-harvest and post storage of raw cashewnut

Cashew nuts can be stored for up to 9 to 12 months in good condition provided the following conditions.

- Harvesting of immature nuts with the help of bamboo sticks is wrong practice that deteriorates the size, weight and quality of kernel. Therefore, only fully mature, fallen nuts on ground are collected and heaped at one place and then the nuts are removed from apple immediately when fresh.
- Raw nuts should be cleaned, if extraneous materials are adhered.
- Raw nuts should be washed with water to remove the adhered dirt.
- Raw nuts should be sun dried for 2-3 days on concrete floor or tarpaulins as the base. Proper turning should be given while drying of raw nuts for uniform drying. The objective is to reduce the moisture content up to 9% for long term storage.
- Do not over dry the nuts as this could lead to overheating and damage to the kernel from leaching of CNSL in the kernel.
- After drying followed by natural cooling of raw nuts, they should be placed

in 300 gauge polythene bags and tie the upper end of bag closed with jute string in order to airtight it and then the bag is placed in gunny bag and sew it with smooth jute string. Such air tight bags are then kept in a warehouse in dry place and 30 cm above the ground in order avoid further spoilage due to contact of surface moisture especially during rainy season and also to reduce damage from pests.

- Pests in storage can cause damage to the crop. The shell of the cashew nut is hard and it checks to most pests in storage; however, the moisture content more than permitted level, then there may be more chance of attack of store pest. Similarly, warehouse which is being used for dried nuts storage should be rodent proof.

Marketing of raw cashewnut

Marketing in respect of cashew involved several players and channels. Marketing begins from the sale of raw cashew nuts by farmers and reaches the level of exporters/retailers for selling of processed and graded kernels to the ultimate consumers. The cashew growers sold a major portion of the produce to local traders, who in turn supplied the nuts to large traders and processing units. There are several entities in the marketing channels that get good share in the total spread between the producer and consumer.

Marketing of raw cashewnut in India has not yet been organized in systematic manner except in Goa where co-operative marketing society is procuring raw nuts to the some extent. A major portion of the produce is brought by itinerant merchants and the agents of the processing units. A number of wholesale merchants and the processing factories open their collecting centres in important cashew producing areas during the harvesting period. The petty dealers who buy the nuts from the growers also dispose the nuts in these collecting centres. Cashew nuts are brought for sale to the assembling markets largely by the itinerant merchants. In certain areas, the resourceful processors contact the producers thus avoiding the commission agent'srole and enjoy good bargaining power by providing credit facilities to the producers.

In Goa where co-operative marketing societies have a major stake in raw nuts trade, where the producers were the major stakeholders acted as intermediary between the producers and the processors. The society had collection centres located in the production areas and procured cashew nuts from the growers. The sales price was fixed (at about Rs. 2 to 5 per kg) above the procurement price and the processors had to lift the produce and bear the transportation cost from the society/collection centres. There was another co-operative set up, which directly procured raw nuts from producers and also had a processing unit on lease. Through this mode, the supply chain was further shortened and was beneficial both to producers and processors (Technical Digest, NABARD, 2007).

Even today, the quality consideration of raw cashew nut is very poor. The nuts dropped off from the trees are collected, dried and sold to processors for kernel extraction. There is no variety wise or size wise grading is done before selling the raw cashew nuts. There is no proper non-destructive method has been developed to assess the moisture content of the raw cashew nuts. After processing, the grading of kernel is done manually to fetch premium price in the market. Moreover, quality standard for raw cashew has not been yet standardized (Saroj and Nayak, 2013). However, methods to judge the quality of raw nuts before processing the different tests are being are as follows.

Cutting test: This test is a physical method of quality evaluation. It involves cutting samples of raw nuts longitudinally and physical examination of the kernels on their fillage and quality. Normally 1 kg of raw nut will be subjected to cutting test, to examine the extend of white kernels, damaged kernels, discoloured ones and the kernel out turn. In factories, raw nut price is fixed based on cutting test. The recovery of good quality kernel should not be less than 25% to qualify the nut as good quality. Kernel recovery will be low, if the nut sample contains more dried immature nuts. Fungal infection, thrips damage, heat stress etc. cause drying up of immature nuts. Panicles and tender nuts dry up due to tea mosquito bug infestation at early stages of nut development and they may not contain good quality kernel. Therefore, such nuts should be separated from good quality ones. Depending on the extent of pest infestation and stage of maturity, the damage to kernel differs. Good quality nuts will contain white kernels and it will be full of kernels. Bad quality nuts will contain no or deteriorated kernels.

Floating test: This is another method commonly use for quality evaluation. Dense nuts usually contain good quality kernels and they sink in water. Poor quality nuts with poor kernel development or damaged kernel may float while dipping in water. The percentage of floats in raw nuts in a sample indicates the quality of raw nut. If the number of floaters in a sample is more than 24 per 100 nuts, such lots may be treated as bad quality.

Count test: This refers to the number of nuts per kg of raw nut. It may vary from 100 to 300 nuts/kg. More the count less will be the kernel size.

Moisture content: The allowable level of moisture content in raw nuts is 8 to 10%. Raw nuts having moisture above 10 per cent may indicate signs of low quality. Harvesting immature nuts, improper drying, improper storage of dried nuts, prolonged storage (beyond 12 months), exposure to moisture etc. are some of the causes of quality deterioration in raw nuts.According to Prabhu (2001), the following quality parameters are to be considered while importing raw cashew nut.

(a) Count of raw cashew nuts/kg: not less than 180 nuts per kg.
(b) Number of floaters/100 nuts: not more than 24.
(c) Percentage of bad nuts in floaters: not more than 15%.
(d) Total kernel yield: not less than 25%.

The quality of cashew nut is calculated in terms of raw "cashew count", "floaters" and doing a cutting test. Only when SSI units resort to these tests, can they take decisions on prices. They however do not have any fixed buyer; they therefore do not document the results. In contrast, the Mangalore units, which have fixed buyers, document the test results to inform the traders with the purpose of improvement in procurement. The quality in terms of the above parameters varies from place to place. Cashew nuts obtained from Banda (Sawantwadi *taluka*), Dodamarg taluka and some parts of Vengurla in Sindhudurg district of Maharashtra are reportedly better since they are harvested at full maturity (i.e. when the cashew apple is fully ripped). This is due to the proximity of market for cashew apple in Goa. In the other talukas, the cashew nuts are most of the time harvested at immature stages mainly due to fear of thefts and to the distance from the Goa market for cashew apples.Some traders and processors do test the quality of the raw material procured from the petty traders or from big farmers. But, except for a few, the majority of processors do not send any feedback on the quality of cashew nuts to the traders.

Marketing of raw nuts through regulated markets

In India,due to absence of regulated markets, farmers are forced to sell the raw nuts at prices determined by the local traders. Even with the existence of regulated market for cashew in Panruti (Cuddalore district in Kerala), raw nuts were sold by the farmers to the processors as well as commission agents, who visited the villages and collected the raw nuts from the farmers. Payment of cess and taxes in regulated markets deterred the producers from resorting to regulated markets.

Seasonality of cashewnut prices: Prices of cashewnuts are associated to seasonality pattern like most other agricultural crops. The domestic prices of the crop are linked to new crop supply seasonality pattern at other origins, which supply raw nuts to India. As regards seasonal production, the harvest period in a growing region is quite short. Since the nuts can easily be dried and stored for at least a year, the processing industry is not very sensitive to finding continuous supplies. The relevance of seasonality is mostly to the anticipation of availability and therefore pricing of raw nuts. The peak seasons of output in different regions are as under;

India, Vietnam, West Africa: March - June

Brazil: July - February

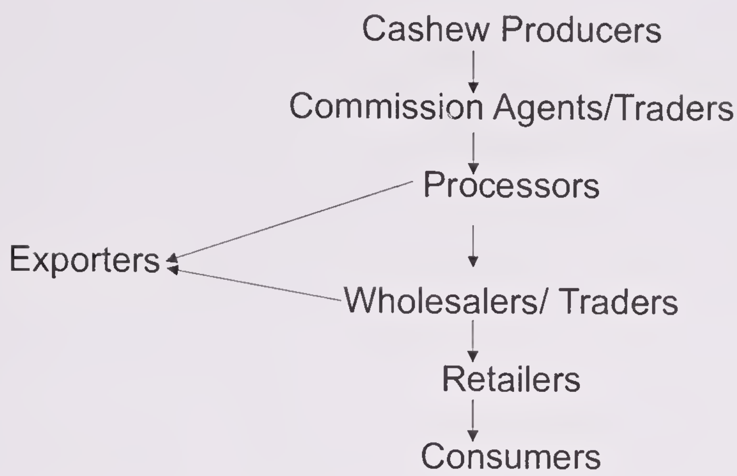
East Africa: October – December

The cashew nut arrivals of India, Vietnam, Côte d'Ivoire, Nigeria and Ghana coincide with one another whereas the arrivals of Brazil, Indonesia and other African countries like Tanzania, Benin, Mozambique and Kenya coincide. Senegal and Guinea Bissau supply cashew nuts to the World during July and August.The seasonal index of imported raw nut prices in India has shown that the prices peak during September and October. The price of the locally produced cashew nuts is also influenced by the price and availability of imported nuts. When there is large inflow of imported cashew nuts, which are available at cheaper prices, the demand for locally produced nuts decline, thereby bringing down the prices (Yadav, 2010).

Price variations between domestic and imported nuts: The unit value of imported raw nuts has been higher than the domestic nuts from 1990-91 to 1999- 2000 and 2004-05. Whereas, during 2007-08, the domestic raw nut prices were ₹ 32.19/kg as against the imported raw nut prices ₹ 28.83. The seasonal index of imported raw nut prices in India has shown that the prices peak during September and October. The price of the locally produced cashew nuts is also influenced by the price and availability of imported nuts. (Yadav, 2010).

Marketing channels for cashewnut

The prominent marketing channel generally prevalent in India is depicted below:



Ipte and Borude (1982) reported that the total cost of marketing of two tins (22.86 kg) of kernels obtained from one quintal of raw nuts worked out to be ₹ 72. The major items of cost were transport (13.20%) and sales tax (68.09%), which was about 5% of the value of kernels. Whereas octroi 7.07%, commission to agent 5.55% and other charges 6.09%. The sale value and the net returns realized was ₹ 1,016.66 and ₹ 1,17.40, respectively. The value addition accounted for 52.66%.

Raikar (1990) identified five channels of trade in cashew nut namely.

1. Grower → Itinerant trader → Processor
2. Grower → Pre-harvest contractor → Itinerant trade → Processor
3. Grower → Village dealer → Processor
4. Grower → Trader (wholesaler) → Processor
5. Gower → Processor.
6. Grower → Commission agent → Trader (wholesaler) → Processor.

The result further revealed that producer's share in consumer's rupee was more in channel 3. This share was reduced to 37.50% when producer sold his standing crop to pre-harvest contractor (channel 2). Sundaravaradarajan and Jahanmohan (2002) studied the marketing cost, margin, price spread and marketing efficiency of cashew in Tamil Nadu, observed following four different marketing channels of cashew.

1. Farmer → Village trader → Wholesaler → Processor → Trader
2. Farmer → Co-operative marketing society
3. Farmer → Commission agent → Wholesaler → Processor
4. Farmer → Processor

A majority of the farmers (60%) adopted channel 1, followed by channel 2 (26.25%), channel 3 (10%) and channel 4 (3.75%). Umesh *et al.* (2002) indicated that the strong and established research and development network, the availability of good number of cashew varieties suitable for varied situations across the country along with scientific production management practices offered good opportunity for the development of cashew industry in the country. There has always been a stable price in the international market for cashew when compared to any other edible nuts. They found that cashew represents a diversification option for inferior/ degraded lands which are less suitable for commercial cultivation of other food crops.

Marketing channel for cNSL

Cashew nut shell oil, extracted from cashew shells is widely used by the resin units in the fields of friction materials, adhesives, etc. The sample CNSL units were selling oil to the resin units who incurred a cost of ₹ 50/litre and sold to the paint industry @ ₹ 55/litre (rate vary at different place). The prevalent marketing channel for CNSL is:

Farmers → Commission agents → Processing units → CNSL → Resin → Paint industry

Issues in cashew marketing

Poor quality of raw cashewnuts: Incidence of pests and diseases like tea mosquito, cashew stem and root borer, improper drying of raw nuts and inadequate storage of dried nuts have resulted into poor quality of raw nuts produced. The yield loss due to tea mosquito bug infestation ranged between 30 and 50% in different years, while the stem and root borer infestation in neglected plantations ranged around 8 to 10% (ICAR-DCR, Puttur). Poor quality of raw nuts in turn leads to inferior quality of processed kernels.

Infrastructural facilities: Godowns for storing of large quantity of raw nuts are inadequate. Deterioration rate is low for properly dried nuts. Drying the nuts immediately after harvesting is essential to preserve their quality and reduce moisture content. The whole nut moisture content of 9 percent or below to be safe for storage. Sun drying of raw nuts is usually done and after drying they need to be stored and protected from rain and stored in local godown as soon as possible. Processing industries also require storage facilities for storing raw material for a year's production. Thus, godowns will facilitate buying operations and nuts may be marketed regularly.

Intermediaries in supply chain: Sustainability is a weak link in cashew. Two important aspects of sustainability are equitable distribution of wealth across the supply chain and reduction in carbon footprint. In the current supply chain, believe disproportionate value accrues to retailer, followed by middlemen involved in transacting raw cashew in unregulated markets and then to intermediaries in regulated markets and thereafter to processors and lastly to small-farmers. There is a need to rebalance the value accrual, more in favour of producers and processors. Secondly, Carbon footprint consideration will bring changes in the industry in the medium term (5 to 8 years), with processors located closer to raw cashew producers and energy intensity is reduced through creative use of by-product and waste.

Traders and middlemen dominate the market for raw cashew nuts and kernels. Since procuring raw cashew is the largest component of the operating costs in cashew processing sector, a slight increase in cashew price adversely affects the entire economics of cashew processing. The individual farmers were in a disadvantageous position as they were forced to sell the produce at a price determined by the traders/leaseholders. Farmers did not use the regulated markets in Cuddalore, as taxes/cess had to be paid by the traders if it was sold through the Marketing Committee (Yadav, 2010).

Declining domestic rawnut prices: There are many challenges to achieve stable prices in cashew- small and dispersed production, production susceptibility to weather, transportation intensiveness, varying labour costs, government policies and preferences and balancing equity amongst the supply chain partners. While many of the constraints may not go soon, the industry is progressing in the right direction. Market reforms such as efficiency gains in processing and innovation should help industry move towards stable price regime with equitable distribution of value across supply chain partners. Raw nuts are imported mainly from African countries at a cheaper rate than that of local nuts. This has posed a problem for the farmers. During 2007-08, the price of raw nuts declined to ₹ 32.20/kg from ₹ 40.89 kg in 2005-06 (Yadav, 2010).

Poor quality of processed kernels: The quality of the processed kernels is not good, as the small processors do not maintain hygienic conditions in their factories. This affects the marketability of kernels in the international market.

Competition from other countries: Vietnam is the major competitor for India for cashew kernels. In order to promote domestic processing and exports, Vietnam Government imposed 15% tax on export of raw nuts in 1995, which resulted in decrease of export of raw nuts. Brazil and Vietnam compete with India in purchasing raw nuts.

Competition from other nuts: One of the major factors that affect the consumption of cashew kernels in the world market is the competition from other nuts. The major importers in developed countries contract their requirements for the whole year based on the sales from previous years. Since cashew cultivation is not organized on a plantation scale in most of the producing countries, there is a fluctuation in the yield every year, which leads to wide price fluctuations of cashew kernels. On the other hand, other nuts like almond and pistachio are grown in large plantations and thus their prices are steady.

Drain on foreign exchange reserves: During 2007-08, the country imported 6.05 lakh tonnes of raw cashew nuts to meet the requirements and import is continued. This has considerable drain on the country's foreign exchange reserves.

Requirement of cashewnut marketing

Raw material handling and storage: India is a producer as well as large importer of raw cashew nuts (RCN) in the world. During the harvesting season (Feb-May) most of the processors stock the local RCN for their future requirement. As the new RCN contains lot of moisture, it needs to be dried to prevent quality loss of the nuts during warehousing. Drying and calibration of RCN are the key processes done at this stage. The nut making rattling sound is the symbol that the raw nuts have been dried properly. However, it is necessary to monitor the drying process as over drying of RCN may cause scorched kernel which may lead to higher breakage during shelling. On the other hand, improper drying of RCN may again cause lower yield of wholes and de-coloring of kernel. In general, for drying 100 bags (8000 kg) of RCN around 700 sq. feet of drying yard area is required. The drying yard should be constructed with 1.5-2 inch (4–5 cm) thick cement concrete floor over flat solid brick or bolder stones. Once RCN is received at the drying premises, the processors will check the moisture level by using moisture meter or some traditional method like poking pointed pin or nails and based on which days of drying is decided. Processors will avoid buying the RCN having more than 17-18% moisture as it may be immature. The RCN is spread on the drying yard throughout the day and kept in covered place during the night. Once the RCN is dried, it is calibrated, bagged, weighted and tagged with details before sending it to warehouse. In general, during the warehousing or storage, the RCN will be carrying 6-9% moisture level (Anon, 2014). Jute bags are used for bagging RCN and 80 kg is the standard quantity stuffed in a bag. Based on the origin, grade, purchase date etc; different lots are created, bagged and stacked accordingly. Warehousing is an important activity not only from the safe storage but also from the traceability of the nuts point of view (Anon. 2014).

Calibration process: It is also called size grading and pre-cleaning of the nuts. At this stage, the dried RCN is separated as per the nut size as well as impurities like dust, plant stalks, mud/stones etc. are removed. This practice is newly adopted by the processors as it is not only very useful in efficient utilization of shelling machine but enhancing the manual cutting/shelling rate also. In this process a calibrator/grader machine is used, the machine will have cylinder shaped sieves having holes of various dimensions/size and RCN passed through different holes will be segregated and collected separately. The size of the hole varies from 17-18 mm to 23-24 mm which may yield 3-5 grades of RCN. However, as per the requirement of the customer the number of grads can vary. In general, in India, the processors would grade the RCN mainly into the three sizes, i.e. small, medium and big (Anon, 2014).

Equipment/machines used: Calibrator/grader machine of various capacities and sizes are available in the market. The capacity ranges from 1000 kg/hr to 2000 kg/hr and dimensions from 5 feet (length) to 20 feet based to the number of grades sorted by the machine. Some large machines would have attached elevator for feeding and screw conveyor for separating the nuts. A simple grader machine with manual feeding options of 1000 kg/hr capacity would require 1 HP motor and based on the additional attachments, it may increase up to 4-5 HP. Selecting the capacity of machine is irrespective of plant capacity as the raw nut is stored after calibrating, in general the size or capacity of this equipment is 3-5 times higher of the processing capacity.

Construction of warehouses: A lot of guidelines are available on the civil construction of the warehouses but processors follow the guideline as per their convenience. In general, the floor of the warehouse should be 1.2-1.5 m above the ground level, flooring should be done using solid bricks and cement plaster above, structure height of 4.6 m from plinth level of the building and single span of tubular truss with color-coated dyne sheet roofing (Anon, 2014). The cashew processing units in Kerala, Tamil Nadu and partly in Karnataka are mostly

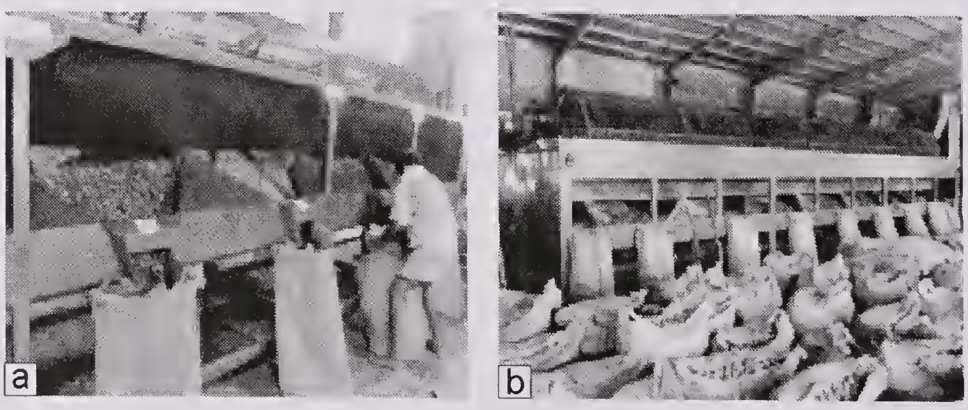


Fig. 16.1 Cashew drying yard

Fig. 16.2 a, b RCN calibration in India, RCN calibration in Vietnam exporting their wholes cashew, whereas in other parts of India, the entire cashew processed is sold in the domestic market. As such the lion shares of wholes consumed in India are sourced from areas like Andhra Pradesh, Odisha, West Bengal, Goa etc. India had basically two elements in particular for its comparative advantage in cashew processing, the first being the skill of cashew workers and the second the presence of a strong market for broken grade cashew kernels. With mechanization in processing turning to be a success, the former aspect is not that relevant today and the only supporting factor for the cashew industry in India today is the presence of a strong market for broken cashew grade. In fact, that is the backbone of the cashew industry in India (Anon, 2014).

Development strategies for cashew:

- India's raw cashewnut production is not sufficient to sustain the processing capacity established in the country. It is, therefore, urgent need to increase our raw cashewnut production and productivity to sustain itself in the international market.
- It is also important to develop and expand domestic market for cashew kernels so that there will be continued good price for the nuts and thereby farmers are encouraged to grow cashew.
- Senile plantations adversely affected the productivity and competitiveness of cashew. Production and productivity can be enhanced through a phased replanting programme. Strong extension activity and credit support is required to make the rejuvenate old plantations as well as to practice intensive cultivation practices.
- Development of better packaging and marketing strategies for domestic and international market.
- Promotion of SHG (Self help group) for marketing of cashew.
- Provision of minimum support price for cashew.
- Production forecast in relation to climate change.
- Development of good quality large storage structure either by private/ Government/NGO/Farmers Co-operative society based for storing of bulk quantity of raw nuts for long duration.
- The producer's share in the processor's rupee was more when sold the produce/raw nuts directly to processing units, than in any other channels. Hence, the farmers should be encouraged to sell their cashew raw nuts directly to the processors.
- Raw material contributes a major share in the investment in cashew processing industry. Inadequate supply and poor quality of cashew nut seem to be major constraints of the entrepreneurs. This might have been happening because of lack of knowledge among the supplier farmers about techniques of proper harvesting and management of harvested cashew nuts. The entrepreneurs and the extension agency may guide the cashew nut growers in this regard (Shinde *et al.*, 2012).
- Organic cashew offers new opportunities for the producers as they command price premium. Concerted efforts are required for promoting certified organic cashew.

- There was no contract farming arrangements for cashew cultivation in India, as cashew has not developed into organized plantation. Contract farming can evade middlemen between the farmers and the processors and ensure adequate prices to cashew farmers.
- To develop cashew progressive growers and cashew scientists'forum in all the cashew growing states, to discuss thoroughly the current problems in cashew production and to encourage the farmers for adoption of cashew technologies; there is a need to increase domestic production to substitute imported raw nuts in order to derive the maximum benefits from a strong processing and marketing capability developed over the years by the Indian cashew industry. Potential for micro-enterprises in cashew processing needs to be tapped by SHGs in cashew growing areas (Yadav, 2010).
- Establishment of cashew clusters among the processors may facilitate the expansion of market linkage, setting up of other ancillary units like CNSL, units, producing jam, pickles, etc. from cashew apples.
- The export of value added salted and roasted kernels from India is insignificant. Value addition and product diversification should receive adequate attention for having competitive edge and higher returns.
- Cashew cultivation and processing including CNSL are financially viable. This indicates the potential of institutional credit for cashew cultivation and processing. Establishment of cashew apple processing units as in Kerala and SHGs undertaking cashew-processing enterprises in Tamil Nadu also open avenues for institutional financing.
- Cashew kernels are high value commodity. In order to compete directly in the world market, high level of standards, branding and marketing is required to be maintained by the processors.
- Standards for raw nut quality like moisture content, and cleanliness of nuts are needed to improve trade. Farmers should be informed about the required production methods like regular harvesting, sun drying, etc.
- The role of middlemen in the market should be reduced and Government procurement system should be strengthened so as to motivate farmers to grow this crop on a sustainable basis and ensure a better price.
- Infrastructural facilities like godowns for storage of raw nuts may be constructed. If godowns are used, the factory will need small storage capacity and will facilitate buying operations of nuts.
- There is a need for yield and area stabilizing policies through appropriate Crop Insurance Scheme for cashew. In order to protect the cashewnut producers from high price fluctuations.
- Institutional support and co-ordination among various developmental and promotional agencies such as DCR, DCCD, CEPC, Agricultural Universities, etc. would help in promoting cashew processing and marketing.

International trade

It has been argued that the 'export boom' is an illusion in that the domestic resource cost of earning foreign exchange has increased over time, the value in dollar terms of Indian cashew kernel exports has been stagnating and the international terms of trade have declined. We are aware that cashew markets at the retail end of the international chain are controlled by a limited number of buyers. We need to know more about how the buyers' market is constituted, the parameters that the buyers have set for suppliers, how they monitor standards compliance and how much they are prepared to invest to enable suppliers to attain these standards, including product quality and labour standards?. When understanding international markets greater consideration needs to be given to the bargaining power of the main players, the particular markets being addressed (nuts or kernels) and the possibility of lead players combining to block entry of others.

Major export markets for cashew

Major export destinations of cashew kernel are the United States of America (USA), United Kingdom (UK), United Arab Emirates (UAE), Netherland, Japan etc. The cashew kernel export to different countries and their export value is given in Table 16.1.

Table 16.1. Major export destinations of cashew kernel

Countries	2009-10		2010-11		2011-12	
	Qty (MT)	Value (₹ 000)	Qty (MT)	Value (₹ 000)	Qty (MT)	Value (000)
United States of America	3,2540	765.29	35,236	911.31	47,611	1,470.47
United Arab Emirates	19,727	494.19	12,295	393.31	14,173	606.11
Netherlands	10,498	258.43	11,178	289.02	11,517	365.57
Japan	5896	155.37	5,944	159.16	7054	237.45
Saudi Arabia	4,030	95.29	3,386	107.53	5,136	207.01
United	5212	108.89	2,798	71.76	3,717	109.45
Others	40,088	924.14	34,918	887.3	42,552	1,394.62
Total	117,991	2,801.6	105,755	2,819.39	131,760	4,390.68

Source: DGCI & S, Kolkata (2011)

India is earning good amount of foreign exchange by exporting cashew products. The trend of cashew kernel and cashewnut shell liquid export from India is given in Table 16.2.

Domestic market for cashew kernels

It appears that about 50 per cent of the kernels produced in India are being sold in the domestic market. With the steady increase of GDP per capita income and the associated Purchase Power Parity, the consumption in India has picked up in every nook and corner. Still the consumption is more concentrated to the northern part of India, may be due to the climatic pattern. Delhi is perhaps the most potential market for cashew kernels in India. It also serves as a distribution hub to other

Table 16.2 Export of Cashew Kernels and CNSL

Year	Cashew Kernel Export		Cashew nut shell liquid (CNSL) Export		Total value ₹ Crore
	Quantity (MT)	Value (₹ Crore)	Quantity (MT)	Value (₹ Crore)	
1990-91	49,874	4,422.4	5,658	5.56	447.96
1991-92	47,738	6,690.9	4,542	4.02	6,694.92
1992-93	53,436	7,454.9	4,258	3.81	7,458.71
1993-94	69,884	1,046.02	3,525	2.90	1,048.42
1994-95	77,000	1,246.02	3,807	2.4	1,248.42
1995-96	70,334	1,240.50	760	1.45	1,241.65
1996-97	68,663	1,285.50	1,735	2.77	1,288.27
1997-98	76,593	1,396.10	4,446	7.17	1,403.87
1998-99	15,026	1,609.90	1,572	3.26	1,613.16
1999-00	92,461	2,451.45	764	1.84	2,453.29
2000-01	89,155	2,049.75	2,246	38.94	2,088.69
2001-02	97,550	1,776.80	1,814	4.19	1,780.99
2002-03	104,137	1,933.02	7,215	9.25	1,942.27
2003-04	100,828	1,804.42	6,926	7.03	1,811.45
2004-05	126,667	2,709.24	7,474	7.91	2,717.15
2005-06	114,143	2,514.86	6,405	7.09	2,521.95
2006-07	118,540	2,455.15	5,589	10.29	2,165.44
2007-08	114,340	2,288.90	7,813	11.97	2,300.37
2008-09	109,522	2,988.40	9,099	26.06	3,014.46
2009-10	108,120	2,801.60	11,227	27.62	2,829.22
2010-11	105,755	2,819.39	12,051	33.77	2,853.16
2011-12	131,760	4,390.68	13,575	59.46	4,450.14
2012-13	104,015	4,067.20	9,192	29.83	4,097.03
2013-14	114,791	5,095.73	9,480	38.61	5,097.34

Source: DGCI and S, Kolkata (2014) and CEPC Cochin

parts of the country. Bombay is anothertrade/distribution hub of cashew, where the consumption is also very high. Ahmadabad in Gujarat, Jaipur in Rajasthan, Lucknow in Uttar Pradesh, Indore in Madhya Pradesh, Amritsar in Punjab, and Kolkata in West Bengaluru are the other potential markets of both wholes and broken grades of cashew kernels in India. The emergence of supermarket chains across India has accelerated the sales of cashew kernel in all parts of India. The 'Tirupati' temple in Andhra Pradesh consumes large volumes of broken grades (Fancy splits) in its 'prasadam' (The Loards offering in the form of sweet 'ladu'). The price of cashew is affordable today to an average Indian, whereas the same was a forbidden item in terms of pricing two decades back. Today, the price of whole grade of cashew in the retail level is around INR.800/kg (GDP/capita @ USD 1085 in 2012), where as two decades back the same was around INR ₹ 450/kg (GDP/capita @ USD 390 in 1990). This shows that thenet effective pricing of cashew has gone down, making it affordable at medium class level.

Of a variety of broken cashew numbering more than 15grades, the most popular and most sold grade is the LWP (the large white pieces, i.e. 1/4th of a white whole kernel). This grade is mostly used in making of sweets, and avariety of food items. FS (fancy splits- the whole cashewcut into two length wise) is another popular item that is mainly used for toppings in sweets and confectioneries. WSP, SWP (white small pieces and scorched small pieces i.e. 1/8th of the whole cashew kernels) is widely used by the ice cream industry. BB (Baby bits) is another popular grade, which is widely used by restaurants for making thick and tasty gravy. Other broken grades (including pieces) are also consumed in small quantities for various purposes. However, no data is available for comparing the relative consumption of various grades within the broken cashew (Bhoodes, 2014).

Indian Market v/s Export Market

The pricing of kernels in the domestic market in India is more or less following the supply and demand positions, though the changes in the international prices have some impacts in sense that the exporters switch their produce to domestic market when the export prices are less, resulting in increased supply levels that brings down the local prices and vice-versa. The quality of cashew from the new generation processing centers in India has to be still improved to make it exportworthy, and hence those products find a market in India only- mainly the secondary markets. But in the case of broken grades, the domestic market offers a better price than the international market. May be that other processing countries like Vietnam, Brazil etc., where there is no local demand for the broken grades are forced to sell their broken grades- produced in bulk quantities in mechanical processing- at very lower prices, the strong domestic market for broken ensures a better price in India. It is a fact that this high Indian market for broken grade kernels is the thriving factor for the very existence of the cashew industry, which otherwise is incurring almost double the processing costs due to manual processing compared to its competitors. The high quality and crispness of cashew kernels processed manually is another reason of wide acceptance of Indian cashewgrades fetching it a higher market and heavy demand. Further, the broken cashew consumption maintains equilibrium with the raw cashew processing. The pricing of other whole grades is more or less at par with the international market. Since, the local prices vary from origin to origin and processor to processor and owing to the fact that a portion of the domestic trades escapes the tax brackets, there is wide variation in pricing and also no official or trade data available for the local pricing of cashew kernels. On the other side, in the domestic market the price difference between wholes and broken have narrowed owing to the fact that whole cashew kernels are priced at par with international market, where as the strong domestic demand for Indian broken grades always ensures a fair price for the broken grades (Bhoodes, 2014).

Imports: threat to Indian cashew economy?

The recent past records an alarming trend in the import of broken kernels to India, mainly from her competitors in the international market. Many of the competitors have adopted mechanization to a larger extent that their cost of production is far low compared to India. In India, cashew is a tradition and the processing is more or less manual. This has provided gainful employment to around one million workers. Retrenchment of these workers cannot be even thought of and the mechanization in India is to be implemented to the effective utilization of full workforce with increase in productivity. The general processing cost in India is 40% more than its competitors, which can be compensated with the strongdomestic market here. The strong market for broken grades here has attracted India's competitors, who always wanted to make use of the same to dump their broken grades, which otherwise difficult to market. To overcome the import duty and make their product marketable at low prices, they mostly resort to fraudulent means of imports by under quoting the prices and bringing cashew kernels declaring the same as cattle and poultry feeds (Bhoodes, 2014).

The imports of cashew kernels to India, provides a feel of added advantages to the competitor countries mainly due to (i) strong market for broken grades in India which otherwise they find difficult to market and dump, (ii) the broken grades are produced in bulk (by more than 10%) in mechanized processing they widelyadopt, iii) once, they can sell out their broken grades, the processing becomes more profitable so that they can increase their volumes and iv) they can gain comparative advantage on India at the cost of Indian domestic market.

The import of cashew kernels can accelerate the cashew processing in other countries and can have multiple adverse effects in India in the sense that on one side that the increased processing elsewhere invites competition in the international market and on the other side it reduces the supply of raw cashew nuts from raw nut producing countries. The Government of India has recently protected the industry by fixing floor prices in imports of cashew kernels. Today, Indian consumption is growing up and almost half of cashew kernels consumed here is in broken forms. The strong domestic market for broken grades in India is the backbone of Indian cashew Industry. The consumption is likely to grow up higher in view of the growing economy (Bhoodes, 2014).

Cashew needs better marketing strategy with proper analyses data on Indian consumption pattern which can support the industry. A primary data collected on surveying the market may bridge the gap for a better analysis. India has the adequate processing capacity which can be multiplied to meet the needs to any level with process automation. The only handicap India faces today is the heavy dependence on imports for raw material. Unless India takes up initiative to attain self sufficiency in cashew production, we may not be able to cater our own market. As such India has to protect the domestic market from foreign 'invasion' to protect the cashew Industry (Bhoodes, 2014).

Cashew, having annual import and export value of more than US$ 4 billion. Being one of the main high value agricommodities, a small change in quality or quantity leaves significant impact on total commercial value. Testing and inspection of cashew plays a critically important role in protecting the interest of cashew growers, processors, traders, exporters, buyers and other stake holders involved in cashew nut business by ensuring the quality of cargo by visual inspection, sampling and testing services, quantity and weight determination, packaging and label verification, checking transport for its cleanliness, cargo loading followed by sealing of transport, fumigation, pest management and real time reporting with situation updates and monitoring the cargo. It is important to keep traceability of cargo at each point of supply chain including production and processing plant, warehouse, container stuffing, truck/rail/vessel/ship hold loading and discharge point. Thakur (2014) suggested the following criteria for inspection and testing of raw cashew during import.

(i) *Raw cashew nut inspections (Import survey):* Weight and quality inspection services for raw cashew import consignments are usually followed. Majority of the raw cashew imports are through 20 containers in 80 kilogram jute bags. The quality of the raw nuts is determined with respect to out-turn in pounds per 80 kg bag.

(ii) *Price of the raw cashewnut:* It is based on the out turn of the nuts in the trade. Cent per cent container weighment is carried out in nominated weighbridges. Representative samples are drawn at random from approximately 10 per cent of the bags during de-stuffingof the cargo from the containers at the buyer's warehouses by our Inspectors. Approximately 2 kg sample per containers is drawn. B/L (Breadth and Length) wise samples drawn from the containers are mixed thoroughly and cutting test is carried out on this sample. Cutting test is done on two samples ofone kg each and the average result is considered for the out turn. Moisture is analyzed at laboratory for one sample B/Lwise. Parameters for cutting test is given in table 16.3.

Table 16.3 Parameters are usually checked during cutting test

Parameters-cutting Test	Protocol-Physical Test	Results	Expressed in
1.	Void	"	%
2.	Rotten	"	%
3	Diseased	"	%
4.	Partly Damaged	"	%
5.	Spotted	"	%
6.	Immature	"	%
7.	Total Defectives	"	%
8.	Yield (Unsound)	"	GMS
9.	Yield (sound)	"	GMS
10.	Total Yield	"	GMS
11.	Out turn	"	Pounds/80 kgs Net Bags
12.	Nut Count	"	Nos/Kg

Problems during import of raw cashewnuts

The reasons and proposes solution as suggested by Vinacontrol (Bach Khanh Nhut, 2014) are as follows:

Mold and musty cashews

It is easy to realize the cashew nuts coated with white or green mold and musty on the top-layer and under the container ceiling, at two side-partitions of the container and behind the container exit and front.

Reasons

- High moisture of the whole cargo or some parts of the cargo (> 10%), the goods have been stored in the container during long days (≥ 40 days)
- Due to natural-breathing of cashew nuts, the temperature inside the container will be increased gradually and as a result, the water vapors will be evaporated from the high-moisture cashew nuts, along with the difference of day-and-night temperature. It will make the water vapors condensed and fallen down the above said positions (the top-layer and under thecontainer ceiling, at two side partitions of the container and behind the container exit and front). This temperature and humidity will be an ideal condition for development of molds and yeasts.

Proposed solutions:

(a) At the ports of loading

- Well drying the commodities for the favourable moisture(< 10%) before loading into the container.
- Besides, the exporter should insert carton papers around and inside the container with desiccant bags in full.
- It will be better if the shippers use containers 40" to load the commodities (Each container 40" is permitted to load 26.5 tonnes only so that it will have more upper space for better ventilation and minimization of molds and yeasts).

(b) At the port of discharge

Sprouting-cashew rot and decay

- Re-drying of all mold and musty commodities at the soonest time after being discharged. However, it will still bring many losses to the importers like (a) actual quantity will be decreased from 2 to 4% based on actual moisture, and (b) actual quality of spoil-cashews after being processed will be poorer than the standard ones.
- The raw cashew nuts which are sprouted and deformed with rot and decay, causes serious losses to the buyers. Quality of the processed cashew kernels will be seriously reduced (rate of blemished/yellow and scorch nuts will be increased, changes of smell, non-natural smell to sour taste).
- Due to very high moisture of the raw cashew nuts (>12%) and being contained in the container for a long time (≥ 40 days)
- The natural-breathing of raw cashew nuts, air humidity inside the container in addition to high temperature and moisture of cashew nuts will be favourable conditions for development of cashew sprouts. As a result, some raw cashew nuts which were deformed with sprouts, rot and decay cannot be used for processing.
- Due to hole-leaking container, rainwater will absorb easily and create good conditions for cashew sprouting. They will be gradually deformed with sprouts, rot and decay if being stored in long time.

Proposed solutions

At the port of loading

- Control the moisture well (<10%) by drying, frequent hoeing upon drying for even moisture.

- Insert carton papers around and inside the container with desiccant bags in full
- Check the container to ensure it tight, clean and no leak

At the port of discharge

- Classifying and removing sprouted and serious damaged nuts out of the cargo.
- Re-drying all remaining commodities of the above said spoil cargo

Delivery of old-crop raw cashewnuts

- Cashew shells are black or yellow in colour.
- After cutting, the testa is red or dark brown in colour.
- The goods are very dry in feelings and its shells arevery dry and hard when cutting, very little cashew liquid or the kernels inside are rot and decay.
- The cashew kernels are shriveled to create a gap between the cashew shell and cashew kernels.
- Qualities of cashew kernels which will be processed by this kind of materials are much poorer (the rate of blemished/yellow, scorch, spot kernels will be increased and their value will be decreased accordingly).

Proposed solution

- Checking the goods carefully and removing the bags containing old-crop nuts before loading into the container.

Baby nuts

The very small raw cashew nuts (baby nuts) will not be used for processing. Currently, most of processing factories are using cutting machines and these machines could not cut the baby cashew nuts. The exporters should check the moisture, quality and quantity of goods carefully before delivery using clean, durable and sealed containers without smell inside. Besides, the exporter should insert carton papers around and inside the container and desiccants.

Conclusion

Raw cashew nuts are a seasonal commodity and main trading season is from March to May. There is no well-defined system of cashew nut marketing. Cashew growers usually supply the raw cashew nuts to village markets where small traders collect and supply to the urban market/industries. The cashew trade is seldom handled by exclusive traders. In general, traders who collect other plantation products also trade cashew nut. Due to the highly competitive nature of the cashew trade, growers have few marketing problems. When large quantities are collected by middlemen, the processors enter in the marketing chain and make wholesale purchases. Grades and standards for raw cashew nuts are yet to be introduced in India. At present, quality is generally determined by appearance and cutting tests that traders employ prior to purchase. The raw cashew nut market involves a large amount of capital where nearly 80% of the produce is transacted within 35 days. Also, there is no cashew growers association in all cashew growing states, which otherwise helpful in marketing of raw nuts. There are no separate godowns for cashew nut storage; processing industries are making their own arrangement. In future, there is every possibility of increasing sale price of cashew kernels due to application of import duty on raw cashew nuts. Though, export of cashew kernels is supported by Cashew Export Promotion Council of India.Therefore, overall marketing and export system needs to be improved.

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Subject Index

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The Cashew

Tree nuts are important source of nutritious food for the mankind. Among important nine tree nuts, cashew occupies third place in global tree nut market after almond and pistachio. Cashew is produced commercially in as many as 32 countries in the tropical regions of Asia, Africa and Latin America. Asiatic zone comprising of India, Indonesia, Philippines, Sri Lanka, Thailand, Vietnam and Malaysia for the last three decades accounting for 53% of total global production. In India, cashew was introduced by Portuguese travellers in 16th century but naturalized so much and found Indian soil homelier than its homeland Brazil. Now, cashew has moved from forest confine to commercial horticulture crop. Today, India is largest processor, exporter and also consumer of cashew in the world and emerged as key player in global cashew trade of cashew kernels. This book will serve as a valuable reference to the academicians, policy planners, development departments and extension workers engaged in cashew research and development in the country.

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