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THE LYCHEE CROP IN ASIA AND THE PACIFIC

FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS
REGIONAL OFFICE FOR ASIA AND THE PACIFIC
BANGKOK, THAILAND

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by

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FOREWORD

Lychee is native to the area between southern China, northern Viet Nam and Myanmar, but is now cultivated in many countries with sub-tropical climates. The crop is most important in China, India, Viet Nam, Thailand, Bangladesh and Nepal. There is also interest in Australia, the Philippines and Indonesia. The Asia-Pacific region accounts for more than 95 percent of world production, at about 2 million tonnes. The crop is very popular throughout the region with strong domestic markets and increasing affluence. Trade within the Region and to Europe and North America is about 60,000 tonnes.

The crop is profitable, and can significantly add to the income of small landholders. A few trees may double the income of such families. The area under cultivation is expanding with many new orchards in China, Viet Nam and India. Average yields are below 5 tonnes per ha, whereas some better orchards can produce three times this.

Although lychee has a long history in Asia, it is a relatively new species in most countries, and efforts to increase production have been small compared with the more established tropical fruit such as citrus, banana, pineapple and mango. There has been much speculation on the factors controlling growth and cropping. The main reason for low yields is failure to flower, although in some seasons, the trees may flower heavily, but carry few fruit at harvest. The yield of cultivars also varies greatly from district to district, so cultivars must be evaluated for their cropping in different areas.

There is a large gap between actual and potential yields, with much work required to raise average productivity. Opportunities to increase production include new cultivars, and appropriate watering, fertilizing and pruning. Improvements in integrated pest and disease management are required. Girdling and growth regulators can also increase flowering and fruit retention under some circumstances. Prospects for increasing production and marketing of lychee are high if some of the growing, post-harvest handling and marketing issues are resolved. These developments are more likely to succeed if countries across the region remain united in their vision for the future of this crop.

In conclusion, I hope that this publication will be useful in raising increased interest in the lychee crop among researchers, students, extension officers, growers and entrepreneurs.

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THE LYCHEE CROP IN ASIA AND THE PACIFIC

1. ORIGIN, DISTRIBUTION, PRODUCTION AND TRADE

Overview

Lychee is native to the area between southern China, northern Viet Nam and Myanmar, but is now cultivated in many countries with sub-tropical climates. It is very well known in Asia, but relatively rare in Africa, the Middle East and America. Production in the Region accounts for more than 95 percent of world cultivation, at about 2 million tonnes. About 58 percent of the world's population lives here, indicating the importance of the crop to the livelihood of millions of farmers.

Production goes back at least 2,000 years in southern China, but is relatively new in the rest of Asia and the Pacific. Production is greatest in China (1,300,000 tonnes), India (430,000 tonnes), Thailand (80,000 tonnes), Viet Nam (50,000 tonnes), Bangladesh (13,000 tonnes) and Nepal (14,000 tonnes), and less important in the Philippines, Indonesia and Australia. Trade within the Region and to Europe and North America is about 60,000 tonnes. The area under cultivation is expanding with many new orchards in China, Viet Nam and India. Average yields are below 5 tonnes per ha, whereas some better orchards can produce three times this. It can be concluded that there is considerable room for improving productivity.

1.1 Origin and distribution

Lychee or litchi (*Litchi chinensis* Sonn.) originated in the area between southern China, northern Viet Nam and the Malay Peninsula. This region is one of the three main cradles of domestication and is the origin of several other important horticultural crops, including tea, members of the citrus group, longan and kiwifruit. Numerous wild lychee trees are found in moist forests in Hainan Island from low elevation up to 600 and 1,000 m, and below 500 m in hilly areas of the Leizhou Peninsular, west Guangdong and east Guangxi.

Wild trees are one of the main species in several of these lowland rainforests, and may account for up to 50 percent of the virgin forest composition. Trees often stand together with *Vatica astrotricha* (green plum), *Hopea hainensis*, *Heritiera parvifolia* of the Chinese parasol family, *Coelodepas hainanensis*, *Polyathia laui* and *Diospyros hainanensis* of the persimmon family. Lychee is usually the dominant species in the upper layer of the forest. Wild trees can also be found in parts of Viet Nam north of Hanoi, although there are fewer pockets of natural rainforests than in China.

Wild specimens are similar in general appearance to some cultivars grown in China and Viet Nam. The fruit are edible, but the flesh or aril is relatively thin and sour, and not commercial. The wild types evolved in two directions, the skin segments becoming protruded and long as in "Tai So" and "Kwai May", or flattened as in "Sum Yee Hong", "Souey Tung", "No Mai Chee" and "Wai Chee".

Lychee has been taken to most of the tropical and sub-tropical world in the last 400 years. The fruit are very popular in China and South and Southeast Asia, but less well known in Africa, the Middle East and America. The commercialization of this species around the world has been slow due to the poor cropping of trees in many areas, as well as the short life of the seeds.

Lychee reached India through Myanmar in 1789, and later on appeared in Bangladesh and Nepal. It has a long history of production in Thailand, but the exact date of its introduction has not been established. It probably arrived from China 150 years ago or perhaps earlier. There are no records of its introduction into the Philippines either, although there is mention of lychee in local literature early in the twentieth century. Seeds were sent to Australia in the 1850s, and marcots imported 70 years later. Thus, the oldest clonal trees are 80 years old. There are older seedling trees in many areas, some perhaps planted 100 years ago. They can carry heavy yields, but are often attacked by birds and other pests.

1.2 Production

The total area under cultivation in China is a staggering 580,000 ha, with production of 1,260,000 tonnes in 1999. In comparison, the output in 1980 was only 50,000 tonnes. Production is expected to rise dramatically in the next few years as thousands of young trees come into bearing, with 35 percent of plantings in Guangdong under five years of age. Before 1990, orchards were generally managed by small landholders, whereas in recent times, large commercial companies have invested in the industry. Trees are distributed in seven provinces, with Guangdong (800,000 tonnes), Guangxi (310,000 tonnes), Fujian (150,000 tonnes) and Hainan (15,000 tonnes), the most important, followed by Yunnan, Sichuan and Guizhou. The main commercial zone of cultivation occurs from 19^{o} to 24^{o}N latitude, with fruit available from early May to early August (Table 1).

Guangdong produces about 65 percent of the crop (Table 2). There are over 80 counties with lychee orchards, although production is centered around Guangzhou. Lychee ranks second after citrus as the most important fruit crop. In Fujian, citrus and longan are more important. Yields of 10 tonnes per ha are possible in well-managed orchards in Guangdong and Fujian, with average yields of 4 tonnes per ha. Productivity is lower in Guangxi, where lychee is considered a poorer proposition than longan. The Guangdong Litchi Technical Association (GLTA) provides information on production and marketing for various sections of the industry.

Marcots were introduced into northern Taiwan Province of China from mainland China in 1760 and again in 1860. However, commercial production did not begin until the late 1920s, when trees were planted in southern areas away from strong winds of the Pacific Ocean. Since that time, material has been distributed to nearly every district in Taiwan Province of China except the north where it is cold and wet. Most of the plantings are in the central and southern parts of the island where there are large areas of alluvial sandy loams. Yields are higher on these soils than on the mountain slopes. Conditions are ideal for flowering, with mature trees carrying 500 kg of fruit in a season. Total production is 110,000 tonnes from 12,000 ha.

Table 1. Major producing areas in China.

Area	Cities or Counties	Season	Comments
S. Guangdong	Maoming, Gaozhou and Yangjiang	early-May to early-June	regular bearing and early maturing
C. Guangdong	Shenzhen, Dongguan, Huizhou, Huilai and Zhuhai	mid- to late- June	largest production, with excellent growing technology
N. Guangdong	Zhaoqing, Conghua and Zengcheng	from July	unreliable flowering and fruit set, with cold damage some years
Fujian	Zhangzhou and Putian	early- to mid-July	strong winds and cold damage some years
Sichuan	Hejiang, Luzhou and Yibin	late-July to early-August	late harvest and unreliable flowering
Guangxi	Beiliu, Yulin, Bobai, Changwu, Linshan, Nanning and Hengxian	early- to mid-July	late maturing
Hainan	Qiongshan and Danzhou	early-May	very early, unreliable flowering
Yunnan	Yuanyang	early-May	unreliable flowering

Table 2. Area, production and average yields for the main growing areas in China.
(Average yields calculated across several years)

Province	Area (ha)	Production (tonne)	Average yield (tonne per ha)
Guangdong	303,080	793,200	3.0
Guangxi	210,000	310,000	1.3
Fujian	40,220	148,700	5.3
Hainan	18,600	15,000	3.2

Northern Viet Nam includes part of the area where lychee originated. Wild trees have been found growing at low elevation in the Bavi Mountains and forests in Tamdao (Vinhphuc Province) and Tuyenhoa (Quangbinh Province). Fruit from these areas were reportedly sent to the Emperor of China in Peking (Beijing), several thousand kilometers away, however, commercial production only began in the 1980s. The total area under cultivation is 30,000 ha, with production centered within 40 to 200 km from Hanoi, with Bacgiang (20,250 tonnes), Haiduong (11,600 tonnes) and Quangninh (7,000 tonnes) more important. The industry is based on a single cultivar, Vaitheiu, and thus has a relatively short season from late May to early June.

There are no official records when lychee was introduced into Thailand, although planting material probably came with Chinese traders and seafarers more than 150 years ago. Some of the largest specimens are more than 100 years old. Lychee ranks eleventh in the list of economic fruit crops in Thailand, whereas longan is in the top three.

The main commercial activity is in the north from 300 to 600 m between Chiang Rai and Chiang Mai (60 percent of production), Phayao, Nan, Lamphun, Lampang, Phrae and Fang in a monsoon climate, with a distinct dry season. Plantings have also been established in the more tropical humid, high-rainfall areas of Chanthaburi, Samut Songkhram, Kanchanaburi and Nakhon Ratchasima, north, east and west of Bangkok. Flowering is more consistent and yields higher in the cooler elevated areas, which account for 90 percent of production. The crop in 2000 was a record 80,000 tonnes from 23,000 ha. Fruit are available from mid-March to mid-June, due to the range in climates and cultivars exploited.

Lychee reached India through Myanmar at the end of the seventeenth century, and the country is now the second largest producer after China. During the last 200 years, it has been distributed to much of the north and northeast of the country. It ranks seventh in area, and ninth in production amongst fruit, and provides income for millions of farmers.

About 75 percent of the crop is produced in northern Bihar (310,000 tonnes), with lychee the most important fruit. The other main areas include West Bengal (36,000 tonnes), Tripura (27,000 tonnes), Assam (17,000 tonnes), Punjab (13,000 tonnes), Uttar Predesh (14,000 tonnes) and Orissa (9,000 tonnes). The total area under cultivation rose from 9,400 ha in 1949 to 56,000 ha in 1998. The latter figure represents 1.5 percent of the area under fruit in India. Both production and yield have increased in recent years, with fruit available from May to June in the different States. Irrigation is necessary for commercial production in many areas, since there is often a long dry season.

Although Nepal is a small country, variations in climate allow the production of a range of fruit including lychee in the plains and low hills from 60 to 950 m. There is increasing interest in the crop with 14,000 tonnes being produced from 3,000 ha. Production is expected to steadily rise in the next few years, as young trees start to bear commercial crops.

The history of lychee in Bangladesh is unclear, although the species was probably introduced from Myanmar in the 1800s. Direct Chinese and Indian imports soon followed. Trees can be found over much of the country, but are especially common in Jessore (1,520 tonnes), Rajshahi (1,380 tonnes), Rangpur (1,100 tonnes) and Chittagong (985 tonnes). Total production is 13,000 tonnes. The fruit are popular, but only available in the market for two months of the year. Cultivation technology is also not well developed, with many young trees dying in the first few years after planting, and low average yields of 2 tonnes per ha.

The Philippines produces many tropical fruit including banana, pineapple, mango and several citrus. Lychee is also grown, but on a much smaller scale. The species was introduced 100 years ago, but has only been considered for commercial expansion fairly recently. The cost of production is high, and the fruit expensive compared with other tropicals. There is an indigenous lychee, *Litchi chinensis* sub-species *philippinensis* that grows in more tropical areas up to 500 m, but it is not commercialized.

Various clonal material and seedlings were introduced into the more tropical areas from China and Thailand, but most failed to flower and crop. Commercial plantings are now based in the Cordillera Autonomous Region in the north, especially in Benguet, and in Ilocos Sur at 1,000 to 1,380 m. There are also smaller orchards in Batangas and Laguna, and in Cagayan de Oro.

Lychee is a minor fruit in Indonesia, with smaller plantings than longan or rambutan. Commercial activity is limited to a few districts in Bali (latitude 8^oS) at 400 to 700 m. The area has average temperatures of 22^o to 31^oC, total rainfall of 2,500 to 3,000 mm, and a four month dry season.

Nearly all of the trees are found in home gardens and along the roadside, with few commercial plantings. There are no specific guidelines for orchard management, although some old trees can carry 200 to 300 kg of fruit in a good season. Fruit are mainly sold in local markets and hotels in bamboo baskets, without any post-harvest treatment.

Lychee was introduced into Australia 100 years ago, although commercial production only expanded in the late 1970s. The industry was initially based around Cairns (latitude 17^oS) and Ingham in northern Queensland, but later expanded to include much of the eastern coastline down to the middle of New South Wales (latitude 30^oS). About 50 percent of production is in north Queensland, 40 percent in central and southern Queensland, and 10 percent in northern New South Wales. Productivity is generally more reliable in central and southern districts. There are 350 growers and 1,500 ha producing 5,000 tonnes worth US$10 million.

About 25 percent of production is exported to Asia, the Pacific and Europe. Improvements in fruit quality, grade standards, quality assurance and the formation of cooperative marketing groups have fostered a successful export market. When properly grown and marketed, returns on a hectare basis more than match those of other tropical crops such as avocado, mango and macadamia. Well-managed orchards can yield 10 tonnes per ha.

1.3 Trade

Most of the fruit grown in Asia and the Pacific are sold close to the areas of production. There is some trade within the Region, and also exports to Europe and North America. The total volume of world trade is 100,000 tonnes per year, with a third of it supplied by South Africa and Madagascar into Europe.

In China, lychee can be used fresh, dried or processed. The peak harvest lasts six weeks from late May to early July, so that in heavy cropping years, up to a third of the production in Guangdong, Guangxi and Fujian is dried as “lychee nuts”. Fruit can be dried in the sun or in ovens, with good retention of flavour. Most of the dried fruit are sold locally, with some exported to other countries in the Region. Processing is less important, with only 2,500 tonnes canned, frozen or fermented each year. Frozen and canned fruit are mainly sent to the United States of America (USA), Japan, Republic of Korea and Australia. “Haak Yip” and “Wai Chee” are the main cultivars used for canning.

China shares in the Hong Kong and Singapore markets, and exports 10,000 to 20,000 tonnes per year, although this still only represents 2 percent of its total production. Taiwan Province of China also exports to these countries, as well as to the Philippines (2,000 tonnes), Japan (1,000 tonnes), Singapore (500 tonnes), USA (1,200 tonnes) and Canada (1,000 tonnes). Exports to Europe are virtually non-existent.

The average price for fruit in China is US$2.50 per kg, but ranges from a low of US$0.50 per kg for medium quality fruit in the peak of the season, to US$10 per kg for high quality "No Mai Chee" and "Kwai May" fruit with small seeds. Average prices are US$6 per kg in Singapore, US$6 per kg in the United Kingdom (UK) and US$15 per kg in North America.

About 70 percent of the crop in Viet Nam is sold in local markets, and the remainder exported to China, Hong Kong, other countries in the Region and to Europe. Most of the crop is sold as fresh fruit, with a little dried, canned or juiced. It is surprising that in the peak of the season, fruit are exported to China.

Thailand is the other country in the Region with a significant export industry, although longans are more important. Exports to Malaysia and Singapore are sent by road, while fruit to Hong Kong and Europe by air. Hong Kong mainly takes fresh lychee (9,000 tonnes), while Malaysia and the USA import canned fruit (6,000 tonnes). The total volume is 25,000 tonnes worth US$40 million. In contrast, the longan trade is worth double this. Overall, 10 to 20 percent of the lychees are exported compared with 50 percent of the longans. Thailand has an advantage in the market-place because it produces fruit earlier than China or India. The average price for the farmer is US$1.50 per kg for lychee and is half that for longan. Many growers consider that longan is a better proposition, because yields tend to be heavier than lychee.

The Philippines is a net importer, with the volume increasing by 8 percent per year. Current trade is 1,500 tonnes worth US$500,000.

India is the second largest producer after China, with over 500,000 tonnes in a good year. However, most of the crop is sold locally, with little interest in exports until fairly recently. The development of marketing cooperatives and improvements in post-harvest technology are assisting exports to the Middle East.

The Australian industry is relatively small by international standards, but has a strong export focus. About 30 percent of the crop is exported to Hong Kong, Singapore, Europe, the Pacific and several Arab states. Marketing groups were established in the early 1990s in the major growing areas, and now export half of their production. These groups have a strong commitment to grade standards, post-harvest treatment and quality assurance. There is currently an application to import Chinese fruit into Australia during the off-season. If this application is successful, efforts will be made to send exports from Australian directly into China. At the moment, most of the fruit enter via Hong Kong.

Australia faces strong competition from South Africa and Madagascar in the European market that is worth 30,000 tonnes during the peak of production in the Southern Hemisphere from December to January. However, Australia has some advantage in the market, since it sends fruit by air without the use of sulphur. The bulk of crop from Africa until fairly recently was shipped in reefer containers and treated with sulphur dioxide. The average return to Australian growers after transport and other costs have been deducted is US$3 per kg. Within Australia, nearly all the crop is sold fresh, with processing virtually non-existent. In fact, canned and frozen fruit are imported from Asia.

Most markets prefer large, highly-coloured fruit with sweet flesh and small seeds. Cultivars with a unique flavour, firm flesh and a high proportion of chicken-tongue seeds are highly sought after in Asia, whereas the markets in Europe, the Pacific and North America are less discerning. There are some concerns about sulphur residues from fumigated fruit especially in Europe, prompting this technology to be phased out. There are also barriers to exports into Japan and the USA for some countries such as Australia because of quarantine issues associated with fruit flies.

The Food and Agriculture Organization of the United Nations has developed CODEX standards for exports of fresh lychee. Mature fruit should have a predominantly red skin, with only a small area of green allowed. The diameter of the fruit should be larger than 20 or 25 mm for second class or standard fruit, and larger than 33 mm for extra class fruit. The total soluble solids content should be greater than 18 percent. The residue for sulphur in the flesh should not exceed 10 mg per kg.

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2. BOTANY AND TAXONOMY

Overview

Lychee (Litchi chinensis Sonn.) is one of the most important members of the Sapindaceae family that has over 2,000 species and 150 genera. Related fruit from Asia include longan (Euphoria longan), rambutan (Nephelium lappaceum) and pulasan (Nephelium mutabile). Rambutan and pulasan are similar to lychee with red or yellow skin; however, long hairs or spinterns replace the protuberances. Rambutan and pulasan are strictly tropical, while lychee and longan crop best in the warm sub-tropics or at elevation in the tropics. The Litchi genus contains two other non-commercial sub-species from the Region. Lychee is a long-lived, evergreen tree that produces its new leaves, flowers and fruit on terminal shoots. The inflorescences produce many hundreds of functionally male and female flowers that carry from 5 to 80 attractive fruit at harvest. The red-skinned fruit contain a single seed, surrounded by a juicy sweet aromatic aril or flesh. Cultivars with large fruit, small seeds and a distinctive flavour are sought after in the market-place.

2.1 Sapindaceae family

The Sapindaceae or soapberry family contains more than 2,000 species from 150 genera, mostly trees and shrubs, but rarely herbs, widely distributed throughout the warm sub-tropics and tropics. The majority of species are native to Asia, although there are a few in South America, Africa and Australia. New species are still being described. The most specialized growth forms are the rather strange unbranched palm-like trees such as *Talisia* and woody climbers like *Sejania* and *Paullinia*. The largest trees including *Schleschesa oleasa* and *Pometia pinnata* (tuan, dawa or Fiji longan) may reach up to 60 m in height.

Several genera include useful ornamentals: *Sapindus saponaria*, a small tree up to 10 m high in Florida, the West Indies and South America; *Koelreuteria paniculata* (golden rain tree), a round-headed species up to 10 m high in China, the Republic of Korea and Japan; *Xanthoceras sorbifolia*, bunge, a small tree up to 5 m high in northern China planted for its attractive flowers; and *Ungnadia speciosa* (Mexican buckeye), a shrub and *Cardiospermum halicacabum* (balloon-vine), an annual vine planted in southern USA.

Many other members of the Sapindaceae are important timber trees, nuts, or sources of beverages, oils or drugs. Saponins are present in the fruits, seeds and other tissues of several species. Some types such as *Sapindus saponaria* are used as soap substitutes in the tropics. *Schleichera trijuga* is the source of macassar oil used in ointments. *Paullinia cupana* is a vine from South America, the source of guarana, much drunk in Brazil and elsewhere. *Blighia sapida*, akee is a fruit from West Africa, with an edible aril, but poisonous if not eaten at the correct stage of ripeness. The mamoncillo or Spanish lime, *Melicocca bijuga* is also grown for its fruit in South America. *Pometia pinnata* is sometimes grown in Papua New Guinea and the Pacific for its edible aril.

Other minor species worthy of evaluation for their fruit include: *Cubilia bancoi*, kubili from low to medium elevations in the Philippines; *Diploglottis cunninghamii*, native tamarind from sub-tropical Australia; *Talisia olivaeformis*, talisia from tropical America; *Alectryon macrococcus*, mahoe from Hawaii; and *Chrysanthus macrobotrys*, ndgulu from Central Africa.

The most important members of the Sapindaceae are the attractive, eye-catching fruit of the sub-family *Nepheleae* from the orient. Lychee (*Litchi chinensis*), longan (*Euphoria longan*), rambutan (*Nephelium lappaceum*) and pulasan (*Nephelium mutabile*) are similar trees, but differ in fruit morphology and ecology. Lychee is the most economically significant member of the group.

Lychee is regarded as one of the kings of tropical fruit and has a very long history in Asia. Fruit are very attractive, with bright red skin covered by angular or conical protuberances. Longan resembles lychee, but the fruit are smaller, smoother, yellow-tan to brown, milder in flavour and less acid. About a third of people in Asia prefer longan to lychee, whereas in Australia, America and Europe, lychee is more popular. Canned longans are more acceptable than canned lychees.

Rambutan and pulasan are similar to lychee, with red or yellow skin, however, long hairs or spinterns replace the protuberances. Rambutan and pulasan are strictly tropical, cropping only in warm, wet, lowland areas, whereas lychee and longan are found in the warm sub-tropics or above 500 m in the tropics.

The Sapindaceae were originally described by Cambessedes in 1828. However, the first detailed systematic study was not published until 1890. Radlkofer based his classification on a wide range of evidence, including the presence or absence of a terminal leaflet, the number of ovules per carpel, the structure of the fruit, presence or absence of an aril, and pollen morphology.

There have been several revisions of the Sapindaceae, but the scheme of Radlkofer's is essentially accepted, with only minor modification. According to plant characteristics, pollen morphology and geography, the Sapindaceae are split into two sub-families – Dodonaeoideae (Austral distribution) and Sapindoideae. The latter can be separated into three main groups, centered around Sapindeae (pantropical), or Cupanieae (pantropical), and a third group separating into Thiouinieae and Paullinieae, both predominantly American.

Members of the Sapindaceae share several characteristics. The leaves are normally alternate, mostly pinately or palmately, sometimes single compound. Flowers are usually unisexual, borne in racemes, panides or corymbs. There are usually four to five free, sometimes fused sepals and four to five petals (often with hairs), which may be absent, and a well-marked disc between the petals and stamens. There are eight to ten stamens in two whorls. The filaments are free and often hairy. The ovary is superior with two to four lobes, and the style simple or divided. The fruit include capsules, nuts, berries, drupes, samaras or schizocarps, often red, containing seeds. They lack endosperm, with the embryo folded or curved.

2.2 The *Litchi* genus

The *Litchi* genus contains two other forms that have not been commercialized. Sub-species *philippinensis* is found in the Philippines (Luzon, Sibuyan, Samar and Mindanao) and Papua New Guinea at high elevation, while sub-species *javensis* is recorded in the Malay Peninsular and Indonesia. The Philippines lychee has long, oval-shaped fruit with long, thorn-like protuberances. Fruit split in the middle when ripe, displaying an inedible aril that only partly covers the seed. Sub-species *javensis* is a rare specimen found in Chinese gardens in West Java and Indo-China and has fruit similar to cultivated lychee, but with a thinner aril. It is reported to flower and fruit regularly in the tropics. Many of the Malayan specimens belong to sub-species *chinensis*.

2.3 Related species of commercial significance

There are seven species in the genus *Euphoria*, all from tropical and sub-tropical Asia, but longan is the only one significantly grown for its edible fruit. *E. didyma* (alpay) has small (2 cm diameter) round, green warty fruit with shell-like rind, big seed and a thin, juicy, sweet, edible aril. The tree is native to the Philippines and is widely distributed in both wet and dry areas. *E. malaiense* (mata kuching) produces fruit of similar size to the alpay and longan. Fruit have a tough skin that is pale dull yellow with dark raised specks. The aril which envelops a big seed is whitish, translucent and sweet, and in good forms nearly 0.5 cm thick, although usually much thinner. Trees grow wild in Malaysia, Borneo, Sumatra and the Celebes.

Rambutan and pulasan are thought to be native to west Malaysia and Sumatra, although trees that have escaped from cultivation blur the original distribution. They are close relatives of lychee, and equally desirable fruit, but are not as well known. Fruit are very similar to each other and are often confused. Pulasan has smaller fruit, narrower leaflets, a more open tree and fewer fruit in a cluster. The fruit skin is thicker and the spinterns or tubercles shorter. Trees are also reported to be less productive than rambutan. Other species with the edible arils grown in Asia include *N. eriopetalum* (lotong), *N. glabrum* (redan), *N. philippense* (bulala) and *N. excrospermoides* (aluao).

2.4 Botany and composition of lychee

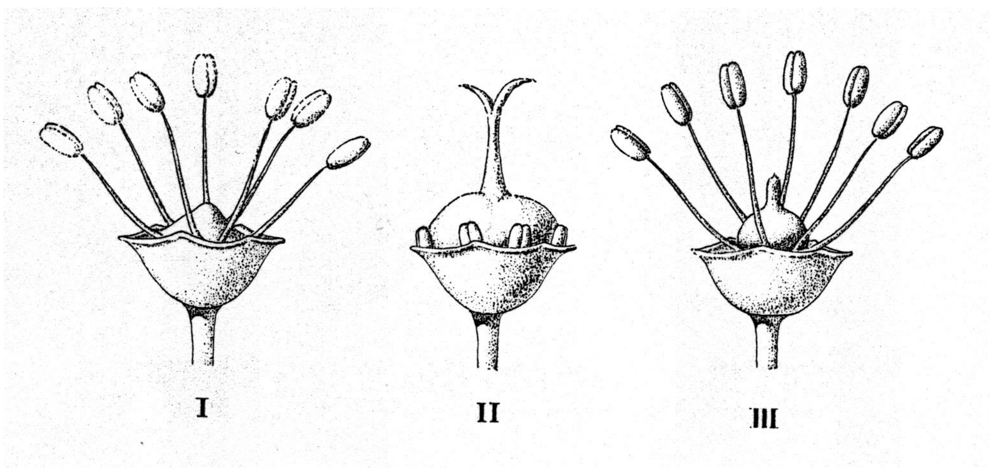
Lychee is a long-lived, evergreen tree up to 30 m tall in old specimens, with a short stocky trunk. In some cultivars, the branches are crooked or twisting and spreading forming a crown broader than high, while in other cultivars, the branches are fairly straight and upright forming a compact, rounded crown.

The leaves are alternative and compound, with two to five leaflets. The leaflets are oblong and 5 to 15 cm long. The new flushes are a distinctive red-brown when immature and light to dark green as they mature. The inflorescences are many branched panicles, each with one or more leaves and up to 3,000 flowers, and from 5 to 80 fruit at harvest (Figure 1).

The flowers are small, yellowish-white, functionally male or female and apetalous. Functionally male flowers have six to ten stamens. There are usually two stages of male flowering overlapping with the female cycle: a true male flower first and then a functionally male flower that opens towards the end of the flowering period. The second male flower has a rudimentary bicarpellate pistil. This is absent in the first stage. Functionally female flowers have six to ten staminodes and a functional, bicarpellate pistil (Figure 2). The last stage of male flowering generally supplies most of the pollen used to fertilize the female flowers.

Figure 1. Panicle, flowers and fruit cluster.

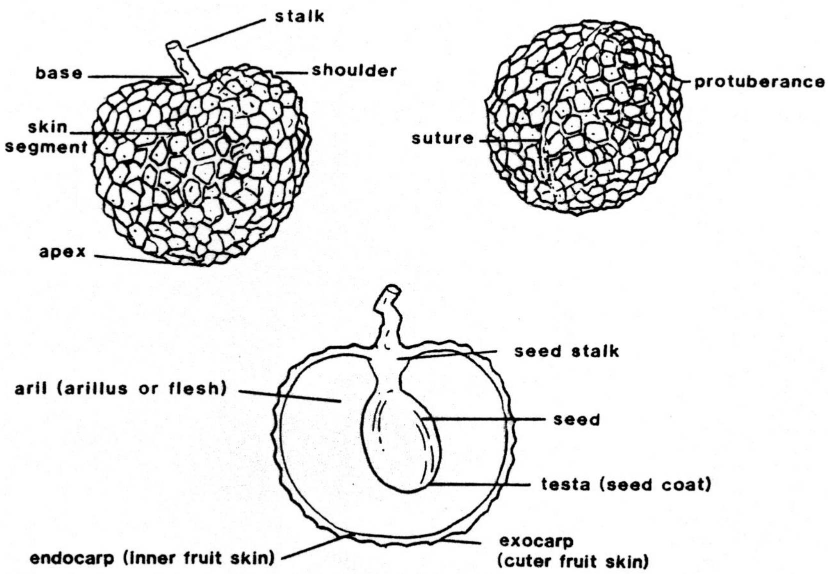
Figure 2. Flower types (♂,♀ and ♂).



Fruit are highly variable, depending on the cultivar (Figure 3). They can be round, ovoid or heart-shaped, and from 2.0 to 3.5 cm in diameter. The skin can be smooth or rough with distinct protuberances, thick or thin, and pink-red, bright red or purple-red. The flesh or aril is an outgrowth of the outer cells of the seed coat (outer integument), and in good cultivars may comprise 80 percent of fruit weight. The aril is generally translucent white, juicy or firm, and sweet and aromatic in better cultivars. Many cultivars can be distinguished by their flavour and aroma. The fruit contain a single dark brown seed 6 to 12 mm wide and 10 to 23 mm long.

Some cultivars have a high proportion of aborted seeds and thus a high flesh recovery. They are popular in the market-place, especially in Asia. There are a few cultivars that produce nearly seedless fruit, although the fruit usually weigh less than 10 g.

Figure 3. Fruit characteristics.



The composition of the fruit determined from studies in Australia was (per 100 g fresh weight): moisture, 81 percent; protein, 1.1 g; fat, 0.1 g; carbohydrate, 18 g; Ca, 2 mg; Fe, 0.5 mg; thiamin, 0.05 mg; riboflavin, 0.07 mg; niacin, 0.5 mg; and ascorbic acid, 49 mg. The total soluble sugar content was 18 percent or higher.

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3. PLANT DEVELOPMENT AND WEATHER AND SOIL RELATIONSHIPS

Overview

Lychee trees go through several phases of plant development during the year. These include leaf expansion, flowering, anthesis and fruit development. There is generally considerable variation in the timing of these different growth stages amongst trees within an individual orchard.

High-yielding trees typically have one or two flushes after harvest, followed by another one in winter. The first flushes are usually vegetative, and the one in winter, floral. This is provided cool weather occurs during early bud development. Inflorescence development continues uninterrupted and leads to anthesis six to twelve weeks after panicle emergence. Fruit set in spring normally lasts two to six weeks for an individual cultivar in an orchard. Fruit mature after 12 to 16 weeks, depending on temperatures during fruit development.

Commercial activity in Asia and the Pacific is mainly found in sub-tropical environments from 17 to 30 degrees latitude. There are also some plantings at elevation in the tropics. Most of the sub-tropical areas have cool or cold winters and warm to hot summers, while rainfall is highest in summer and least in winter and spring. Temperatures below 20^oC induce flowering, whereas drought is not essential. Extremes of temperature influence productivity by affecting male and female flowers, pollination and fruit set. There can also be problems if trees are droughted during fruit development. A high proportion of the fruit can brown, split or abscise before harvest in some locations. Average yields are low compared with many tropical fruit such as avocado and mango, usually less than 1 to 5 tonnes per ha, although yields of 10 tonnes per ha or more have been recorded in some areas, with close spacings and irrigation.

A model showing the relationship between potential flowering with latitude along eastern Australia can be used to estimate the reliability of cropping at different elevations in more tropical areas.

Orchards can be established on many different soils, provided they are well drained to at least a metre. Clay loams of medium to high fertility are preferred. Light sandy soils may dry out during hot weather, while there can be problems with micronutrients at extremes of soil pH. Many soils in the Region are acid or have been acidified and applications of lime or dolomite are required. In contrast, many of the soils in India are calcareous with a pH above 7.0 and trees are also susceptible to moderate levels of salinity. Mature trees may have many roots below a metre and are thus able to extract soil water to a considerable depth. Mycorrhizal fungi have been isolated from roots, but whether they are required for commercial lychee production is not known.

3.1 Plant development

Lychee trees go through several phases of plant development during the year. These include leaf expansion, flowering, anthesis and fruit development. There is generally considerable variation in the timing of these different growth stages amongst trees within an individual orchard. There can also be differences between different branches on an individual tree.

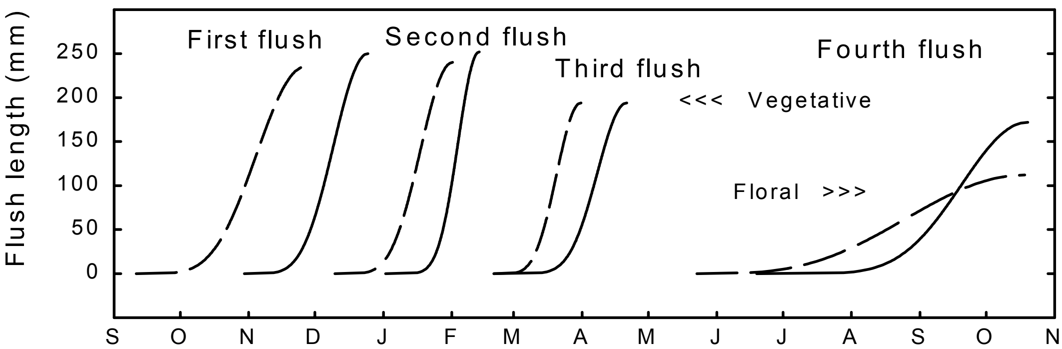
High-yielding trees typically have one or two leaf flushes after harvest, followed by a floral one in winter, if cool weather occurs during early bud development. In southern Queensland, the main period of leaf growth occurs from January to March for early cultivars such as “Tai So” and from March to May for late cultivars such as “Wai Chee”. This would be equivalent to July to September, and September to November in Guangdong. Inflorescences develop without a dormant period, with the flowers opening after six to twelve weeks. In southern Queensland, panicles normally emerge in April to May in early cultivars and from June to July in late cultivars. These periods are equivalent to October to January in southern China. Inflorescences can have several leaves especially when buds develop during warm weather. There may also be vegetative outgrowth of lateral buds below the inflorescences.

Anthesis in spring normally lasts two to four weeks for an individual cultivar in an orchard, with fruit mature 12 to 16 weeks later. The duration of each stage varies from orchard to orchard and year to year. Anthesis occurs from August to October in southern Queensland, and from February to April in Guangdong. Maximum growth occurs during the last six weeks of fruit development. Fruit are harvested from December (“Tai So”) to February (“Wai Chee”) in southern Queensland, and from May to August in much of Asia.

3.1.1 Leaf development

Shoot elongation is by repeated flushes during which several leaves and internodes expand. At the end of leaf expansion, the leaves thicken and change from light to dark green. The minimum interval between successive vegetative flushes (or between vegetative and floral shoots) is approximately six weeks. The interval can be much longer, depending on the weather and the physiological state of the plant. Low temperatures, low light, drought and nutrient deficiencies increase the interval between successive flushes. Pruning can be used to alter the pattern of shoot elongation, and if carried out at the correct time can induce flowering in some locations (see Figure 4).

Figure 4. Flush development in lychee cultivar Kwai May Pink in northern New South Wales.



(Shoot elongation shown for two trees pruned initially in September (broken line) and October (solid line). Both trees flowered the following spring. Pruning for tree size control is normally carried out after harvest from January to March.)

3.1.2 Panicle development

The inflorescence is composed of several multiple-branched panicles initiated on the present season's wood. The panicles are normally produced terminally in clusters of ten or more, although in some trees, a high proportion of axillaries may be produced. Inflorescences are generally mixed, with the lowest buds producing leaves only, the middle buds producing floral buds in the axils of the leaves and the topmost buds producing only floral branches and sometimes very small leaves which do not persist. This pattern of development is related to differences in temperature experienced by different buds during early shoot development.

Growth of the inflorescences is usually complete in six to twelve weeks, with considerable variation in the growth of individual branches within a tree. It is possible to determine shoot development by studying the external appearance of the buds as they emerge. Shoots with the terminal and axillary buds dormant tend to remain vegetative. Shoots with the terminal bud dormant, but axillary buds stalked tend to form small panicles, while those with both buds active give rise to regular panicles.

Differences exist between cultivars with respect to the type of panicle initiated. Early cultivars such as “Tai So” in Australia produce large multi-branched panicles with large numbers of mostly male flowers, while late cultivars such as “Wai Chee” produce small panicles with few branches and mostly female flowers. Flower development after initiation is normally earlier in warm weather and is delayed or prevented by frosts. When the terminal buds are frosted, a large number of axillaries may be produced. Some growth regulators can elicit a similar response.

The proportion of female flowers varies with orchard, year and cultivar. Only the female flowers can set fruit. Cultivars with a high number of female flowers have the potential to be high yielding. Inflorescences that develop early in autumn during warm weather in southern Queensland often have predominantly male flowers. This also affects lychee in Asia. Cultivars vary in the number of male and female flowers: “Wai Chee” produces more female flowers than “Kwai May Pink” in southern Queensland.

3.1.3 Flowering

Flowers normally open for 20 to 45 days within an individual orchard and cultivar, depending on seasonal conditions. Flowering is more compact when it occurs late in spring in warm weather. There is no pollination unless the male and female stages overlap. This can be a problem in some seasons when the weather warms up very quickly. These conditions increase the rate of development of the male flowers. Consequently, the male flowers have finished when the female flowers open. Generally, the last stage of male flowering provides most of the pollen for the female flowers.

Flower opening occurs during both the day and night, with peak opening in the early morning, provided temperatures are above 15^{o}C. Flower opening in Queensland normally corresponds with the dry season. Under very dry or warm conditions, the young flowers may wither and fail to develop. In contrast, it is often wet during fruit set in southern China. Male flowers shed pollen for three days after opening, however, not all the anthers shed pollen at the same time. Pollen is short-lived, lasting no more than a day after shedding. Individual female flowers also have a limited life. If the female flower is not pollinated within three days of opening, it will not set. Once again, extended hot or dry weather can dry out the stigmas.

The flowers posses nectaries and attract many insects, including native and European honey-bees. Some authors have shown that bagging inflorescences or screening trees more or less completely prevented pollination. However, others have achieved satisfactory fruit set without insects. This area requires further research. Cool overcast weather, strong winds and some insecticides reduce foraging by the bees. Hives are installed during flowering in some orchards within the Region. Usually two or three hives per hectare of orchard are sufficient. Application of carbaryl and some other insecticides should also be avoided at this time.

Far more female flowers are produced than develop into fruit. This can be due to premature flower shedding, excessive numbers of male flowers or occasionally poor pollination. In some seasons, insects such as flower-eating caterpillars, thrips, flower-eating beetles and erinose mites can damage the flowers and reduce yields. From 1 to 10 percent of the female flowers carry a fruit to harvest, with some cultivars more productive than others. This is a relatively high rate of set compared with other tropicals such as avocado and mango, which may set less than 0.1 percent of the female flowers.

3.1.4 Fruit growth

Only one of the two ovaries of the female flower normally develops into a fruit. Very rarely, two lobes develop, with the mature fruit superficially resembling two fruit adhering to each other at their bases, each containing a seed. Depending on the season and cultivar, fruit take about 12 to 16 weeks to mature. Fruit growth is normally faster when it occurs late in the season during warmer weather.

Not all parts of the fruit develop at the same time. During the first seven to eight weeks after fertilization, the fruit skin, the embryo and the seed skin are formed. At the end of this stage, the aril or flesh is only a negligible portion of the fruit. During the next two to three weeks, the cotyledons (or seed leaves) that comprise most of the seed are formed, and the development of the aril begins. At the end of this stage, the aril is about a third of fruit fresh weight. The final period of fruit growth is dominated by rapid growth of the aril (seed development also continues). At fruit maturity, the aril is about 65 to 75 percent of fruit weight (Figure 5).

Maximum fruit weight occurs about two to three weeks before the fruit mature. In most cultivars, the colour changes from green to yellow-red to red with advancing maturity. This change is associated with a flattening of the skin segments and protuberances, and an increase in sugar/acid ratio and eating quality.

Fruit weight is related to weather and tree culture, and ranges from 15 to 35 g for different cultivars. Cultivars that have a high proportion of chicken tongue seed normally produce smaller fruit. Some of these cultivars may also produce nearly seedless fruit. These normally weigh only 8 or 10 g.

High leaf nitrogen and potassium concentrations and regular irrigation are essential for good fruit yields. Temperature can also affect the plants. High temperatures often accelerate fruit development at the expense of fruit weight. However, at very low temperatures, photosynthesis is reduced. The largest fruit are generally produced at intermediate temperatures.

3.1.5 Fruit abscission

Far more fruit are set than harvested. Typically, premature fruit abscission commences soon after anthesis and continues to fruit maturity, with most fruit abscising in the first two to six weeks (Figure 5). This varies greatly with locality, year, cultivar, weather and culture, and in some cases all of the fruit are shed. The initial abscission is thought to be due to failure of fertilization. Fruit can also fall after embryo abortion.

Later abscission is thought to be due to competition for assimilates. Girdling at this stage often reduces fruit drop, while drought, shade and leaf removal increase it. Fruit thinning at this time also increases the retention of the remaining crop. Surprisingly, the major fruit drop period occurs before the peak demand in carbohydrates by the developing crop. The young green fruit can photosynthesise, however, most of the carbohydrates for the fruit come from current assimilation in the leaves behind the fruit clusters. Reserves in the branches can also be used. Young leaves do not induce fruit abscission unless they develop directly behind the fruit cluster. This generally only occurs when fruit set is poor.

Nutritional and hormonal imbalances have been implicated in premature fruit abscission. Experiments by Israeli scientists have shown that fruit retention can be improved by applying auxins when the fruit weigh about 1 to 2 g. Earlier or later applications are ineffective. Some of these growth regulators can also increase fruit size.

Fruit-sucking bugs and fruit borers induce fruit abscission in many orchards within the Region. In some areas, they can account for more than 90 percent of green fruit drop.

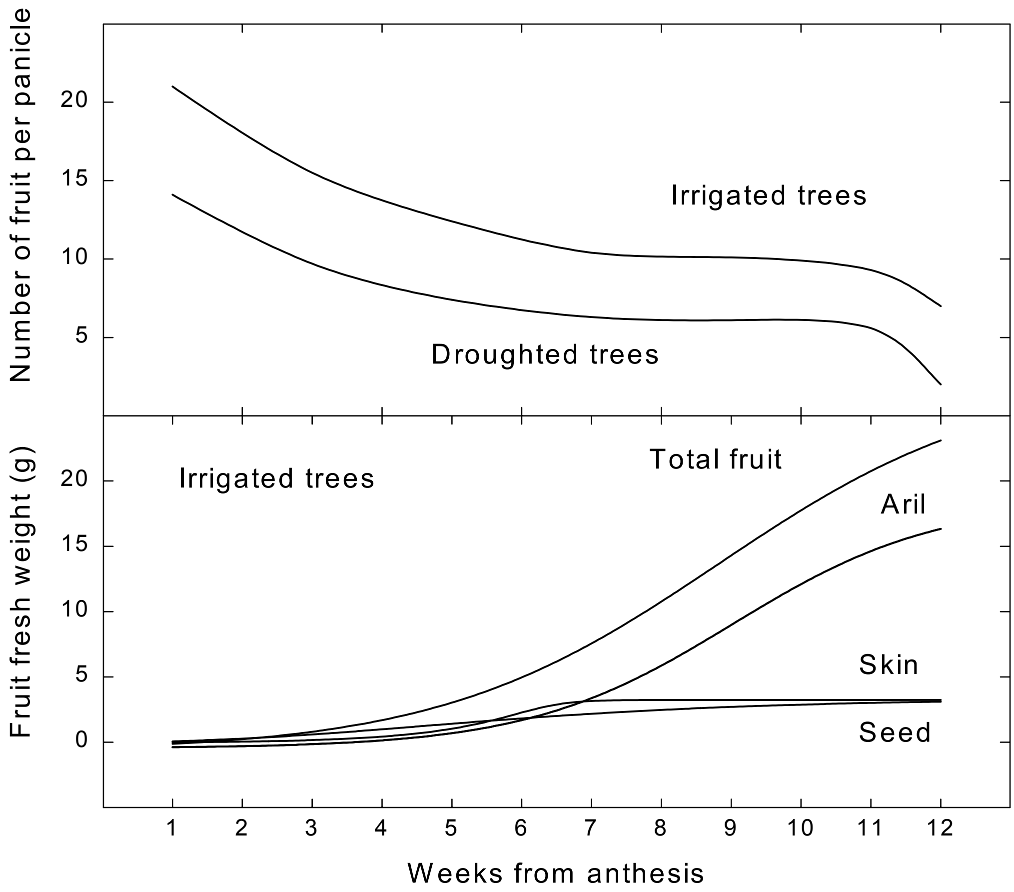
3.1.6 Fruit disorders

Sunburning and skin-cracking (splitting) occur throughout Asia and the Pacific, and are often associated with hot, dry weather, drought and low calcium concentrations. However, the relationship between these disorders and tree management is not clear.

Skin cracking often occurs when trees are droughted soon after fruit set. If the drought is severe enough, fruit development will be affected, particularly the development of the fruit skin. Cell division is reduced and the fruit skin becomes inelastic, and often splits when the aril grows rapidly before harvest. This can occur after irrigation or heavy rain, or just an increase in relative humidity.

Insects, hail, and the sun can damage the skin during cell expansion and induce cracking towards harvest. These damaged areas cannot expand with the rest of the fruit, creating a weakness in the skin that splits.

Figure 5. Pattern of fruit drop and fruit growth for lychee cultivar Tai So.
(Trees droughted from panicle emergence until after harvest)



3.2 Relationship between plant development and weather

Although lychee has a long history in Asia, there have been few critical studies on the response of the plant to weather. Many of the earlier studies were conducted under field conditions where sunshine, temperature and water supply are often correlated. It was not until the late 1960s, that the first glasshouse experiments on flower initiation were initiated. Later studies examined the relationship between flower development, pollination, fruit growth and environment.

3.2.1 Weather in different areas

The main commercial plantings in Asia and Australia are found at low elevation in the sub-tropics from 17 to 30 degrees latitude. A few small industries are also based at 300 to 600 m in tropical locations in the Central Plains of Thailand near Bangkok and in a few selected areas of the Philippines and Indonesia. Most of the sub-tropical areas have cool to cold winters and warm to hot summers (Table 3). Rainfall is highest in summer and least in winter or spring. Lychee is found in a narrow range of climates, whereas many other tropical fruit such as citrus, mango and banana are cultivated from the cool sub-tropics to the warm equatorial tropics.

Most of the commercial areas have winter minima below $20^{o}C$ and usually below $15^{o}C$ (Table 3). Winters are dry, with rainfall of less than 50 mm. Maxima during fruit set are usually between 20^{o} to $30^{o}C$. Rainfall is usually light, with less than 50 mm in spring, although some areas such as Fuzhou have more than 100 mm. Summers are warm to hot, with maxima of 28^{o} to $33^{o}C$. Average summer rainfall is at least 150 mm and usually more. In near equatorial areas such as Ho Chi Minh City (latitude $11^{o}N$; elevation 9 m), minima do not fall below $20^{o}C$ during the year and yields are very unreliable, even though there is a distinct dry season.

3.2.2 Effect of solar radiation on plant development

Lychee originated as one of the dominant species in sub-tropical rainforests of Asia. However, as with many crops, the original environment may not be ideal for commercial production. Both flowering and fruiting are reduced once adjacent trees start to crowd each other in an orchard, and thinning becomes necessary. The decline in yield in crowded orchards begins when sections of the canopy are shaded for most of the day.

Don Batten analysed data collected by Xu in Fujian (latitude 24^{o} to $25^{o}N$) and showed that yield (3 to 9 tonnes per ha) was correlated (r^2 = 64%) with March sunshine hours (20 to 220 h) over ten years. No similar relationship could be established for Alstonville in Australia (latitude 29°S), which has more sunshine hours than Fujian in September (equivalent to March): 244 h compared with 106 h. This work suggests that light may limit flower development in Fujian, although high sunshine hours would be expected to be correlated with higher temperatures and therefore earlier anthesis as proposed by Batten.

Table 3. Climates of different growing areas.

Location	Winter		Spring		Summer	
	Mean min. temp. (°C)	Rain (mm)	Mean max. temp. (°C)	Rain (mm)	Mean max. temp. (°C)	Rain (mm)
Fuzhou, China (26°N, 88 m)	7.8	27	16.6	124	32.1	170
Guangdong, China (23°N, 18 m)	9.2	45	20.8	101	32.7	215
Hanoi, Viet Nam (21°N, 16 m)	13.3	18	23.3	38	32.8	318
Chiang Mai,Thailand (19°N, 317 m)	13.3	<3	34.4	8	31.1	210
Patna, India (26°N, 58 m)	10.6	15	32.2	10	32.8	290
Mareeba, Australia (17°S, 404 m)	11.2	5	28.1	5	31.2	195
Cairns, Australia (17°S, 3 m)	16.7	30	27.9	36	31.5	399
Nambour, Australia (27°S, 29 m)	6.9	50	24.2	45	28.0	284

(Data presented for winter, spring and summer. Temperatures are means for the three months and rain is total for the three months.)

The reported reduction in fruit set during cloudy weather in Fujian could be due to lack of assimilates for flower development, but is more likely to be related to a direct effect of rain on the anthers or stigmas. Overcast weather may have also reduced bee activity, although their role in pollination is yet to be resolved.

Weather data in Zhang Zhou, Fujian over 22 years showed that in the first ten days of April, the average temperature was 18.4°C and rainfall 49 mm compared with 20.5°C and 43 mm for the middle 10 days of the month and 21.9°C and 39 mm for the last ten days. It was suggested that the early flowering failed because of cool, overcast weather during fruit set.

The effects of light (average irradiance of 4, 7, 9.5 or 13.5 MJ per m^2 per day (from 280 to 2,800 nm) on the growth and flowering of “Wai Chee” were studied over two seasons in Brisbane, Australia (latitude 28°S). Plants were shaded from June to September in year one, and from February to September in year two. Inflorescences emerged from August to September. More than 75 percent of terminal branches flowered, even if the plants were shaded several months before flowering. Average seasonal changes in light would not be expected to strongly influence flowering, unless overcast weather persists for several weeks.

Heavy shade for one week increased fruit drop in cultivar H1224 in Guangzhou (latitude 23°N). Branches were covered with shade cloth to reduce light levels to 10 percent of full sun.

With shading at full bloom, the number of fruit per panicle after three weeks was 0.2 compared with 8.5 in the control. When shading began three weeks after full bloom, the number of fruit retained per panicle three weeks later was 0.8 and 2.2. Overcast weather is common in southern China, although most commercial areas in Asia have clear, dry weather during anthesis.

3.2.3 Effect of temperature on plant development

High temperatures increase the rate of shoot elongation. In contrast, a few weeks of cool weather in winter favour flowering. Extended periods of temperatures above 30°C during anthesis and fruit development can also reduce fruit set and possibly fruit quality.

The effects of temperature on vegetative growth were initially studied in Australia using seedlings. High day/night of 30°/25°, 25°/20° and 20°/15°C compared with 15°/10°C increased shoot growth in six selections, with a mean daily base temperature of 11°C. In a later study with marcots, trees flushed twice at 30°/25°C and once at 25°/20°C over 18 weeks. High temperatures reduced both the duration of flushing and the interval between flushes.

The time of floral initiation in "Calcuttia" and "Rose-Scented" was studied at Kanpur, India. Longitudinal sections of apical buds were sampled every one to two weeks from mid-September (year one) or mid-November (year two). The first signs of floral differentiation occurred about three to four weeks after the minima fell below 10°C, although sampling in the first year missed the actual start of floral initiation. Daily maxima at the start of these observations were as high as 30°C. These studies highlight the difficulty of relating productivity of fruit trees to weather.

Nakata and Watanabe from Hawaii provided the first direct evidence that low temperatures promote flowering. Marcots were placed outdoors or in a glasshouse, with some of the plants moved to a growth room at night. Average daily minima of 13.9°C in the growth room compared with 22.2° to 22.7°C outdoors and in the glasshouse increased flowering. The greatest number of inflorescences per branch occurred if the low temperatures were maintained until anthesis, although flowers were slower to develop compared to those on trees moved outdoors after floral induction. No plants flowered in a growth room at 23.9°C. Flowering only occurred when the night temperature was maintained at 15.6°C for two months. In Australia, all cultivars flowered at 15°/10°C and remained vegetative at 25°/20°C or higher.

Temperature also affects the rate of reproductive development, with panicles emerging earlier at 15°/10°C than at 20°/15°C, but taking longer to reach anthesis. This is consistent with the behaviour of cultivars in Australia. In cooler sub-tropical areas such as Nambour (latitude 27°S), panicles emerge from "Tai So" in May and fruit are harvested in December. However, in warmer tropical areas such as Cairns (latitude 17°S), fruit are harvested in November, although panicles do not appear until July.

In Australia, higher numbers of female flowers were associated with an average maximum during early flower development of 18°C, with lower numbers at 23°C. In contrast, the rate of flower opening was related to the number of flowers per panicle. It was concluded that areas with winter maxima above 25°C were not well suited for lychee culture.

The relationship between fruit set and weather is not well understood. There was no correlation between the proportion of female flowers setting fruit (19 to 26 percent) and daily maximums from 25° to 35°C or maximum vapour pressure from 1.5 to 3.5 kPa in northern New

South Wales. However, continuous hot, dry conditions may reduce yields, since fruit set failed at a constant 33°C in a glasshouse. Bagging can improve fruit quality, possibly due to cooler temperatures and higher humidities.

Temperature has been shown to have strong effects on pollination, but these responses do not necessarily translate into better fruit production. The relationship between pollination and temperature was studied by using glasshouses maintained at 15° to 33°C. The normal time for fertilization to occur was estimated by counting pollen tubes in the ovaries. Maximum fertilization occurred when the number of pollen tubes per ovary did not increase with time after fertilization. Pollination was optimum at 19° to 22°C, with maximum fertilization obtained after seven days. At 15°C, pollen tube elongation was strongly inhibited. However, from 15° to 27°C, at least 10 percent of ovules contained pollen tubes indicating that they were fertilized. Such a level of fertilization appears sufficient for most cultivars to produce a high yield, although at 33°C, all female flowers abscised, suggesting a limitation for good yields when days are above 30°C for long periods.

In southern Queensland, the proportion of female flowers that set was greater with later flowering when the maximum was 30°C than with earlier flowering when the maximum was 24°C. In contrast, fruit set or yield in northern New South Wales could not be attributed to differences in average or maximum temperatures during anthesis. It was proposed that fruit set failed because the male flowers failed to produce pollen. The other possibility was that the early female flowers were sterile.

The average number of days from full bloom to harvest in “Shahi” in India was 68 days, equivalent to an average of 813 degree-days above 15°C. These authors choose the base temperature from data of Batten and Lahav that were based on stem growth not fruit development, although other workers reported that shoot growth still occurred with days of 15°C. Ray *et al.* showed a strong correlation (r^2 = 99%) between the number of days from full bloom to harvest and the number of degree-days above 15°C, although there were two years out of five with the same number of days to harvest, but with different numbers of degree-days. This agrees with the more rapid fruit development in tropical areas.

3.2.4 Effect of drought on plant development

Drought can assist flower initiation, but is not essential. In contrast, drought during fruit development generally reduces production.

Nakata and Suehisa studied the effects of irrigation in eight year old “Tai So” trees in Hawaii, where it is generally dry between April and November. The ‘wet’ treatment maintained ψ_S (soil water potential) at 45 cm depth above -0.03 MPa from June to February. Panicles emerged in December. The ‘dry’ treatment had an average ψ_S of about -0.5 MPa from June to August and then a ψ_S of -1.5 MPa from September to December. Heavy rain occurred in December and ψ_S rose to -0.03 MPa. In the ‘covered’ treatment, ψ_S declined from -0.03 MPa in October to -0.8 to -0.9 MPa during December and January, and then increased to -0.03 MPa in March after irrigation. Only 50 percent of tagged branches flowered in the ‘wet’ plot compared with 80 and 85 percent in the ‘covered’ and ‘dry’ plots, respectively. Average yields were 50, 71 and 84 kg per tree.

A similar trial was conducted in Israel with six year old trees of “Mauritius” (“Tai So”) and “Floridian” (“Brewster”?). It is generally dry from April to October. A week after water was withdrawn from a set of trees, ψ_S (30 to 90 cm depth) declined to -0.07 MPa. Irrigation was withheld for a further two weeks until the mature leaves started browning (equivalent to a noon ψ_L or leaf water potential of -3.2 MPa compared with -1.5 MPa in control trees). ‘Dry’ trees were then given limited irrigation of 1 mm per day for another week that would hardly balance evapotranspiration. Full irrigation at this time of the year was 3 mm per day. The severe drought in October inhibited leaf growth in November and increased flowering and yield. Flowering occurred after the trees were re-watered. These results demonstrate that drought can induce flowering, but the response is probably related to a shift in the timing of shoot growth. Several glasshouse experiments in Australia showed that drought had no direct effect on flowering.

Shoot growth is very sensitive to changes in tree water status. Menzel *et al.* examined the vegetative flushing of “Kwai May Pink” under different irrigation regimes in a glasshouse. Growth decreased as the level and duration of drought increased, but none of the trees flowered at high temperatures. A period of drought before flower induction may assist flowering by delaying early shoot growth until winter. This can be used in areas such as northern Thailand that have dry winters.

Once flower panicles are initiated, best fruit set is achieved when plants are well watered. A cyclic drought (predawn ψ_L of -2.0 MPa) achieved by watering the plants every four to seven days to field capacity reduced panicle growth and the numbers of flowers compared with plants watered daily (ψ_L above -0.7 MPa). Most of the flowers abscised prematurely in droughted plants and the few flowers that reached anthesis were male. These results indicate that trees should be irrigated from panicle emergence to prevent water deficits reducing fruit set, although they do not indicate a threshold ψ_L below which production is affected. Experiments in small pots may not necessarily predict the response of mature trees in the field, with a deep root system and slower development of drought.

There is very little information on the response to irrigation during fruiting. The results on hand indicate that there may be different effects on fruit production depending on the level and timing of the water shortage.

Batten *et al.* compared a set of unirrigated trees and trees irrigated weekly to replace 85 percent of potential evapotranspiration at Alstonville in Australia (latitude 29^{o}S). Potential evaporation is the water use of a well-watered grass sward. This was not mentioned in the text. For a Class A pan with a wire bird cover surrounded by grass, potential evapotranspiration of the grass is about 85 percent of the evaporation from the pan. Consequently, the irrigated trees were watered to replace 72 percent of the pan evaporation (pan factor of 0.85 and a crop factor of 0.85). The eight to ten year old “Bengal” trees were growing in a deep, well drained clay soil and were droughted from flowering until harvest.

Predawn and noon ψ_L declined to -0.9 and -2.4 MPa in unirrigated trees, while minimum ψ_L in the controls were -0.4 and -2.0 MPa. It took six weeks before any significant difference in ψ_L between the two groups was noted. Fruit were 10 percent smaller in the unirrigated trees than in control trees, but the number of fruit was more than double in the dry treatment (26 fruit per panicle compared with 12 fruit per panicle in the controls). Greater fruit retention was attributed to less competition between leaf flushes and fruit, although no shoot growth data were presented.

The effects of irrigation on “Tai So” were studied in South Africa. A ‘wet’ group of trees was irrigated weekly to replace evapotranspiration, while a ‘dry’ set was allowed to dry out gradually over six months from panicle emergence. Minimum ψ_L declined to -2.8 MPa in the early afternoon in the ‘dry’ treatment compared with -2.2 MPa in the ‘wet’ treatment. Minimum ψ_L on the shaded side of the trees at 0900 h were -2.6 and -1.5 MPa in the ‘dry’ and ‘wet’ treatments, respectively. It took about six weeks before there were appreciable differences in tree water status between the two groups of plants. Drought reduced the number of fruit per tree, average fruit weight, flesh recovery and yield. The main reason for the lower yield in the ‘dry’ treatment was increased rate of fruit splitting just before harvest compared with control trees. The differences in the results in Australia and South Africa need to be resolved.

Skin cracking is a serious problem in many countries such as India where up to 50 percent or more of the crop may be lost. Temperatures are above 38^{o}C and relative humidity below 60 percent during much of fruit development. However, it is not a major problem in Viet Nam, where the weather is less extreme.

The role of hot, dry conditions on fruit drop is not known. There have been no experiments in which humidity and temperature conditions have been controlled or the pattern of fruit drop has been correlated with daily weather data. Fruit drop in sub-tropical Australia was not related to rainfall after fruit set in irrigated orchards, although higher rainfall would be expected to increase relative humidity. Spotting bugs (*Amblypelta nitida* and *A. lutescens*) are more important factors in some areas, accounting for 25 to 99 percent of green fruit drop in several locations.

3.2.5 Predicting areas suitable for lychee production

The key factors to consider when assessing the potential of different areas for lychee are temperatures in winter that affect flower initiation, temperatures and light levels in spring which affect fruit set, and reliability of rainfall which affects fruit development. Normally temperatures below 20^{o}C induce flowers, while flowering is irregular at higher temperatures, with the exception of a few tropical ecotypes in Thailand.

A short drought in winter may assist flowering, especially in the more tropical cultivars, but is not essential. Annual rainfall of 1,200 to 1,500 mm is probably required in the absence of irrigation. Long dry periods during fruit development will invariable reduce returns. This will limit production to the wetter areas in Asia.

The other critical part of the crop cycle is fruit set that is reduced when temperatures fall below 20^{o}C for extended periods during flowering. Persistent cloud cover at this time can also be a problem. This could be a concern at higher elevation in some areas in southern Australia and elsewhere.

Olesen developed a model showing the relationship between potential flowering with latitude along eastern Australia (Figure 6). This was related to the number of days per year with mean temperatures below 20^{o}C. At lower latitudes or more tropical sites, there were few days suitable for flowering, while at higher latitudes or more sub-tropical sites, there were several weeks of suitable temperatures. This model is supported by the relative performance of mature trees in the different areas. The data can be used to show the changes in mean temperature in July with latitude as well (Figure 7). You can then predict flowering in other environments if you have access to temperature data (Figure 8), with a plot of likely flowering versus mean temperatures for the coldest month.

The model can be used to estimate the reliability of flowering at different elevations, instead of latitude in Asia. These can be derived by estimating the change in mean temperature with elevation, using a base temperature for a site that is close to sea level (Figure 9). McAlpine *et al.* used a similar model to derive changes in temperature with elevation in Papua New Guinea. Other models are available, but they are generally similar, with temperature falling by about 0.6°C for each 100 metre rise in elevation. Once mean temperatures for the coldest month are determined, estimates can be made of flowering at different elevations for a more tropical location, say at a latitude of 12° (Figure 10). This analysis is dependent on the actual temperature at elevation being close to that predicted by the model. Previous work using data from five sites indicate a difference of ± 1.0°C between the predicted and actual temperatures. The reliability of the model was confirmed.

Figure 6. Relationship between number of days per year suitable for lychee flowering and latitude in Australia.
(Latitude varies along 2,000 km of coastline. Data from Menzel et al. 2000).

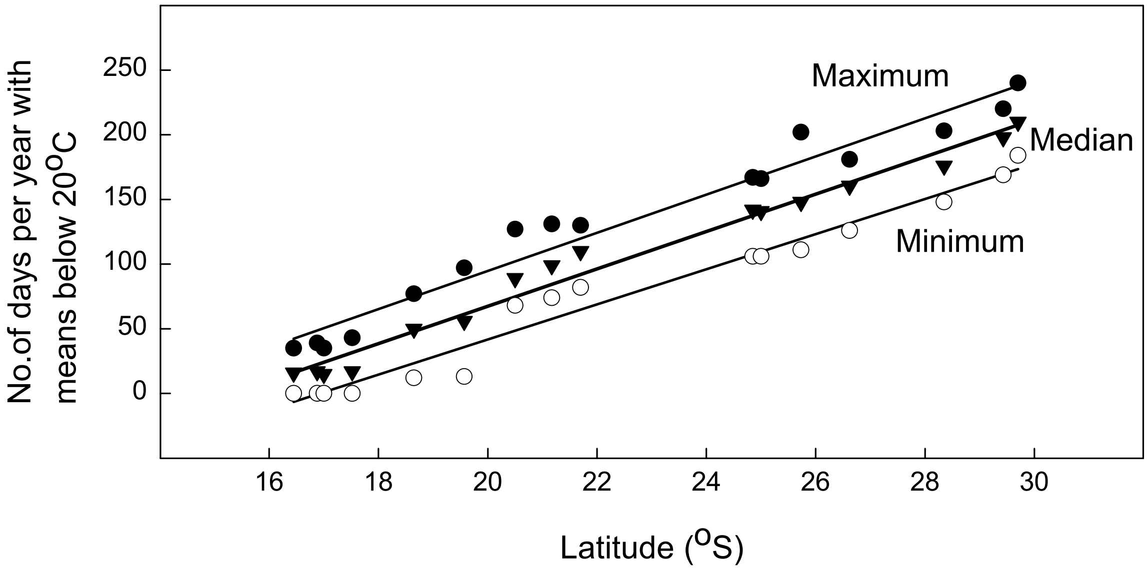


Figure 7. Relationship between average temperatures in July and latitude along eastern Australia.
(Latitude varies along 2,000 km of coastline. Data from Menzel et al. 2000).

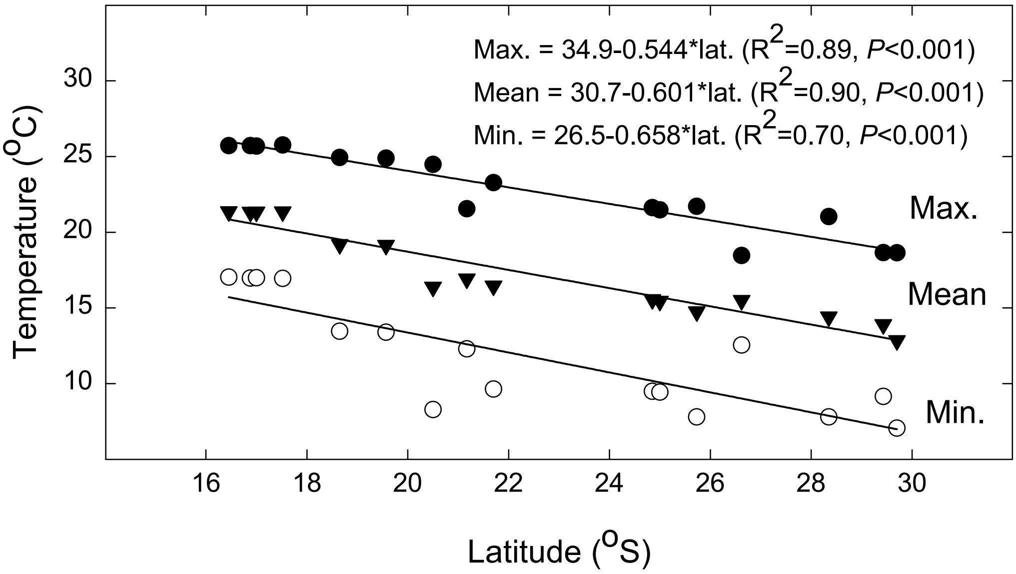


Figure 8. Relationship between number of days per year with means below 20°C, and mean daily temperature in July in eastern Australia.
(Data from Menzel et al. 2000. Mean temperatures in July have been calculated from Figure 7).

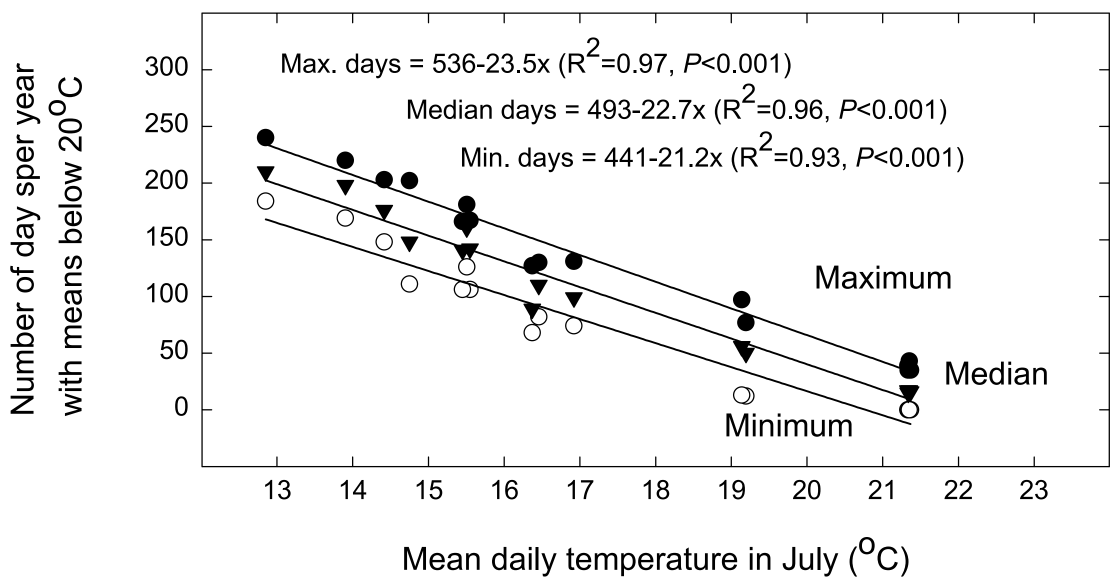


Figure 9. Relation between temperature in January and elevation at a tropical location (latitude 12°).
(Analyses from McAlpine et al. 1983).

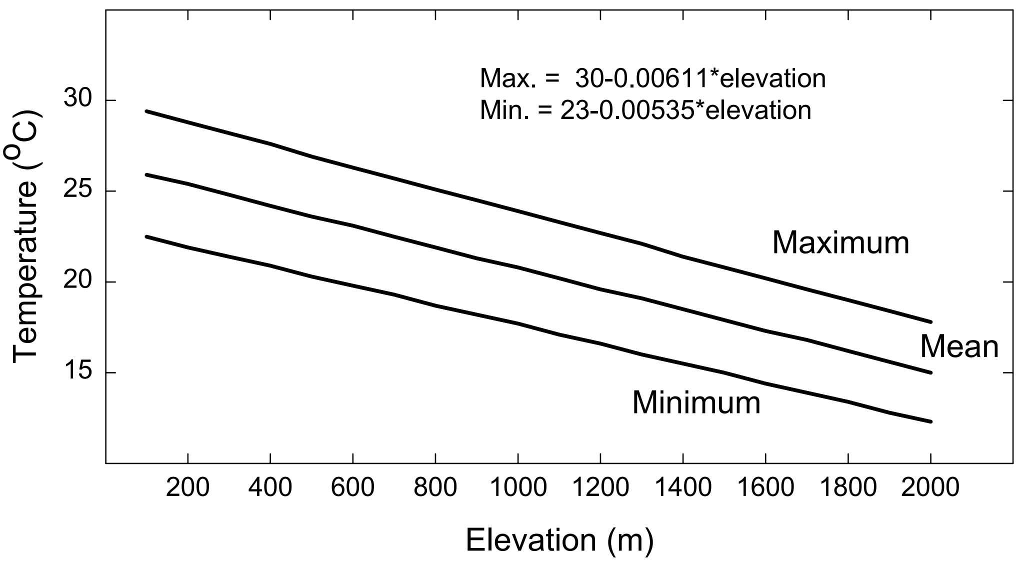
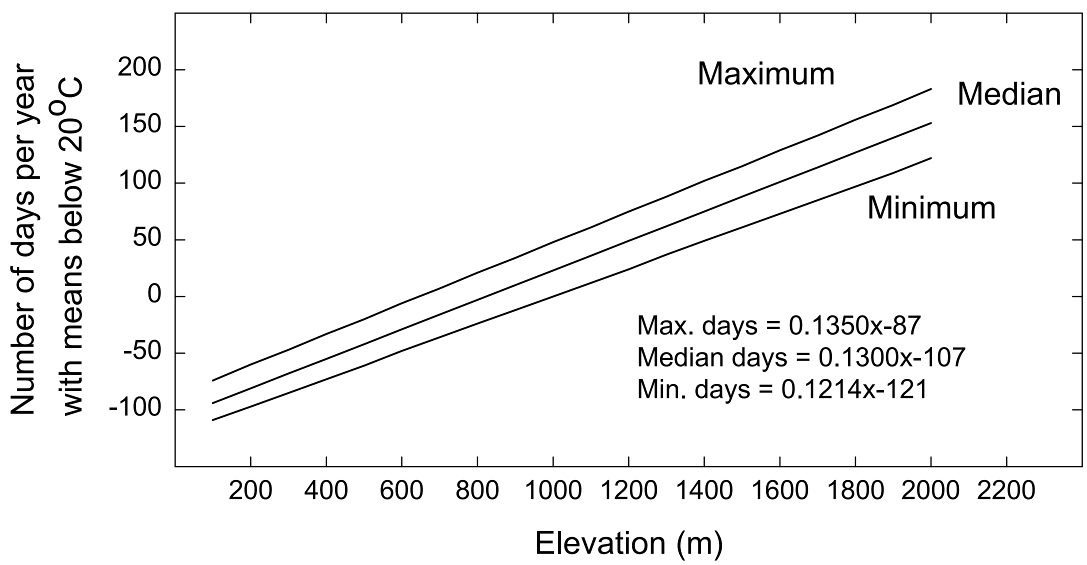


Figure 10. Relationship between number of days per year with means below 20°C, and elevation at 12° latitude.



3.3 Relationship between cropping and soil type

3.3.1 Soil type

Lychees can be found growing on a range of soils, including alluvial sands, loams, heavy clays, and soils with a high content of organic matter, lime or rocks. Trees perform best on well drained clay loams of medium to high fertility with a minimum one metre of well drained topsoil. They may die on heavy clay soils that become waterlogged. There can also be problems on very sandy soils that dry out during hot weather, and on calcareous soils with potential iron, zinc or manganese deficiencies. These soils need to be carefully managed. Slopes greater than 15 percent are also best avoided as they do not allow the safe use of machinery, and may erode.

In Guangdong, many of the newer plantings have been established on heavy clays. Traditionally, the best trees were found close to the rivers, on alluvial sands with good drainage and access to the water table. There were also many orchards planted in terraces 1.5 to 2.0 m wide in gravelly sandy loams and in swampy areas bisected by canals where the soil was built up in levees about 0.5 to 1.0 m above high tide.

In Guangxi, most of the trees are found on heavy red clays on slopes, although sometimes they are grown on sandy loams of alluvial origin along the rivers. The bulk of the red clays are of low to medium fertility, with only average concentrations of organic matter, phosphorus and potassium. The soils are generally acid, and need regular applications of lime or dolomite. Some of the trees are grown in mounds (less preferred) or on mounded rows to improve drainage during extended wet weather, however, these mounds may dry out in hot weather.

The soils in Fujian are high in clay, poorly drained and acid. When trees are grown in terraces, the planting site is generally filled with quality loam and organic matter to improve soil structure and fertility.

In Viet Nam, trees are grown in many different soils, from silty loams to clay loams with a wide range in colours from red, brown, yellow and grey. Physically, most of these soils are suitable for cropping, provided organic materials are added, and are well drained to at least one metre. However, chemical and pH levels vary, and these need to be managed carefully.

In India, well drained alluvial soils with access to the water table are considered ideal. Production is generally much lower in the poorly drained, heavy clays. In northern Bihar, there are many calcareous soils, with a pH of 7.5 to 8.0. Nutrition has to be carefully managed on these soils to avoid deficiencies of micronutrients such as iron.

3.3.2 Water relations and root growth

Lychees can withstand up to 14 days of immersion, provided the water does not become stagnant, but will die after prolonged waterlogging. Trees subjected to continued flooding in China are smaller than those on better drained soils. Poor drainage in heavy clays can increase the incidence of collar rots and root diseases. In southern Queensland, hilling of the soil along the rows to give ridges 0.5 m high is recommended in wet sites. The addition of drainage pipes can also assist growth in wet soils.

Nel observed a tremendous network of roots in ”Tai So” growing down to one metre in sandy soils in South Africa, while trees growing in clay soils had a shallow root system. Most of the roots of an eight year old “Tai So” tree growing in a sandy clay loam overlying a heavy clay in Queensland were in the top 30 to 40 cm. Other experiments showed that soil type influenced total root density and feeder root distribution (depth of the soil where 80 percent of roots are located). There were more roots in a sand than in a clay, but a smaller proportion was found at depth (feeder root distributions of 0 to 20 cm and to 0 to 60 cm, respectively). About 90 percent of the roots were less than 2 mm in diameter, with no effect of soil type or depth.

Howard showed that although some roots were found below 300 cm in a deep calcareous sandy loam in India, most roots were located in the top 45 cm. The deep roots were, however, capable of absorbing enough water during the dry season to support a large crop.

3.3.3 Soil pH

Trees are capable of growing on either acid or alkaline soils, although there is little critical information on the optimum pH. Most growers aim for a pH between 5.5 and 6.0, although lower pH is probably acceptable. Nutrition management, especially the application of micronutrients needs to be modified at extremes of soil pH.

The pH in China is usually about 5.5, with the soils naturally acid or acidified by liquid fertilizers or organic mulches such as straw. In contrast, in India, many soils are alkaline with up to 30 percent free lime.

Table 4 shows the suggested rates of lime application for soils with different pH in Queensland. No more than 5 tonnes of lime per ha should be applied in a single application on sandy soils. Where more lime is required, a second amount should be applied three months later. Dolomite can be used instead of the lime, if soil magnesium concentrations are low.

Table 4. Lime requirement (tonnes per ha at 10 cm depth) for soils with different pH. .

Mehlich soil buffer pH	Lime required to bring soil to pH (water) to 5.5	Lime required to bring soil to pH (water) to 6.5
4.5	8.6	18
4.7	7.1	15
4.9	5.7	12
5.1	4.4	10
5.3	3.2	7.5
5.5	2.2	5.7
5.7	1.3	4.1
5.9	0.7	2.8

(Only apply lime when the soil pH (water) is lower than the target pH. Data from Phil Moody and Bob Aitken, Queensland Department of Natural Resources and Mines).

3.3.4 Salinity

There is little information on the response to excess salts. Lychee appears to be less sensitive than avocado or macadamia, but is still in the low tolerance class of plants. It is recommended that trees should not be irrigated with water having an electrical conductivity greater than 0.5 dS per m or about 500 mg soluble salts per litre. Damage sometimes occurs during dry weather, especially when young trees are over-fertilized. The tips and margins of the old leaves die.

Australian Scientists grew marcots in sand culture irrigated with 6 or 12 mM NaCl. At both concentrations, older leaves were shed with each new flush of growth. "Tai So" was more sensitive than "Bengal", and this was reflected in greater uptake of salts. The concentrations of Na in the leaves of "Tai So" after 13 months in the control and 12 mM NaCl treatments were 240 and 22,000 ppm, respectively. Similarly, leaf Cl concentrations were 0.3 and 2.6 percent.

3.3.5 Mycorrhiza

Coville was the first to detect mycorrhiza in lychee. Fungi were isolated from root tubercles of seedlings grown in peat and sand, whereas no such tubercles were found on plants grown in the standard mix of loam, sand and manure. Seedlings with the tubercles were larger and had more roots than plants without the fungi. Kadman and Slor showed that "Tai So" seedlings were larger when grown in peat plus mycorrhizal soil compared with peat plus regular soil.

Pandey and Misra described the taxonomy, morphology and habit of the mycorrhiza. *Rhizophagus litchi* belongs to the vesicular-arbuscular group of phytomycetous endophytes. The endophyte could not be cultured on artificial media, the presence of living roots being necessary for its survival. Mycorrhiza were only found on short-lived sublateral roots. The fungi penetrated the roots through the epidermal cells into the cortex, whereas the root hairs, endodermis and vascular tissue were free of infection.

Since the earlier work of Coville, many authors have suggested that lychee requires mycorrhiza to grow satisfactorily, although healthy plants have been examined which were completely devoid of tubercles. In China and India, it is suggested that new plants be grown in soil taken from the vicinity of old trees to introduce the mycorrhiza. Further experiments are required to establish the role of these organisms in commercial production.

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4. CULTIVARS AND GENETIC IMPROVEMENT

Overview

Lychee has been cultivated and undergone intensive selection for thousands of years in Asia. The main cultivars in China include "Fay Zee Siu", "Bah Lup", "Lanzhu", "Baitang-ying", "Haak Yip", "Kwai May" (Red), "No Mai Chee" and "Wai Chee". Some industries are mainly based on cultivars that are of Chinese origin. "Tai So" and "Wai Chee" form the basis of production in northern Thailand, while "Tai So", "Kwai May Pink" and "Wai Chee" dominate plantings in Australia. In contrast, local seedling selections of Chinese cultivars are used in Viet Nam, India, Nepal, Bangladesh and southern Thailand. Cultivars developed in the last 50 years that are becoming increasingly important include "Donguan Seedless", "Hexiachuan" and "Maguili" (Guangdong), "Sah Keng" (Taiwan Province of China), "Kom" and "Chacapat" (Thailand), "UPLB Red" (The Philippines) and "Salathiel" (Australia). Cultivars differ greatly in growth, yield and fruit quality. Opportunities exist for improving productivity in the Region by breeding new selections, with the emphasis on traditional breeding rather than on biotechnology.

4.1 Introduction

The first official mention of lychee in China appeared in the second century BC, while unofficial records date back 1,600 years earlier. A "Lychee Register" indicated that there were 16 cultivars in Guangdong in 1034 and 30 in Fujian in 1059. These figures had climbed to 100 by 1076 in Guangdong and a similar number, somewhat later (1597) in Fujian. Limited descriptions of cultivars were provided in the eleventh century, and full descriptions in the seventeenth century. Growers could distinguish the best ecotypes for the plains or hills. Marcotting was used in the fourth century and grafting in the fourteenth century. Propagation by seed was eventually eliminated in the sixteenth century.

The Chinese claim that lychee has more cultivars than any of their other fruit. A monograph on this species written by Ts'ai Hsiang in 1059 is considered to be the first publication in the world devoted to fruit culture. However, only about 15 of the 100s of cultivars available, are exploited commercially. In many other countries, production is based on one or two cultivars.

4.2 Standardization of names and classification of cultivars

A large number of cultivars are grown around the world, although the same cultivar may be known under several different names in different places, or even within a given country. This leads to confusion amongst researchers, advisors, growers and nurserymen. The standardization of cultivar names has been reviewed in Australia (Table 5), although some workers prefer the Pinyin spelling.

Chinese researchers report that the shape of the skin segments and protuberances can be used to identify cultivars. These characteristics are more reliable than fruit size, shape or taste. The key to the major cultivars is as follows.

A. The protuberances are protruding and hard.

1. The protuberances are relatively fine, dense and sharp-pointed. The skin segments are small and irregularly arranged. Group 1. “Tai So” type.

2. The protuberances are large, sharp and short-pointed. The skin segments are small and regularly arranged. Group 2. “Kwai May” type.

3. The protuberances are relatively blunt and short. The skin segments are relatively large, and irregular in size and arrangement. They are often small segments among the normal skin segments. Group 3. “Jin Feng” type.

B. The protuberances are hair-like or sparse, fine and sharp-pointed.

1. The skin segments are irregularly in size and arrangement. The fruit shoulder is extremely wide and pronounced. The stalk is thick and strong. Group 4. “Sum Yee Hong” type.

2. The skin segments are regular in size and arrangement. The fruit shoulder is flat. Group 5. “Haak Yip” type.

C. The protuberances are smooth or not evident.

1. The skin segments are obviously protruding, usually long and narrow-shaped, and arranged in longitudinal rows. Group 6. “No Mai Chee” type.

2. The skin segments are smooth or slightly protruding, usually near round in shape and irregular in arrangement. Group 7. “Wai Chee” type.

4.3 Productivity

The average yield of orchards in China is only 1.6 to 2.9 tonnes per ha. Not all trees are of bearing age, and many of the orchards are neglected. A well-managed orchard can produce 15 tonnes per ha in an 'on year'. Mature trees may produce 150 to 250 kg of fruit.

There is a paucity of published yield records of cultivars from replicated trials. Jawanda and Singh indicated that average yields of ten cultivars in India ranged from 12 to 130 kg per tree. The highest yields were obtained from “Calcutta” followed by “Seedless Late”, although the former cultivar is biennial bearing. Menzel *et al*. grew four cultivars in a replicated trial in Nambour in sub-tropical Australia. Yields after eight years varied from 0.1 to 28.5 kg per tree, equivalent to a maximum of 6.6 tonnes per ha at a density of 230 trees per ha. “Wai Chee” was superior to “Bengal” and “Tai So”.

Productivity is a problem in many orchards in the Region, with the reason for low average yields varying with country and district. Poor floral induction, fruit set or retention can affect individual orchards, districts or regions. Depending on climatic conditions within a given area, early- or late-season cultivars may be more regular. This often depends on when the trees flower and set fruit. Biennial bearing can also be a problem where orchards are neglected. Some cultivars are more susceptible than others.

Table 5. Standard names for cultivars in Australia.

Name in Australia	Pinyin name	Meaning	Name in Thailand
Sum Yee Hong	Sanyuehong	Third month red	
Souey Tung	Shuidong	East of the waterways	
Bah Lup	Baila	White wax lychee	
Tai So	Dazao	Big crop	Hong Huay
Brewster	Chenzi		
Fay Zee Siu	Feizixiao	Concubine laughing	
Haak Yip	Heiye	Black leaf	O-Hia
Kwai May Red	Guiwei	Cinnamon flavour	
No Mai Chee	Nomici	Glutinous rice grain	
Tim Naan	Tianyan	Sweet cliffe	
Wai Chee	Huaizhi	Cherished lychee	Kim Cheng
Soot Wai Zee	Xuehuaizi	Snow white lychee	

("Kwai May Pink" grown in Australia is not known as a separate cultivar in China. "Tai So" is similar to "Mauritius" in many countries).

4.4 Characteristics used to identify cultivars

4.4.1 Harvest season

The harvest normally lasts five to ten weeks for a range of cultivars in any one location. Cultivars can be broadly classified as early-, mid- or late-maturing, although the order varies from year to year, depending on seasonal conditions. There is also some variation in the Region, presumably due to differences in environment or culture.

4.4.2 Tree

You can learn to identify cultivars using tree characteristics, however, they change with weather, soil and culture. Differences in tree size and shape, and length and spread of branches are commonly used. For example, "Brewster" is vigorous and erect, with very wide strong crotch angles; "Tai So" is vigorous, with a spreading habit and sharp weak crotch angles; while "Wai Chee" is slow, compact and dome-shaped.

4.4.3 Leaves

Useful characteristics include leaf size, shape and colour. For example, "Tai So" has large, glossy, dark green leaflets that have an upward curl from the midrib to be almost canoe-shaped. "Bengal" has large leaflets, mid-green in colour with a distinctive twist along their length. "Haak Yip" has dark, glossy green leaflets that are long, narrow- pointed and slightly curled at the tip. "Wai Chee" leaflets are small, oval-shaped and curve upwards from the midrib and down along their length. The new flush of growth is red in "Wai Chee" and "Kwai May Pink" and green-bronze in "Tai So".

4.4.4 Fruit

The shape of some cultivars is very distinctive (Figure 11). The round fruit of “Kwai May Pink” distinguishes it from the egg shape of “Tai So” or the heart shape of “Haak Yip”. The shoulders of the fruit can be smooth or flat as in “Wai Chee” and “Kwai May Pink”, or uneven as in “Souey Tung” and “Bengal”. The apex or tip of the fruit can be round as in “Kwai May Pink” and “Wai Chee”, obtuse or blunt as in “Souey Tung” and “Brewster”, or pointed as in “Bengal”.

Typical colours are bright red (“Bengal”), dull red (“Wai Chee”), purple-red (“Haak Yip”) or pink-red (“Brewster”). The skin can be thick as in “Wai Chee”, “Bengal” and “Kwai May Pink”, or thin as in “Haak Yip” and “Souey Tung”. Skin segments at full maturity can be smooth (“Haak Yip”), swelling (“Wai Chee”) or sharp-pointed (“Kwai May Red”). Similarly, the protuberances on each segment can be smooth as in “Haak Yip”, sharp-pointed as in “Kwai May Red” and “Bengal”, or hair-like and sharp as in “Tai So”. The presence or absence of an obvious suture line can distinguish some cultivars such as “Haak Yip” and “Souey Tung”.

The texture, juiciness, taste and aroma of the flesh can aid description, although experience is needed to make clear distinctions. For example, “Wai Chee” is watery, “Kwai May Red” is firm, “Kwai May Pink” is spicy and “Bengal” is very sweet.

The proportion of small or shrivelled seeds is important, but varies with season and orchard. Cultivars with a high proportion of chicken tongue seeds are favoured. In Australia, “Salathiel” nearly always produces fruit with small seeds, while “Bengal”, “Souey Tung”, “Haak Yip” and “Wai Chee” produce hardly any. Other cultivars such as “Tai So” and “Kwai May Pink” vary.

4.5 Major cultivars in the Region

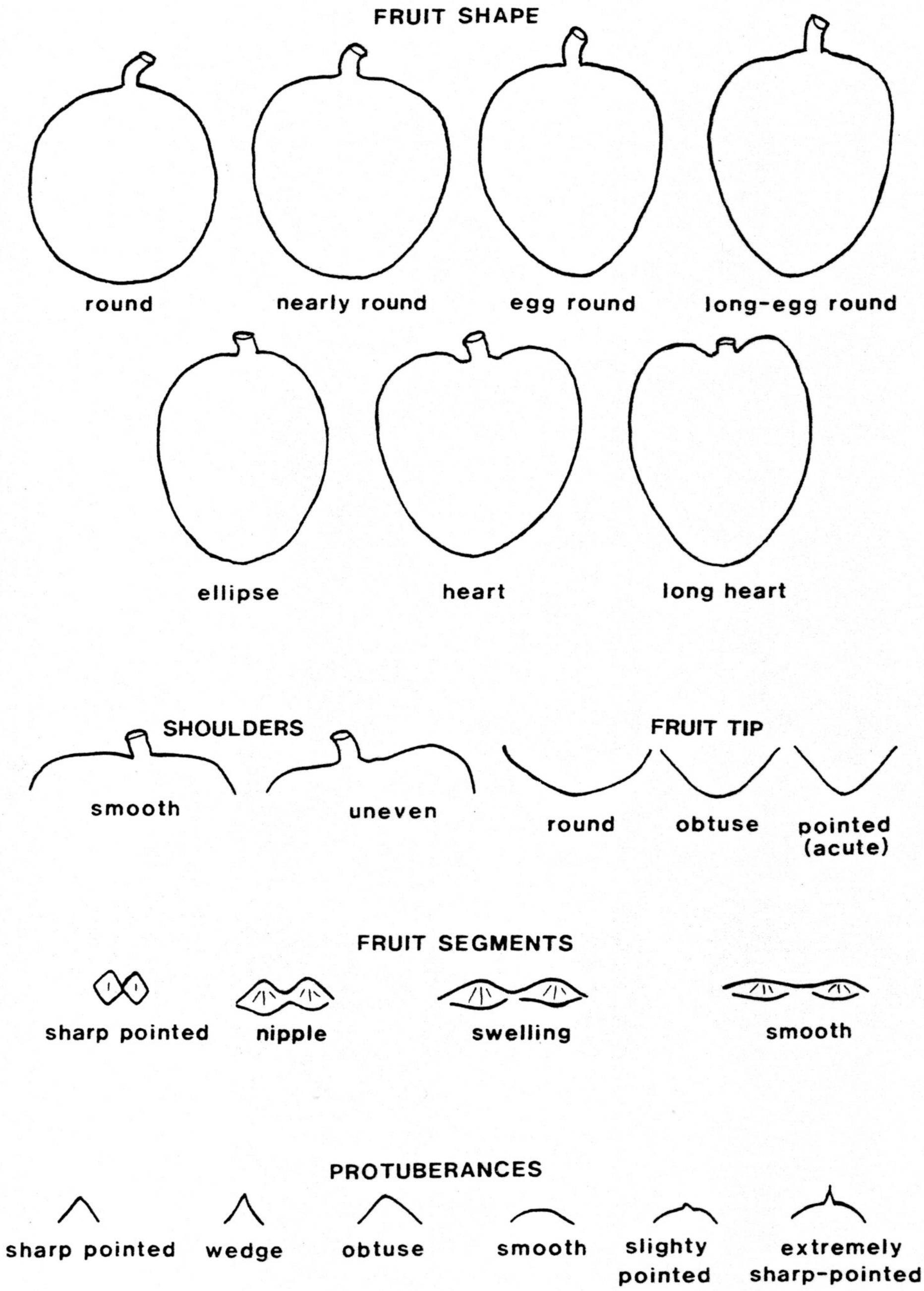
Major cultivars in the Region are listed in Table 6.

The most important cultivars in Guangdong are “Bah Lup” (27,000 ha), “Baitang-ying” (27,000 ha), “Haak Yip” (34,000 ha), “Fay Zee Siu” (27,000 ha), “Kwai May” (60,000 ha), “No Mai Chee” (60,000 ha) and “Wai Chee” (40,000 ha). “Wai Chee” accounts for over 80 percent of plantings in Guangxi, and bears consistently because it flowers late and avoids cool weather in spring. In Fujian, “Lanzhu” dominates plantings. Some new cultivars have been developed recently including “Donguan Seedless” and “Hexiachuan” that produce seedless or small-seeded fruit, and “Maguili” that crops late in the season.

“No Mai Chee” and “Kwai May” have excellent eating quality and a high proportion of chicken tongue or aborted seeds. “Fay Zee Siu” is also popular because of its excellent eating and size (24-32 g). Some cultivars are best eaten fresh, while others are more suitable for canning or drying. Cultivars exported include “Sum Yee Hong”, “Fay Zee Siu”, “Haak Yip”, “Kwai May”, “Wai Chee” and “No Mai Chee”.

“Haak Yip” is the most popular cultivar in Taiwan Province of China and accounts for over 50 percent of plantings. Other important cultivars are “Sum Yee Hong”, “Chong Yun Hong”, “No Mai Chee” and more recently “Sah Keng”.

Figure 11. Fruit characteristics used to describe different cultivars.



Eight cultivars are grown commercially in Viet Nam; however, production is dominated by a single cultivar, "Vaithieu" that accounts for 80 percent of plantings. Because the industry is based on a single cultivar, the harvest is unduly short, lasting only four to six weeks.

The main cultivars in northern Thailand are "Tai So" ("Hong Huay", 65 percent of production) and to a lesser degree "Wai Chee", "O-Hia" ("Baidum") and "Chacapat" ("Chakrapad"). A different set of ecotypes has been developed for the areas around Bangkok, including "Kom" (11 percent of plantings), "Luk Lai", "Sampao Kaow", "Kaloke Bai Yaow", and "Red China". The quality of these selections is not as good as those in the north.

Table 6. Major cultivars in Asia and the Pacific.

Country	Major cultivars
China	Fay Zee Siu, Bah Lup, Lanzhu, Baitang-ying, Haak Yip, Kwai May (Red), No Mai Chee and Wai Chee.
Viet Nam	Vaithieu
Thailand	Tai So (Hong Huay), Chacapat (Chakrapad), Wai Chee (Kim Cheng), Haak Yip (O-Hia) and Kom.
India	Shahi, China, Calcuttia, Bedana, Late Bedana and Longia.
Nepal	Mujafpuri, Raja Saheb, Deharaduni, China and Calcuttia.
Bangladesh	Bombai, Muzaffarpuri, Bedana and China 3.
Indonesia	Local selections
Philippines	Sinco, Tai So and ULPB Red.
Australia	Kwai May Pink, Tai So, Souey Tung, Fay Zee Siu, Salathiel and Wai Chee.

Most of the cultivars in India have been selected from seedlings sent from China, although a few appear to be renamed Chinese cultivars, as in Thailand and Australia. Selections have been developed which can crop in the hot and dry conditions. Of the 30 or so cultivars grown, only six are commercially important: “Shahi” (“Muzaffarpur”), “China”, “Calcuttia”, “Bedana”, “Late Bedana” and “Longia”. These generally have large fruit and excellent quality. In West Bengal, “Bombai”, “Shahi” and “Rose Scented” can produce 40 kg per tree compared with 15 to 25 kg per tree in many of the other cultivars.

In the hilly areas of Nepal, commercial production is based on various seedlings, whereas there are established cultivars in the plains (“Majafpuri”, “Raja Saheb”, “Deharaduni”, “China” and “Calcuttia”). Most of these probably came from India. The most important cultivars in Bangladesh are “Bombai”, “Muzaffarpuri”, “Bedana” and “China Number Three”. “Bombai” is the oldest cultivar. “Bedana” has the best quality, but is low yielding.

“Mauritius” and a local selection from China, “Sinco” dominate production in the hilly areas of the Philippines, while an introduction from Thailand, “UPLB Red” is planted in the lowlands. The Department of Agriculture is also evaluating two new selections for the warmer areas. Lychee is a minor crop in Indonesia, with a few Government nurseries selling clonal material.

Lychee plants (seedlings?) were growing in the Sydney and Brisbane Botanical Gardens in Australia in the 1850s. Air-layers of “Tai So” and “Wai Chee” were not introduced until the 1930s. Plant material was subsequently distributed further along the eastern coastline, and production now extends from Cairns and The Atherton Tableland in northern Queensland to Coffs Harbour in northern New South Wales. “Kwai May Pink”, accounts for more than 50 percent of plantings, with “Tai So”, “Souey Tung”, “Fay Zee Siu”, “Salathiel” and “Wai Chee”, the other main cultivars.

4.6 Description of major cultivars

"*Sum Yee Hong*" is the earliest cultivar in Guangdong, and finds a ready market in spite of its average quality compared with later cultivars. It is grown along watercourses particularly in the suburbs of Guangzhou and Zhong Shan District and can be a heavy cropper. "Sum Yee Hong" has also been imported into Australia, but is found only in northern areas. The tree is medium in size with an open, spreading habit and long, thin, fragile branches. The leaves are long, narrow, shiny dark green and much thicker than other cultivars. The fruit are exceptionally large (26-42 g) with bright red, thick skin that peels easily. The flesh is very juicy, and sweet-acid. The seeds are generally large.

"*Souey Tung*" is a popular early cultivar in Fujian. It has been distributed to Australia, but is not as widely grown. "Souey Tung" tolerates a high water table and is planted along watercourses in China. It is reported that rain near harvest causes the fruit skin to discolour, due to black mildew. The tree is relatively low with thin, long, open, spreading branches that point downwards. Leaflets are large, flat, dark glossy green and pointed. The new flush of growth is bronze changing to red and green with maturity. Fruit are medium (20-22 g), and heart-shaped with distinctive uneven shoulders. The skin is thin, dull dark red to purple, and smooth. The fruit tip is obtuse or blunt. The flesh is soft, juicy, sweet and of excellent quality. Seeds are variable in size, but mostly medium giving a good flesh recovery of 65 to 75 percent. There are only 5 to 10 percent abortive seeds.

"*Bah Lup*" is a productive Chinese cultivar and has better quality than others available at the same time such as "Sum Yee Hong" and "Souey Tung". It is grown in Dian Bai and Gao Zhan Counties in Guangdong and is an important early variety for export. The tree is medium in vigour and dome-shaped. Leaflets are long, narrow, dark glossy green with a short point. Fruit are near heart-shaped, medium to large (20-29 g) with thin, soft, brilliant red to slightly purple skin. Protuberances are obtuse. The flesh is juicy and delicately sweet. Fruit usually have large oval seeds. Flesh recovery is up to 77 percent.

"*Tai So*" is a common cultivar in China, Thailand and Australia, although yields tend to be irregular. Trees often flower poorly or have insufficient numbers of female flowers to provide good fruit set. Trees are vigorous and spreading with an open crown, and have branches with weak crotch angles that can split. Even large trees may suffer damage. Leaflets are large, glossy dark green and have an upward curl from the midrib to be almost canoe-shaped. The new flush of growth is bronze changing to dull mid-green to pale green with advancing maturity.

Fruit are large (22-26 g) and somewhat egg-shaped, with flat shoulders and a round tip. The thin skin is bright red changing to dull red at maturity (Plate 1). Protuberances are hair-like/sharp-pointed when the fruit are ready to harvest. Fruit are not of good quality until fully mature. Flavour is sweet-acid when immature, sweet when fully ripe, and bland when overripe. Flesh is slightly chewy becoming moderately crisp when fully mature. Seeds are medium, giving a fair flesh recovery of 60 to 70 percent. Up to 50 percent of fruit have chicken tongue seeds, depending on the season. Fruit often split or brown in hot dry weather.

"Fay Zee Siu" is ranked as one of the best export lychees in China, and has been recently imported into Australia. The fruit is described as having the colour of amber, the size and shape of a goose egg, and the sweetness of honey. It is mainly grown in and around Guangzhou, with fruit maturing early in the season, before "Tai So". The tree is vigorous with long, sparse, fragile branches that can break. Leaflets are large, narrow and deep glossy green.

Fruit are large (24-32 g), round to oval-shaped with thin, light red, splotchy skin. The flesh is firm, sweet, delicious and very fragrant. Seeds are variable, giving a flesh recovery of 77 to 82 percent.

"Haak Yip" is a very popular cultivar in China, Taiwan Province of China and northern Thailand ("O-Hia"), but has undergone limited distribution elsewhere. It is commonly canned in Taiwan Province of China. Fruit mature about a week after "Tai So". Trees are medium, with dense foliage and long, thin, fragile branches. The leaflets are very dark, glossy green, long, narrow-pointed and slightly curled at the tip.

The heart-shaped fruit are medium (20-22 g) and formed in large compact clusters (15-30 fruit). The purplish red skin is thin and soft and prone to insect attack, and has a distinctive suture line. Shoulders are wide and even. The skin is smooth, with no raised protuberances. The flesh, which separates easily from the seed, is sweet, crisp, slightly aromatic and of excellent quality. Seeds are medium and fully developed, giving a flesh recovery of 68 to 76 percent. Fruit are exported from China. "Haak Yip" can be distinguished from the related "Souey Tung" by its slightly later maturity, even shoulders, obvious suture line, firmer flesh and more uniform and slightly larger seeds. Both are good marketing types when grown well.

"Brewster" was obtained from Fujian by the Reverend W. M. Brewster and propagated in Florida in 1903. It was also sent to Australia, but is not popular. In 1948, W. Groff suggested that "Brewster" was, in fact, the recognized Chinese variety "Chen Zi" ("Chen Family Purple") and recent information indicates that they are the same cultivar. Production in Australia has been disappointing, whereas in Fujian, trees grown along the rivers yield consistently, with a high proportion of small seeds. Fruit with chicken tongues shed more readily under drought or heat than those with full seeds.

Trees are small and upright, with wide, strong crotch angles and dense foliage. "Brewster" is one of the few cultivars with distinct lenticels or corky outgrowths on the branches. Leaflets are large, dark green and pointed at the tips. The new flush of growth is reddish-brown. The medium to large fruit (20-26 g) are heart-shaped and have a bright pink-red, thick, rough skin, and are borne in small loose clusters. The shoulders are uneven, with one raised ridge along the suture line of the shoulder. The fruit tip is round in full seeded fruit to pointed in chicken tongue fruit, and have small nipple-form protuberances. The flesh is slightly fragrant, juicy and sweet when fully ripe, but acid when immature. Seeds are small to medium, with up to 80 percent undeveloped after cool weather. Plump seeds are oblong with a blunt tip. Flesh recovery is 65 to 75 percent.

"Kwai May Red" is highly regarded in China, but is not grown widely elsewhere. Fruit are of good quality, although the tree is a shy bearer. Panicles normally carry only a few fruit due to poor set. In Australia, trees resemble those of "Kwai May Pink", but are more spreading. They have long, thin branches that curve upwards towards their tips. Leaflets are small, oval-shaped and shiny green. Leaflets are slightly larger than "Kwai May Pink" and flatter. The new flush of growth is red. Fruit are almost identical to those of "Kwai May Pink", except that "Kwai May Red" has red rather than pink-orange skin, firmer flesh, a higher proportion of chicken tongues (50-60 percent), higher flesh recovery (70-80 percent), and a slightly better flavour. The fruit are distinctly aromatic and are exported from China.

"No Mai Chee" is one of the most highly-prized cultivars in China and widely grown in the suburbs of Guangzhou, Dong Guan, Zong Cheng, Pan Yu and other districts. It appears on the market late in the season and commands a high price; usually three to four times that of other cultivars. The fruit are large (21-28 g) and nearly all with chicken tongues, giving a flesh recovery of 75 to 85 percent. The flesh is very smooth, firm and clean, with a distinctive sweet fragrant flavour. It is suitable for fresh fruit and drying. The tree is large and tall with a dense canopy and slim branches that hang down. The leaves are small, soft and thin, with a wavy edge. "No Mai Chee" has been in Australia for a long time, but is not widely grown. It does not appear to crop as heavily as in China.

"*Wai Chee*" is one of the most common cultivars in China and is also popular in Thailand ("Kim Cheng") and Australia. It is fairly regular across most districts in China, but variable in Australia. Trees often flower lightly in the warm northern areas, and may be biennial in southern districts. Mature fruit can hang on the tree for several days. This adds some flexibility to harvesting and extends the production season. Trees initially lack vigour and establish slowly after planting. They are low, dome-shaped with thick branches, compact foliage and many growing points. They are susceptible to wind damage, unless thinned out and the lower branches removed. The small leaves are oval-shaped and curve upwards from the midrib and down along their length. New flushes of growth are deep red.

The small (16-18 g) rounded fruit are formed in small loose clusters. The skin is deep red (Plate 2). Shoulders are flat, although often ridged on one side along the suture line. The skin is of medium texture (less rough than "Haak Yip"). The flesh is soft, very juicy and sweet. Most seeds are fully developed giving a flesh recovery of 63 to 73 percent. Although fruit have full flavour, their large seeds and soft flesh reduce eating quality and price in Asia compared with "Haak Yip", "Kwai May Red" and "No Mai Chee".

"*Kom*" was developed in Thailand from material imported from China. It crops under tropical conditions, but fruit are not as good as those from cultivars grown in the north. It is the most popular of the tropical cultivars. "Kom" has been imported into Australia, but has not been distributed elsewhere. Fruit mature about a week before "Tai So", and are variable in size, shape and flesh recovery, depending on the season. They tend to be small in southern Queensland when cool weather extends into early summer. Average fruit size is a little better in Thailand. Although "Kom" is high yielding, its poor quality in southern Queensland limits its potential. It is not considered a good marketing type because of its small fruit and poor flavour. Trees are vigorous and erect, and have long, strong branches and dense foliage. Leaflets are narrow, pointed, medium and dark green. They are generally flat, but curve downwards slightly towards the tip. The new flush of growth is red changing to green with maturity.

Fruit are variable in size (8-20 g), and long-heart to nearly round, depending on the season. They tend to be small and long heart-shaped after cool weather. The very thick skin is blotchy yellow to purplish red at maturity. Shoulders are flat or even, and the fruit apex obtuse. The skin segments are smooth at maturity and variable in size, shape and arrangement. The protuberances are sharp-pointed. Fruit are borne in small loose clusters. The flesh is tough to fibrous, and mild becoming bland once mature. Seed and fruit size are in proportion, with small fruit having chicken tongues. Flesh recovery ranges from 60 to 80 percent.

"*O-Hia*" ("Baidum") is the third most important cultivar after "Tai So" and "Wai Chee" in northern Thailand. It resembles "Haak Yip", but does not match it in all characteristics. Fruit of "O-Hia" are slightly smaller, less uniform in size, have blotchy markings on the skin, which is yellow-red rather than purple-red at maturity. Fruit are not as sweet as "Haak Yip" and have more chicken tongues. Fruit are available mid-season. Trees are medium, with dense foliage on long, thin branches (not as long as Haak Yip). Leaflets are large, narrow, dark green and slightly curled upwards from the mid-rib. The new flush of growth is reddish-brown. Fruit are medium (20-22 g) and heart-shaped. The skin changes from blotchy yellow to deep red with maturity. Skin segments are irregular in size, shape and arrangement, swelling, with smooth to obtuse protuberances. Flesh is juicy and sweet. Seeds are mostly plump (10-15 percent chicken tongue), giving a flesh recovery of 65 to 75 percent.

"Chacapat" is grown in Thailand and has also been imported into Australia. It is the last cultivar in both areas, and very popular in Thailand. Fruit are sweet and acceptable in Thailand, but often acid in Australia. Cropping ability in Australia is also average. Trees may set small fruit with small seeds. Under these conditions, it is not considered a good marketing type. Trees of "Chacapat" are moderately vigorous, erect, and have long branches and dense foliage. Leaflets are small, long, narrow, pointed and dark green. They curl upwards from the midribs and downwards along their length towards the tip. The new growth is green.

Fruit are normally large (28-32 g) and round to slightly heart-shaped. The skin is thin and soft, deep red with yellow markings (not as prominent as Salathiel). Shoulders are flat and the fruit tip round. Skin segments are swelling with obtuse protuberances. Flesh is moderately juicy, remaining acid when fully ripe. Seeds are nearly all large, giving a flesh recovery of 60 to 70 percent.

"*Shahi*" ("Muzaffarpur", "Rose Scented") is the most popular cultivar in Bihar, and can also be found in other parts of India, as well as in Bangladesh. Fruit are medium (20-25 g), oval-shaped with crimson-red skin. Flesh is juicy, sweet and fragrant. Seed size is variable. Yields are heavy and regular, with large trees carrying 100 to 150 kg of fruit early in the season. However, they often crack.

"*China*" ("Purbi", "Calcuttia", "Bengalia", "Bombaiya") is an important cultivar in India that ripens when most of the other cultivars have been harvested. Its origin has not been determined, although there is a similar cultivar in Bangladesh – "China Number Three". Trees are relatively short and high-yielding, but alternate bearing. Fruit are large (25 g) and orange-red. The flesh is soft, juicy and very sweet, but not as good as "Shahi". Seeds are normally small.

"*Early Bedana*" ("Early Seedless") is a popular early cultivar from Bihar, Uttar Predesh, the Punjab and Bangladesh. Trees are medium in height and yield, with regular fruit production. Fruit are medium (15-18 g), oval or heart-shaped, with rough deep red skin at maturity. The flesh is white, soft, juicy and sweet. Overall fruit quality is rated as "good."

"*Late Bedana*" ("Late Seedless") is a late cultivar from northern India. Trees are vigorous, with average yields of 60 to 80 kg for ten year old specimens. Fruit are medium, with good flesh recovery. The flesh is creamy white, soft, juicy and sweet. Seeds are usually small.

"*Bombai*" is an important early cultivar from West Bengal in India, and Bangladesh. Trees are vigorous and yield 80 to 90 kg of fruit. Ripe fruit are an attractive deep red, with grey white, soft, juicy and sweet flesh. It is similar to "China" grown in other areas.

"*Dehra Dun*" ("Dehra Rose") is an important cultivar from Uttar Pradesh and the Punjab. Trees are medium, and produce medium to high yields. Fruit are bright pink-red at harvest, and very attractive. Fruit have small seeds, but are susceptible to cracking.

"***Bengal***" is a seedling of the Indian cultivar "Purbi" sent to Florida in 1929. It was selected in Florida in 1940 and does not resemble any Chinese cultivar. It was the second most important cultivar after Tai So in Australia, but has now lost favour. Fruit are attractive and pleasant tasting, but have large seeds and poor flesh recovery. They also ripen unevenly. Average cropping is disappointing, although trees can have very high yields in an 'on year'. Trees are vigorous and spreading with thin branches, but are reasonably resistant to wind damage. Leaflets are large, mid-green and have a distinctive twist or curl along their length. The new flush of growth is reddish-brown.

The fruit (23-27 g) are formed in large clusters of up to 50 or more. The thick skin is very rough and attractive bright red. The fruit are egg-round to lopsided heart-shaped, with uneven shoulders. The fruit tip is distinctively pointed. Protuberances are sharp-pointed to wedge-shaped. The flesh is soft, sweet and moderately juicy. Fruit do not keep their flavour if left to hang. There are very few abortive seeds. Under drought conditions, the aril is often undeveloped and may not cover the seed at the pointed end. This gives a flesh recovery of 50 percent or lower. For these reasons, "Bengal" is not considered a good marketing type.

"***Kwai May Pink***" is thought to have originated in China possibly as a variant or seedling of "Kwai May Red". It is popular in Australia, with large numbers of trees planted, but relatively unknown elsewhere. Bearing ability is good in most districts. It has a long harvest, possibly due to the development of acceptable sweetness and flavour well before fruit mature. Fruit are available mid-season. Trees are large and very erect, and have long, slim branches that point upwards. They are reasonably strong in storms. Leaflets are narrow, long, oval-shaped and shiny light green. They curl upwards slightly from the midrib and downwards along the length. The new flush of growth is an attractive red.

Fruit are medium (18-22 g), and round, with very rough thick skin. The skin changes from yellow to yellow-pink to orange-pink with maturity, with some green on the shoulders (Plate 3). Fruit are over-mature when fully coloured. Shoulders are usually flat, but one is sometimes raised along the suture line. Flesh is firm, crisp, sweet, juicy and aromatic. Fruit are sweet well before full maturity. Seeds are variable, with up to 70 percent chicken tongues. Flesh recovery is 67 to 77 percent. Fruit are exported.

"***Salathiel***" was found growing near Cairns in northern Australia, but its parentage is unknown. It is similar to "No Mai Chee" from China, but is not identical in all characteristics. Yields are variable in sub-tropical districts and light in tropical areas. Fruit are harvested late, just before "Wai Chee". Trees are small and compact, and sometimes produce long branches with undeveloped leaves. Leaflets are small, broad and curve down slightly at the tip. The tip of the leaflet is round with a short distinctive point. The new flush is red changing to green with maturity.

Fruit are small (15-18 g), egg-shaped to ball-shaped in cooler areas, and borne in small loose clusters. The skin is thick, moderately rough with prominent markings. The skin changes from blotchy-yellow to deep red at maturity (Plate 4). The fruit tip is obtuse changing to round in cooler areas. Flesh is thick, crisp, juicy and very sweet. Fruit are sweet long before they are fully coloured. Most fruit have chicken tongue seeds, giving a flesh recovery of 76 to 80 percent. Occasionally, fruit can be almost seedless, although these fruit are very small and unmarketable. Fruit attract a high price in domestic markets and are also exported to Asia.

"***Sah Keng***" was developed in Taiwan Province of China in the 1970s and appears to be a seedling of "Haak Yip". It was introduced into Australia, but is not grown commercially outside Taiwan Province of China. "Sah Keng" produces large and small seeded fruit, with significant variation amongst trees in a single orchard. Fruit are available mid-season. Yields are heavy, but irregular. Trees are medium, dome-shaped with short, fragile branches. Leaflets are 6 to 8 cm long and mid-green. The new flush of growth is green. Fruit are large (30-35 g), heart-shaped, with purple-red skin. The skin segments are swollen and protuberances blunt. The flesh is soft and sweet. Seeds are variable, often small, giving a flesh recovery of 75 percent.

"***Kaimana***" was developed in Hawaii about 20 years ago from a population of "Haak Yip" seedlings. It has been distributed to Australia for further commercial evaluation. Small trees can bear heavily in Kona and in some parts of Australia. Fruit are available mid-season. Trees are medium, spreading with long, strong branches. Leaves are large, elongated and mid-green. The new flush of growth is green. Fruit are large (25 g), heart-shaped with purple-red skin. The skin segments are swollen and the protuberances smooth when the fruit are mature. The flesh is crisp, sweet and excellent quality. Seeds are medium.

4.7 Plant improvement

The chromosome number of lychee has been reported as 2n = 28, 30, 32 or 34. There is little information available on the inheritance of morphological or physiological characters. Yang and Chen, however, indicated that shrivelled seed was inherited in the related longan. Different cultivars have been separated through the use of genetic markers. Various cultivars have been shown to have similar parentage.

New cultivars have mainly been developed from the selection of open-pollinated seedlings from existing cultivars. Most of the modern cultivars have been developed in China, with new cultivars still being released in Guangdong. Some of the industries elsewhere in Asia are based on seedlings of cultivars imported from China. Breeding programmes have generally been limited to a few thousand seedlings.

Breeding objectives include regular high yields, good tree structure, large fruit, bright red skin, small seed or seed abortion, better flavour and texture, and early or late fruit maturity. Resistance to pests and diseases and extremes of environment, acceptable fruit ripening pattern and acceptable shelf life have received less attention. Seedlings from a cultivar generally resemble the parent tree, but few bear regularly. Cultivars developed in the last 60 years include "Salathiel" in Australia, "Sah Keng" from "Haak Yip" in Taiwan Province of China, "Bengal" from "Purbi" in India and several new types from Guangdong.

The development of better cultivars is very slow, because it takes several years for most seedlings to begin bearing fruit. When they do fruit, less than 1 percent of the seedlings are worthy of selection. Storey *et al.* selected "Groff" out of a population of 500 "Tai So", "Brewster" and "Haak Yip" seedlings, but these are not premium cultivars. In any case, "Groff" has never been grown commercially. Future efforts in plant breeding need to concentrate on the cross pollination of selected cultivars with desirable traits. Yen *et al*. had a population of 2,500 seedlings from open- and controlled-pollination; however, he did not indicate whether all the male flowers on the mother tree were removed to exclude the possibility of self-pollination. Seedlings can be planted close together at a density of 2,000 to 2,500 trees per ha. Standard densities are normally 70 to 280 trees per ha.

Various methods of biotechnology have been explored for their role in developing new cultivars, especially in China. These include tissue culture of young embryos, anther or pollen culture to obtain haploid plants, and protoplast culture. No new cultivars have been developed at this stage.

Wild plants have been sought as sources of disease resistance or dwarfing in other sub-tropical trees such as citrus, avocado and mango. This approach may have potential in lychee. The Sapindaceae family contains many species and genera in the tropics and warm sub-tropics. Longan has been suggested as a source of cold or drought tolerance or resistance to erinose mite. Lychee x longan hybrids have been produced in China and Australia, but no commercial cultivars have been released to industry.

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5. PROPAGATION AND ESTABLISHMENT

Overview

Trees can be propagated by marcotting (air-layering), grafting and cutting. Many old orchards in Asia were based on seedlings, but these have generally been replaced by clonal material. Seedlings of course, are the source of new cultivars. Lychee nurseries generally supply marcots for new plantings, although grafting is also used in China and Viet Nam. Marcotting gives a strike rate of at least 80 percent, whereas grafting is more variable. The use of rootstocks for manipulating tree size, production and fruit quality is not well developed.

5.1 Seedlings

Propagation by seed is not usually recommended, since most seedlings take ten years or more to bear, and have poor to average fruit quality. Nevertheless, new cultivars can only be developed from the selection of seedlings with improved characteristics. New cultivars might bear more regularly, earlier or later than existing cultivars. They might also have larger fruit, brighter skin or smaller seeds. Some may store better than others.

Seed will keep for four weeks in the fruit after harvest, but begin to lose viability within a day if removed, and none germinate after four days at low humidity. More seeds germinate when stored in water for a day than when stored in vermiculite or air. Seed removed from fruit keep for eight weeks if stored in moist peat moss or similar media at 8°C.

Eighty percent of fresh seed germinate after three weeks, provided soil water and aeration are adequate. Large seeds germinate better than small seeds, and also have stronger growth initially. In contrast, chicken-tongue seeds are not viable. Growth is usually best with organic mixes, acid pH and inoculation with mycorrhiza. The seedlings should also be watered regularly and protected from strong winds. Temperatures from 25^{o} to 30^{o}C with high humidity are ideal. Seedlings that are to be evaluated as potential new cultivars can be planted out after a year. They are usually spaced one metre apart, much closer than in commercial orchards.

5.2 Cuttings

Few commercial plantings are based on stem cuttings. Success depends on choosing the correct type of wood, misting or fogging, and good temperature control in the propagation house. The rooting media also needs to be free draining. Some cultivars can provide an 80 percent success rate, however, cuttings take four months to root and another eighteen months in the nursery before they can be planted out. Young plants about 50 to 60 cm high are recommended. Smaller specimens often die.

Sixty to eighty percent of semi-hardwood and hardwood cuttings rooted in Australia with shoots are collected from older wood behind the soft tips in May prior to flowering. Soft terminal cuttings were unsuccessful. Authors in India and elsewhere report better results if the shoots were girdled a few months before taking the cuttings. Carbohydrates presumably accumulated above the girdle. Auxins also improve rooting, with the best response obtained with 100 to 200 mg per litre after soaking for a day, or with 5,000 to 10,000 mg per litre in a dip. Higher doses are toxic.

Some reports in India and Florida indicate that rooting is better when the cuttings are grown under partial shade. Provided the leaves do not dry out, full sun generally gives a quicker turnaround. Intermittent misting, or better still, fogging keep the leaves wet and cool without waterlogging the soil. Air temperatures of 20^{o} to $25^{o}C$ and roots at 30^{o} to $32^{o}C$ are recommended. The cuttings can be grown in sand with a little peat or vermiculite, but the pot must be well drained. Some workers also favour the application of fungicides. If the plants are growing quickly and not over-watered, diseases are less of an issue.

5.3 Marcots or air-layers

Marcotting or air-layering has been practiced in China for thousands of years, and is the most popular method of propagation. A branch on the parent tree is girdled down to the central hardwood to encourage adventitious rooting at the distal cut surface. Care must be taken to remove all the cambial tissue surrounding the white central wood. Otherwise, more vascular tissue is produced rather than new roots.

The marcot is detached from the tree after a few months and planted out in the field after a year or so. The success rate for commercial nurseries is normally more than 80 percent. Marcots come into bearing earlier than slower-growing cuttings or grafted trees, but have a shallow root system, with some cultivars susceptible to wind damage.

Upright branches about 2 cm in diameter and 80 cm long from well-developed trees, free from pests and disease are recommended. Rooting is best on sun-lit branches with mature growth. Marcots taken from thin, shaded branches often die or take longer to establish. Most authors recommend marcotting during the warm humid part of the year, when the roots are less likely to dry out.

The traditional method used soil, organic matter, sawdust and woodchips wrapped in cloth to enclose the marcot. However, moist peat moss and polyethylene bags are now exploited in many areas (Plate 5). The use of the plastic alleviates the problem of daily hand watering. A medium consisting of 100 percent peat moss and limed to a pH of 6 is ideal. Auxins sometimes improve rooting, but are not essential. Similarly, there is no need to girdle the branches beforehand.

Marcots are detached from the parent tree once they have formed sufficient roots to survive on their own. The appearance of old roots which turn brown is a good indication. Branches should be trimmed to form a good framework and 50 percent of the leaves removed to reduce transpiration. The marcot should be carefully removed from the plastic since the roots are very delicate at this stage, and planted in a well drained potting mix in a warm protected spot. A little shade at this stage often helps. Intermittent misting is also a good idea. You can retain more of the leaves and improve the turn-around of plants. Marcots seldom recover once they have lost their leaves.

Fertilizers can be applied once the young plants begin to produce new growth. The marcots should be gradually hardened off after completing two leaf flushes under full sun, before being transplanted in the field. Bare defoliated marcots sometimes sent overseas without soil can be difficult to establish.

5.4 Grafted and budded plants

Grafting and budding are used in some nurseries in China and Viet Nam. However, marcotting is more popular in other countries. The Chinese grafted and budded new cultivars several centuries ago, but they relied mainly on marcots for commercial propagation. It is only recently that this material has been evaluated in high-density orchards. Little thought has been given to using rootstocks to control tree growth, productivity and fruit quality as in apple and stonefruit. Related species and ecotypes have been suggested as potential rootstocks, but no commercial orchards have been developed on these systems.

Budding and grafting often fail because of incompatibility between the scion and stock. Poor grafting technique, grafting at the wrong physiological stage and poor care in the nursery can also cause problems. Incompatibility has been reported in some countries in the Region. For instance, "Wai Chee" is a better rootstock for "Salathiel" than "Tai So" in southern Queensland. "Wai Chee" is often used in China. Grafting techniques are well developed in fruit crops, and readily apply to lychee. Attention to the type of wood, protection from heat and sun, and the use of girdling all need to be considered.

5.5 Methods of propagation in different countries

Both marcotting and budding are popular in China. For the marcots, paddy soil with straw, sawdust or coconut husk are used for the potting media. Marcotting can be undertaken all year in Guangdong, but is generally carried out from April to July. Seedlings of "Wai Chee" are often used as rootstocks for "No Mai Chee", "Kwai May", "Bah Lup" and "Baitangying", while "Haak Yip" and "Tai So" are used for "Fay Zee Siu". The rootstocks are grown in field nurseries, 20 cm x 13 cm apart. The scions are taken from one year old twigs in late spring and early autumn to avoid hot, chilly or rainy weather, and the grafted plants planted out in the field after six months.

Marcotting has been traditionally used in Viet Nam; however, grafting has become popular since the 1990s. Sour lychee seedling rootstocks are used, with the scions taken from well-selected mother trees. Government nurseries covering some 8 ha produce one million plants a year.

Marcotting is the most common form of propagation in Thailand, India and Bangladesh. The best time to place the marcots on the trees is from late spring to early summer, with the new material ready for planting after eight months. In India, there are many Government and private nurseries supplying material, with about 300,000 plants produced every year. The Government nurseries are very popular selling good quality material at a low price. Prices are also lower in the Government nurseries in Thailand. In Bangladesh, there are 70 Government nurseries selling about 90,000 marcots annually. Seedlings were mainly used in Nepal, however the focus has now shifted to clonal material (marcots). There are many Government establishments, a few private nurseries, and some imports from India. The best time to strike the marcots is from March to May, with a reported 90 percent success rate.

There are a few private and Government nurseries selling marcots for about US$2.50 in the Philippines. The number of nurseries selling material reflects the limited cultivation of lychee in this country. Production of nursery material is also very limited in Bali, with only a few mother trees in Government plantings. Material for new plantings in Australia is normally only available as marcots. Cutting and grafting are very rare. Private nurseries account for most of the sales (US$6 per marcot).

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6. ORCHARD MANAGEMENT AND PLANT HUSBANDRY

Overview

Young orchards need regular fertilizing, irrigating, pruning and spraying. Irrigation is not available in all countries, but is recommended for new plantings. Pruning should be carried out in young orchards to improve tree structure, minimize wind damage and to increase fruit bearing area. Young trees can be infested with a number of insect pests and broad-leaf weeds and grasses growing through the leaf mulch also need to be controlled.

Traditionally, orchards were planted at low densities of 100 to 200 trees per ha, and the trees thinned out when they began to crowd each other. Other crops were planted between the rows to make use of the land during the early life of the orchard. Many countries are now adopting high-density plantings with 300 to 1,500 trees per ha. These orchards may have double the returns of other plantings, but must be pruned every year after harvest to keep the trees small. Growers also need to pay close attention to watering and fertilizing. Research in Australia has shown that small trees are just as productive as large trees, when yields are expressed per unit of canopy surface area.

Nutrition generally has a small impact on production, unless trees have a deficiency or excess of one or more nutrients. Trees take a long time to respond to fertilizers, with new leaves, flowers and fruit dependent on reserves in the tree rather than on fertilizer applied to the soil. On the other hand, once nutrient concentrations fall below critical values, it may take several years for tree health and production to fully recover. Leaf standards have been developed from surveys of high-yielding trees in Australia, and have application in other environments. Responses to some nutrients have been reported, whereas the time of fertilizer applications has little effect on yield or fruit quality. Nutrients are best applied to the soil rather than to the leaves as foliar sprays.

Most orchards in the Region are dependent on regular rainfall, with irrigation either too expensive or not available. Research has shown that drought can affect growth and fruit production in South Africa and Australia, but its importance in Asia has not been measured. Mulching and cover crops can assist water conservation, however, it is recommended that new orchards be irrigated if possible. In the absence of irrigation, an annual rainfall of 1,200 to 1,500 mm is required for regular production.

Synthetic auxins were used in the 1950s and 1960s to control growth and flowering in Florida and Hawaii. There were many instances where the treatments increased yield, however, often the responses were unpredictable. More recently, Australian horticulturists showed that ethephon could be used to control early red leaf flushes when applied in May or June in sub-tropical areas. Girdling or cincturing can be used in the same way as the auxins or ethephon to improve flowering. However, it cannot substitute for cool weather at the time of flower initiation. Chemicals applied at this time are also not likely to increase flowering unless followed by cool weather. Growth regulators and girdling have also been used to improve fruit retention, but the long-term effects of these treatments on tree health are unknown.

6.1 Care of young orchards

6.1.1 Fertilizing

During the first three years, fertilizers are used to promote rapid tree growth. Do not apply fertilizer until the trees produce their first leaf flush. A suggested programme from Australia is indicated below. Amend your nutrition applications to suit local situations. Many areas in Asia use greater quantities of organic fertilizers.

In year one, apply 30 g of urea or equivalent every month, 30 g of mixed fertilizer every three months and a little organic matter in spring (8 litres of fowl manure or equivalent). Increase the urea and mixed fertilizer to 40, 60 and 80 g in subsequent years, along with some organic matter in spring. In frost prone areas, do not apply fertilizer during autumn or winter, and do not exceed the recommended rates. Excessive amounts of organic or inorganic fertilizers can kill trees, especially on shallow, poorly drained soils. Keep fertilizers at least 20 cm away from the trunk to avoid tissue burn. Apply the fertilizer evenly under the canopy and out to a point 30 cm past the dripline or edge of the canopy. Water in well or apply during rain.

6.1.2 Irrigating

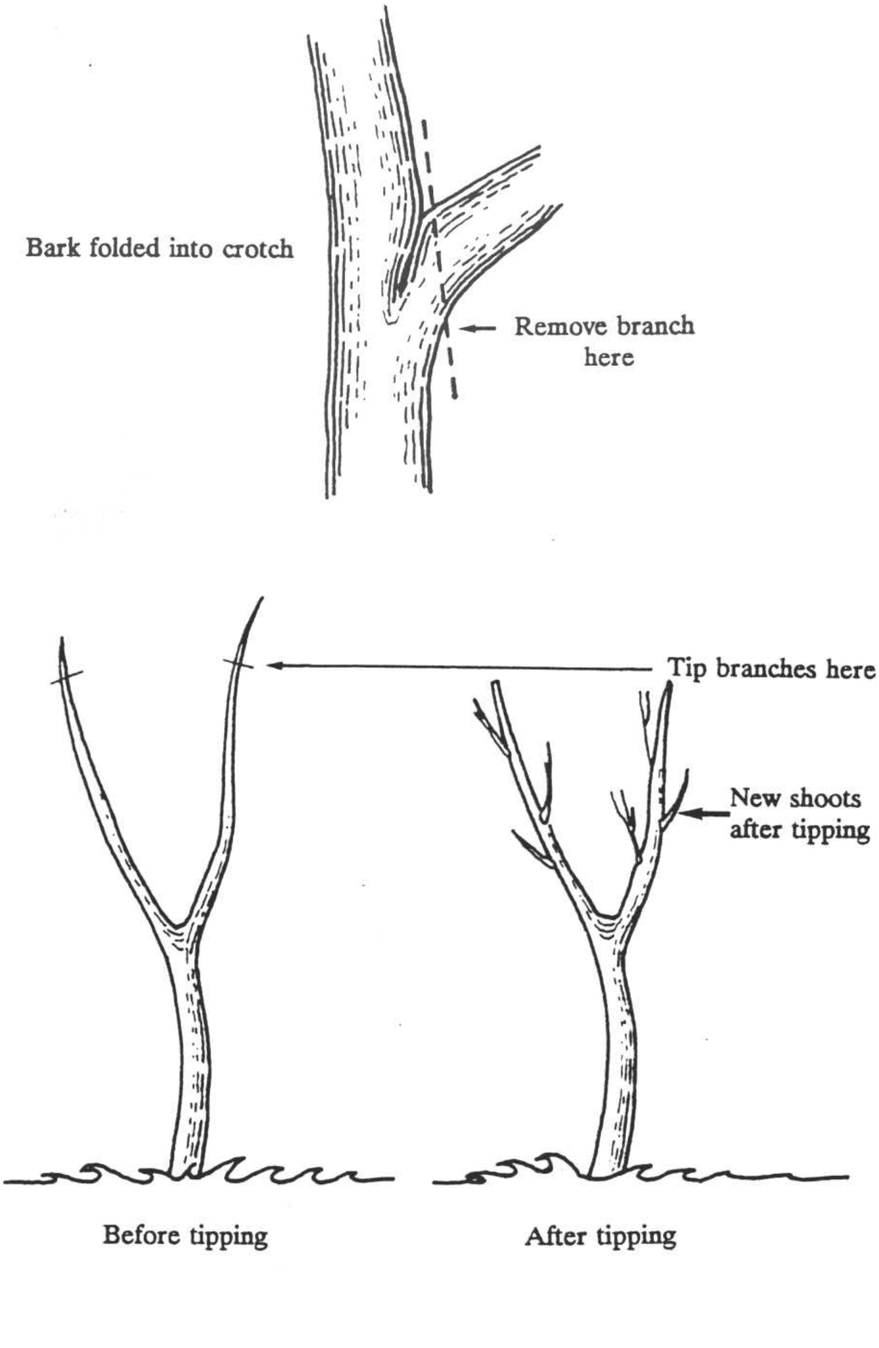
Not all orchards in Asia have access to irrigation, however, supplementary watering during the first few years will assist tree establishment. The timing and quantity of water applied varies with tree size, soil, weather and time of year. The following offers a guide based on evaporation in southern Queensland. Some areas in Asia such as India may be drier. In year one with a canopy diameter of 0.5 m, apply 3 litres per tree in winter. This increases to 12 litres, 30 litres and 60 litres in years two (canopy diameter of 1.0 m), three (canopy diameter of 1.5 m) and four (canopy diameter of 2.0 m). Rates in spring (x 2), summer (x 2.5) and autumn (x 1.5) are higher than those in winter. Maximum water use in year four in summer would be 160 litres per tree. Irrigate two to three times a week in sands and one to two times a week in heavy clays. Mulching can assist water conservation, particularly in the absence of irrigation.

6.1.3 Pruning

Young trees are pruned to provide a strong structure, minimize wind damage and increase fruit bearing area. Wind damage is an important issue for some cultivars. Cultivars with long branches such as “Fay Zee Siu” and “Tai So” are susceptible to branch splitting, while others with short dense crowns such as “Wai Chee” and “No Mai Chee” can break off at the ground.

Trees should be inspected regularly during the first four years and the following action taken where necessary. Remove branches with weak, narrow crotch angles where the bark is folded into the crotch (Figure 12). On susceptible cultivars such as “Tai So” and “Kwai May Pink”, these branches can later split away from the trunk and destroy the tree. Don’t remove branches until the trees are at least one year old.

Figure 12. Removing weak crotch angles and tip-pruning long branches.



Tip-prune cultivars such as “Tai So” and “Kwai May Pink” which produce long branches or dominant leader branches. Remove approximately 15 cm in spring of year two (Figure 12). This increases the number of growing points and thus provides more flowers and fruit. It also reduces the risk of limbs breaking.

Thin out very dense cultivars such as “Wai Chee” and “Kwai May Pink”. Remove approximately 10 to 20 percent of the branches within the canopy in the third year (Figure 13). You should be able to see broken sunlight on the ground under the canopy when you have finished. This practice allows wind to move through the canopy and reduces the risk of the tree twisting out during heavy winds. Check the trees and repeat each year if necessary.

Skirt trees from the third year onwards by removing all branches and shoots to a height of 50 cm leaving a clean single trunk (Figure 13). Skirting also helps minimize the twisting effect of high winds and prevents fruit and leaves touching the ground. This allows slashing, weeding and fertilizing to be carried out efficiently, without damaging the trees. Ant and scale control is made easier and fewer fruit are damaged by insects and rots.

In spite of pruning, some cultivars such as “Tai So “still produce weak crotches that can split. To minimize this risk, growers in Australia have devised a strapping and bracing system using heavy gauge wire to link the main branches (Figure 14). This approach is suitable for similar cultivars in Asia.

6.1.4 Pests

The most important pest of young trees is erinose mite. The mite causes the leaf surface to blister, while the underside develops a brown felting. If not controlled, the pest can damage trees and reduce flowering and fruit production. The best control is to prevent the mite entering your property by dipping new trees. If symptoms appear, remove and burn infested leaves. If most of the trees are infested, spray each new growth flush with dimethoate or wettable sulphur every 10 to 14 days, from just before the flush emerges until it hardens off. Repeat for each new flush. Stop spraying once the new growth shows no symptoms. Sulphur is less disruptive to beneficial insects and is preferred, except during hot weather when days are above 28^{o}C.

Occasionally, ants, scales, leaf-eating caterpillars, leaf-eating beetles and twig girdlers attack young trees. These can be controlled with registered chemicals (see section on major pests). Borers sometime attack individual branches, although whole trees rarely die. No chemicals are effective against these pests.

Figure 13. Thinning and skirting young trees.

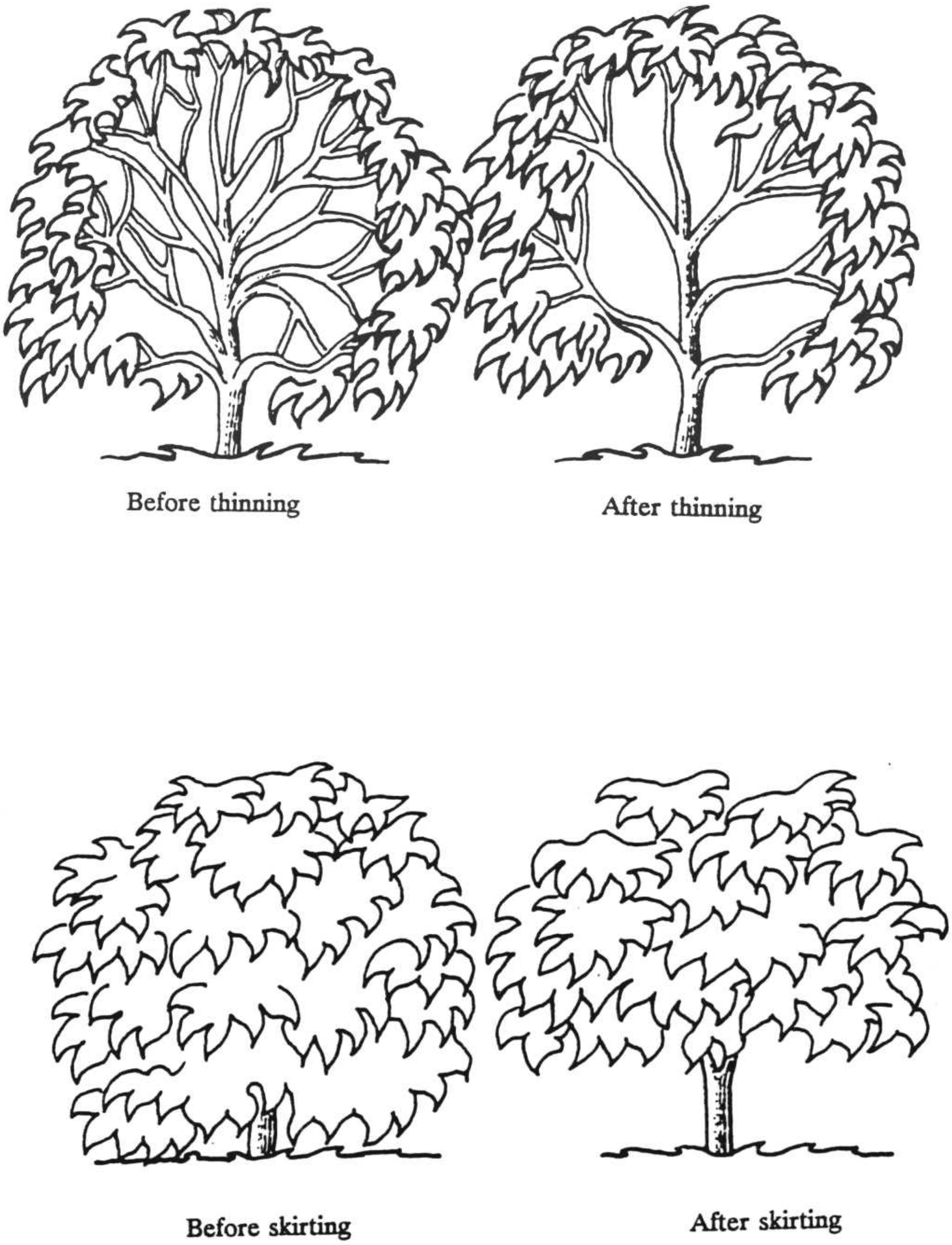
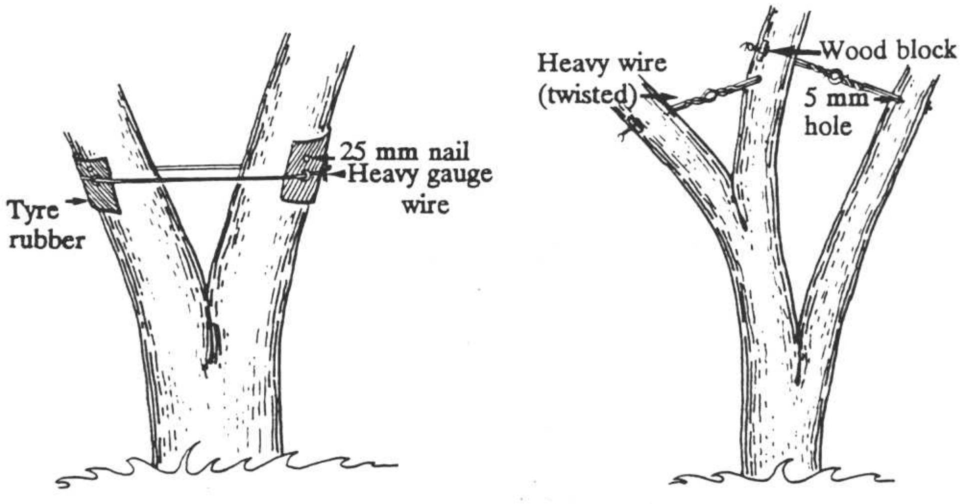


Figure 14. Braces to support split branches.



6.1.5 Weeds

Weeds compete with the trees for water and nutrients. If allowed to grow, considerable damage to the tree's roots can occur when they are removed. Problems are avoided by maintaining a mown sward of mixed grasses and broadleaf species or cover crops between the rows. Weeds under the trees can be controlled by mulching, chipping and spot-spraying with herbicides.

Mulches used include wheat, barley or rice straw, hay, sorghum stubble and similar materials. Reduce costs by growing mulch material between the rows for later slashing. Renew the mulch as it breaks down. Keep it well away from the trunks as collar rots may develop. Mulches also increase soil organic matter, improve soil structure, increase water retention and help reduce fluctuations in root temperature.

Apply herbicides to the border of the mulched area and to individual weeds that grow through the mulch. Use glyphosate at 5 to 10 ml per litre or paraquat at 1 to 6 ml per litre plus a wetter at 1.25 ml per litre to control grasses and broadleaf weeds. Grasses can also be controlled with fluazifop-p (Fusilade 212) at 1.25 to 10 ml per litre. Don't allow the herbicides to contact any green part of the tree, including the trunk. Drift can be minimized by using a shielded, low-pressure fan or flood nozzle, or alternatively, use a rope wick applicator. Herbicides are very expensive in parts of Asia. With relatively low labour costs, chipping is more practical.

6.2 Canopy management

Plant production depends on the conversion of sunlight into chemical energy, and, for the most part, this process takes place in the leaves. There has been a strong move to improve the productivity of temperate fruit trees in the past 30 years or so, based on an understanding of the relationship between yield and light interception. Modern apple and stonefruit orchards are planted at high density and trees kept small through the use of dwarfing rootstocks and intensive pruning. These systems maximize the interception of light by the canopy. This philosophy is not well developed in lychee and most other tropical fruit trees, with few dwarfing rootstocks or validated pruning strategies.

6.2.1 Orchard layout

A well-managed orchard should have a long commercial life. Hence, close attention to orchard layout and land preparation will have their rewards for many years. You need to make decisions on row direction, spacings, placement of waterways and drains, mounding, wind protection and all weather access to the block. Your local horticulturist should be able to help you with the layout of your orchard and care of young trees.

Many old orchards in Asia and Australia were planted at spacings of 9 m or 10 m x 12 m or even 12 m x 12 m, equivalent to 70 to 80 trees per ha. Such plantings can have very high yields on a tree basis after 10 or 15 years, but are wasteful of land in the early years. There are also problems with harvesting, spraying, and protection from birds and bats in large trees in some areas.

Newer orchards are planted at closer spacings of 6 m x 8 m or 4 m x 6 m or 7 m x 3 m, equivalent to 200 to 460 trees per ha. These orchards require regular pruning to keep the trees small. Otherwise, some of the trees must be removed when they start to crowd each other (Figure 15). There are high-density plantings up to 1,500 trees per ha in southern China, but these are dependent on hand spraying. They are not suited to operations using heavy machinery.

The economics of high-density plantings in Australia and elsewhere have yet to be fully analysed. There is also probably no advantage in very close plantings where the trees start to crowd each other before they begin to bear at year four or five.

6.2.2 Strategies in different countries

In China, there is no standard layout, although most farmers prefer close plantings of 2.5 to 3.0 m x 3.5 to 4 m (825 to 1,100 trees per ha). They usually plant other crops such as bean, peanut, sweet potato, vegetables, pineapple and papaya in the inter-rows, and thin the orchard to 300 trees per ha after a few years. Some sections of the industry have adopted high-density plantings up to 1,500 trees per ha. These are often based on the popular early cultivar "Fay Zee Siu", and are dependent on close attention to pruning, girdling, watering and fertilizing.

Figure 15. Thinning strategies for close plantings in Australia for upright (top) and spreading cultivars (bottom).

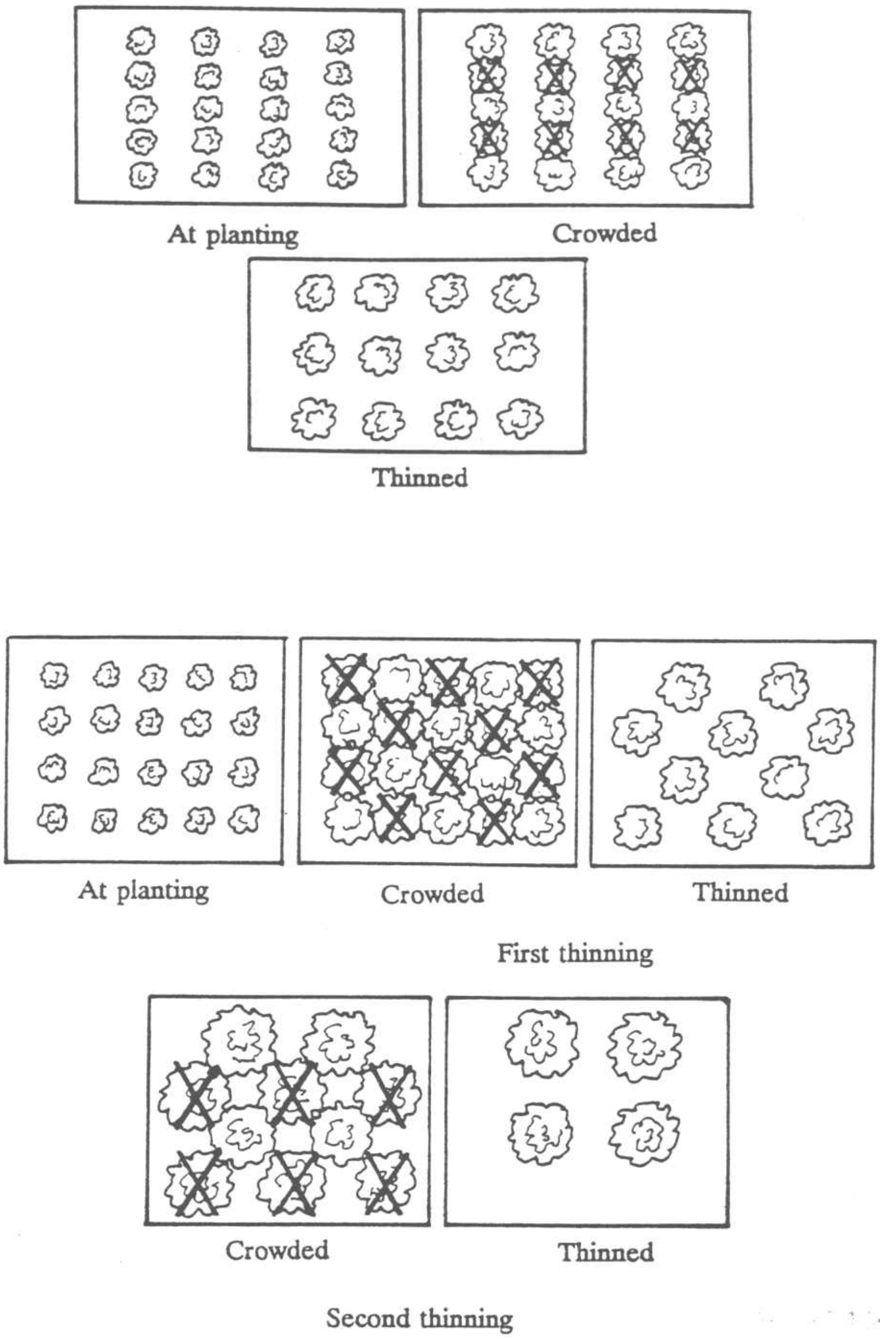
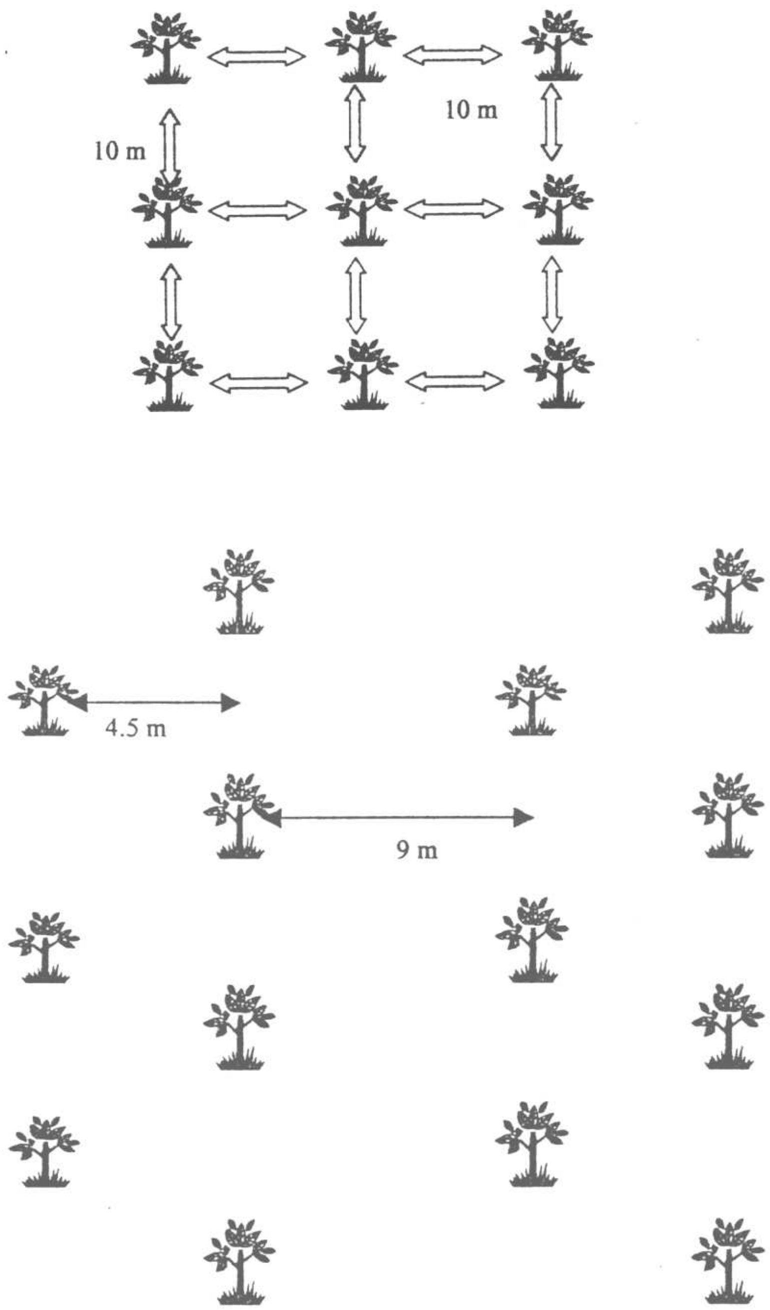


Figure 16. Plan of orchards in India showing square system for traditional plantings (top) and double hedgerow for closer plantings (bottom).



In Viet Nam, the normal spacing adopted is 7 or 8 m, depending on the fertility of the soil and topography. There are very few high-density orchards. Planting distances in Thailand range from 3 to 8 m, with the closer spacings requiring a higher level of orchard management than traditional plantings.

The traditional growers in India use a spacing of 9 to 10 m, equivalent to 100 trees per ha planted in a square system. Old trees in these orchards may be 10 or 12 m high. There are also experimental plantings at 4.5 m x 4.5 m x 9 m (329 trees per ha), in double hedgerows (Figure 16). The closer plantings provide greater fruit production per hectare, and equally good fruit as traditional plantings. A light pruning is recommended after harvest.

In Bangladesh, old orchards were planted at 7 to 12 m; however, many of the new plantings are spaced at 4 m. Traditional spacings of 10 to 12 m are still used in Nepal, with the inter-rows planted with vegetables or other crops. These are removed after about eight years. Planting distances in the Philippines are 7 or 8 m, equivalent to 150 to 200 trees per ha.

Plantings in Australia range from 100 to 300 trees per ha. Recommended spacings are 8 m x 6 m for spreading cultivars such as “Fay Zee Siu” and “Souey Tung” (equivalent to 140 trees per ha). Suggestions for upright or low vigour cultivars such as “Kwai May Pink”, “Salathiel” and “Wai Chee” are 6 m x 6 m or 6 m x 4 m, equivalent to 280 to 460 trees per ha. Many of the close plantings are grown as hedges, and pruned every year after harvest (Plate 6). There are some closer plantings that potentially can provide greater returns, but they are only experimental at this stage.

6.2.3 Relationship between yield and tree size

Horticulturists studied the relationship between yield and tree size for a group of ten small trees growing in an orchard in southern Queensland. This was to test whether larger trees were more productive per unit leaf area. There has been no previous study on allometric growth in lychee.

There was no apparent trend in relative yield over a 3.4-fold range of canopy surface areas (Table 7). This is consistent with the trees being small and widely-spaced, such that there were only minor differences in the degree of self-shading and shading from other trees. There was also similar relative partitioning of resources within the plants. It would appear, therefore, that from early in an orchard’s life, fruit production is simply a function of the effective canopy surface area.

There was also no apparent trend in relative yield with relative leaf area index. These results suggest that a higher leaf area index conferred little additional productive benefit. It might be that mature trees have a considerable number of shaded leaves that contribute little to overall productivity.

Table 7. Range in number of leaves per tree, total leaf area per tree, canopy surface area, relative leaf area index (RLAI), specific leaf weight (SLW) and yield for the ten lychee trees at Bundaberg in southern Queensland.

Tree	No. leaves per tree	Total leaf area (m^2 per tree)	Canopy surface area (m^2 per tree)	RLAI	SLW ($g\ m^{-2}$)	No. fruit per tree
One	2730	11.8	23.6	0.50	120	474
Two	3135	15.3	31.7	0.48	134	558
Three	3453	15.4	32.0	0.48	125	563
Four	4021	20.5	31.3	0.66	113	252
Five	4603	18.7	33.3	0.56	121	518
Six	4753	20.9	28.9	0.72	135	635
Seven	6168	25.6	33.1	0.77	135	712
Eight	6784	38.6	51.1	0.76	123	956
Nine	8227	40.4	48.4	0.83	110	1321
Ten	9138	33.6	53.2	0.63	134	1274

(Data from Menzel et al. 2000).

For “Kwai May Pink”, there were about seven leaves per harvested fruit. This compares with two to three for “Tai So” and one to two for “Souey Tung” in South Africa. However, these two experiments are not directly comparable. The work in Australia used whole trees, whereas the previous estimates were based on girdled branches, where assimilates are stored in the branch and do not contribute to the rest of the tree. The leaves of “Kwai May Pink” are also smaller than those of “Tai So”.

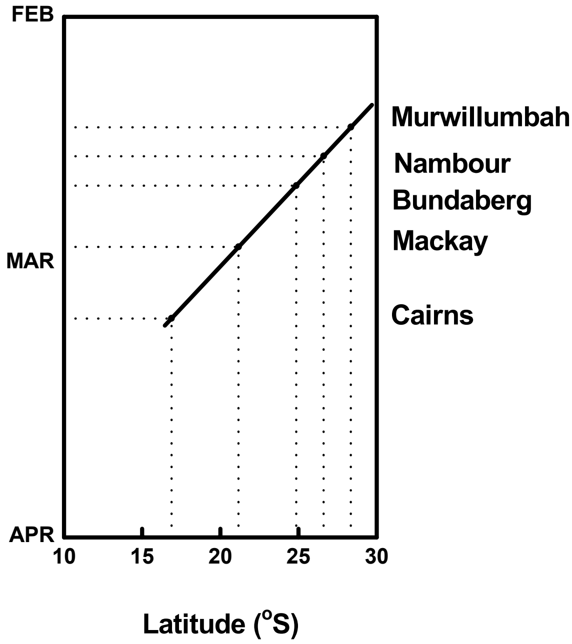
6.2.4 Development of pruning strategies

Left unchecked, lychees grow into large trees that are difficult to spray, harvest and net. Exclusion nets are an effective way to control the important bird, bat and piercing moth pests in Australia, but is most practical with small trees. Small trees can be closely planted and provide greater returns in the early life of an orchard.

The effects of pruning on flowering and yield have been studied in Florida, Taiwan Province of China and Israel. Trees were pruned in summer, autumn or winter, but responses were mixed. Experimental work has also been carried out in Guangdong and Australia to address some of these issues. This research has shown that tree size and production can be regulated, and has opened up the prospects of high-density plantings. The same principles probably apply to the related longan and rambutan.

Scientists in Australia developed a model to assist growers choose the most appropriate time to prune their trees. The optimum time of pruning varies from northern Queensland to northern New South Wales (Figure 17). The model allows for one or two growth flushes before winter in warmer areas and one flush in cooler areas. In any one location, the optimum time of pruning does not appear to vary dramatically across different cultivars. The model is a significance advance as it takes into account the effect of weather on the flushing rate in different localities. Previous research did not provide recommendations for individual growing areas. If pruning leads to leaf flushes in winter, they can be controlled with selective ethephon applications or a light manual pruning.

Figure 17. Variation in the optimum date of pruning for lychee in different latitudes along eastern Australia.



6.2.5 Yield and assimilate supply

Experiments were conducted in Australia on "Tai So", "Bengal", "Brewster", "Kwai May Pink" and "Wai Chee" to evaluate the role of assimilates on fruit retention. Girdling of trees or large branches increased fruit yield by an average of 15 to 20 percent compared with ungirdled plots. The best responses generally occurred when the girdles were applied between flowering and early fruit growth (30 days from anthesis) compared with application later in the season. In contrast, girdling did not increase the yield of small branches.

Yields were reduced by 45 percent when all the leaves from the last flush or previous flush were removed from terminal shoots, and by 35 percent when all the old leaves were removed. These results indicate the importance of the leaves behind the fruiting clusters for cropping. Fruit retention was very low on girdled branches that had been defoliated, especially when the leaves were removed in the first 20 days after anthesis. This suggests that the yields of girdled branches were determined by the availability of assimilates soon after fruit set. In contrast, the number of fruit retained on ungirdled branches was unrelated to the number of leaves, with defoliation having no effect on yield. Fruit growth on these branches was supported by resources from elsewhere in the tree.

Removing 20, 50 or 80 percent of the flowering panicles had no significant effect on yield compared with unthinned plots (77, 75, 65 and 82 kg per tree). Thinning apparently increased fruit retention in the remaining clusters. Lychees set more fruit than the tree's resources can carry to harvest. The tree's assimilates may be diverted to areas with strong demand. Opportunities exist for increasing yields by defining the optimum tree shape and leaf area index.

6.3 Fertilizer management

Lychee requires soil nutrients and water for satisfactory growth and cropping. Nitrogen (N) is the major nutrient and occupies an important position in the fertilizer programme. The other major nutrients are phosphorus (P), potassium (K), calcium (Ca) and magnesium (Mg). The micronutrients, iron (Fe), boron (B), copper (Cu), zinc (Zn) and manganese (Mn) are required in very small amounts. When the concentration of a nutrient reaches abnormally low or high levels in a plant, characteristic symptoms appear in the leaves, stems, flowers or fruit. Normally, growth and yield are reduced long before visible symptoms appear. The only way to avoid this is to monitor the concentrations of the nutrients in the plant and soil, and maintain these within the acceptable range established from healthy, high-yielding orchards.

Fertilizers generally have small impacts on production, unless trees have nutrient deficiencies or excesses. Yield and fruit quality are usually adequate over a wide range of leaf nutrient concentrations. Trees take a long time to respond to fertilizer applications, with new growth more dependent on reserves in the tree than on fertilizer applied just recently to the soil. On the other hand, when leaf concentrations have fallen below critical levels, it may take several years for the trees to recover.

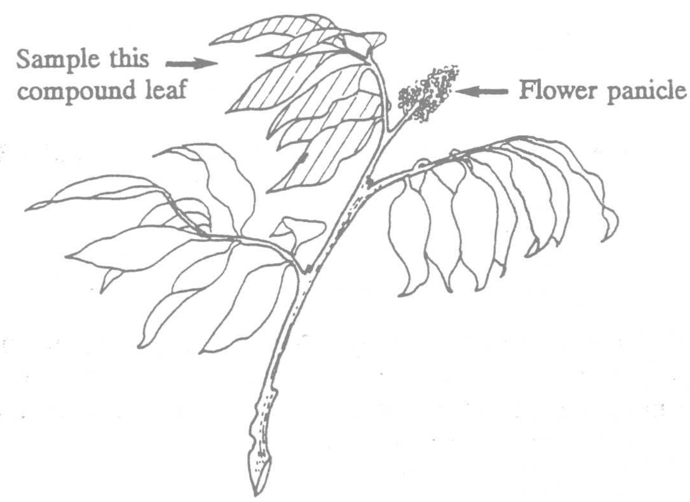
6.3.1 Leaf analysis

Horticulturists in Australia developed leaf nutrient standards in 1992. These were based on surveys of high-yielding orchards in southern Queensland, but have application in other environments. The recommended time for sampling is one to two weeks after panicle emergence or about May to August in Australia, depending on cultivar and season. The equivalent period in Asia is from October to December.

Whole leaves are sampled from the first leaf under the panicle (Figure 18). Leaves from eight branches, uniformly distributed around the tree are selected. The leaf sample should be accompanied by a soil sample from 0 to 15 cm each year. A leaf and soil sample should represent a planting of no more than three hectares, with separate samples recommended for each soil, block and cultivar. Approximately 20 uniform trees that are well spread should be selected.

The results should be supported by a record of leaf colour, tree vigour and yield so that fertilizer management can be adjusted for the next crop. The ultimate fertilizer programme depends on tree size, crop load, cultivar and soil type, and will vary considerably between different districts, orchards and years.

Figure 18. Leaves for nutrient analysis are collected from just behind the flower panicle in winter.



Recommended leaf nutrient concentrations are as follows: N, 1.50 to 1.80 percent; P to 0.14 to 0.22 percent; K, 0.70 to 1.10 percent; Ca, 0.60 to 1.00 percent; Mg, 0.30 to 0.50 percent; Fe, 50 to 100 ppm; Mn, 100 to 20 ppm; Zn, 15 to 30 ppm; Cu, 10 to 25 ppm; B, 25 to 60 ppm; Na, <500 ppm; and Cl, <0.25 percent.

Leaf tests are widely used in Australia, but are less common in Asia. Many farmers cannot afford the cost of the analyses. However, samples can be collected by Government Extension Officers to provide a guide to nutrition management in different areas. For instance, this approach can be used to monitor for certain trouble nutrients such as boron or zinc. Symptoms of nutrient deficiencies have been described in Australia and India, but are not a good basis for fertilizer management.

6.3.2 Soil analysis

Soil analysis can be used to assess the nutritional status of tree crops. It can ensure that a particular site does not fall outside the range of fertility considered adequate for that particular crop and soil. Soil tests have a role for correcting or avoiding problems such as acidity, salinity and nutrient interactions and toxicities, which are not directly related to plant composition. The analysis should preferably be taken with a leaf test.

Scientists in Australia developed a sampling technique for soil analysis and proposed tentative nutrient standards. Several high-yielding orchards were sampled over four years, with the data then used to create an optimum range.

Soil samples should preferably be taken at the same time as leaves collected for tissue analysis. This is normally just after panicle emergence in winter, prior to the application of fertilizer. Collection of soil samples just after fertilizing is best avoided, due to sampling errors associated with the uneven distribution of fertilizer in the topsoil. Research has shown that the feeder roots and nutrients under the trees are concentrated in the topsoil. Consequently, sampling the 0 to 15 cm layer provides the most reliable estimate of soil nutrient reserves.

A soil sample should be taken every year to a depth of 15 cm. Each sample should be accompanied by a leaf sample collected from the same trees. Take a sample from half way between the trunk and the drip-line or edge of the canopy. The leaf mulch should be removed first. Separate samples should be taken for each block, soil and cultivar.

Recommended soil nutrient concentrations in Australia are as follows: pH, 5.5 to 6.0; organic carbon, 1.0 to 3.0 percent; electrical conductivity, <0.20 dS per m; Cl, <250 mg per kg; Na, <1.0 meq per 100 g; NO_3-N, 10 mg per kg; P, 100 to 300 mg per kg; K, 0.5 to 1.0 meq per 100 g; Ca, 3.0 to 5.0 meq per 100 g; Mg, 2.0 to 4.0 meq per 100 g; Cu, 1.0 to 3.0 mg per kg; Zn, 2 to 15 mg per kg; Mn, 10 to 50 mg per kg; and B, 1.0 to 2.0 mg per kg. It is not known if these data apply to soils in Asia. Local values can be collected for other areas.

6.3.3 Role of different nutrients

Nitrogen is the most important nutrient affecting growth and productivity. Deficiency symptoms have been reported when leaf concentrations fall below 1.3 percent. Because nitrogen moves from old to young leaves when concentrations are low in plants, the first signs of deficiency (yellowing) are noted in the older leaves. In cases of severe deficiency, the margins of the leaves may curl, leaves may be small or fail to develop or be shed prematurely. Growth is stunted and flowering and fruit set prevented. Fruit are small, with low flesh recovery and eating quality.

Increases in fruit set, retention and yield with nitrogen have been reported in India, China and Australia. In contrast, this nutrient does not have a direct effect on floral initiation. In any case, it is difficult to shift tree nitrogen concentrations and flushing patterns with nitrogen fertilizers. There was no consistent relationship between flowering, and time of nitrogen application and soil nitrogen concentrations in several studies in Florida in the 1950s and 1960s. Temperature exerted a greater influence of floral initiation.

Low phosphorus concentrations are rare where mixed fertilizers have been applied regularly. This is because phosphorus is not readily leached from the topsoil. Once soil concentrations are high, they should be sufficient for several years. The first symptoms of deficiency show as dead patches on the tip and margins (coppery brown colour) of mature leaves that progress towards the midrib. Eventually, the leaves curl, desiccate and are shed. These severe symptoms have only been recorded in sand culture in India and Florida.

Many orchards in the Region have potassium concentrations below 0.80 percent. This can occur late in the season when potassium is translocated to developing fruit, after heavy nitrogen applications, or after heavy rain. These problems are more likely to occur on sandy soils. The leaves start to yellow, the leaf tips die and later the bases of the leaves. The old leaves are eventually shed. Consequently, the canopy consists of small terminal cluster of leaves. Severe deficiency in sand culture can restrict shoot and root development. Plants flower, but do not set. Trees may die.

Symptoms of calcium deficiency have been achieved by growing plants in sand culture, but are rare in the field. Typically, the plants in the sand had smaller leaves than those fertilized with calcium. Eventually, the new leaves, stems and roots stopped growing. Plants flowered, but did not set. No general responses to calcium have been reported in the field, although research in China implicates a role for this nutrient in fruit development. Foliar applications have been suggested for the control of skin browning and cracking.

The concentrations of magnesium are often low, especially when trees are grown on sandy soils that are readily leached. Deficiencies can also be induced by heavy applications of nitrogen and potassium. Magnesium is not readily transported from old to young leaves, hence, symptoms occur first on young tissues. Plants grown in sand culture without magnesium had small leaves that died between the veins, and eventually dropped. Flowering was suppressed when leaf concentrations fell below 0.25 percent.

Orchards established on sandy soils often have low iron levels, especially after excessive superphosphate applications that interfere with iron uptake by the roots. There can also be problems in alkaline soils with a pH above 7.0, or after excessive lime applications. There is a general yellowing of the young leaves, spreading to older leaves. When the deficiency is severe, the branches may die. Concentrations below 40 ppm are considered a problem.

Zinc deficiency occurs on acid leached soils where native zinc is low, or on alkaline soils where zinc is not readily available to plants. These problems are often exacerbated after heavy nitrogen applications. There may be general bronzing or mottling of the leaves, smaller shoots and smaller fruit. The branches may die when leaf concentrations fall below 10 ppm.

Copper deficiency is most likely in sandy soils with an inherently low copper content, but is not common. Often the young leaves roll and die. Shoots may also die when leaf concentrations fall below 6 ppm. In some soils in Australia, copper and zinc deficiencies occur together.

Leaf boron concentrations are often below 30 ppm in China, Thailand and Australia. Low boron concentrations are associated with the death of new shoots and roots, poor fruit set and misshapen fruit at harvest. The range between deficiency and toxicity is small, so care should be taken when applying boron fertilizers.

There have been many attempts to increase fruit set and fruit size with foliar applications of zinc, copper and boron. However, most of these sprays did not result in consistent increases in yield. Few authors presented data on leaf or soil nutrient concentrations. Responses to foliar applications would only be expected if leaf nutrient concentrations were below critical values.

6.3.4 Nutrient reserves

Destructive harvests in Australia showed that the greatest reserves of nutrients occurred in the leaves, twigs and small branches, which accounted for about 75 percent of the total reserves of the tree. The amount of nutrients in the other plant parts was usually less than 5 percent. The high reserves in the leaves, twigs and small branches were mainly because these tissues accounted for a large proportion of the plant's weight, although the concentration of nutrients was also higher. The concentrations of nutrients in the leaves reflected the reserves in the rest of the plant indicating that they are a reliable index of the tree’s nutrient status. These reserves are used for new leaf, flower and fruit growth, but can last a long time. For instance, nitrogen concentrations were maintained for four years in Australia after fertilizer was withdrawn. This explains why it can take several years to respond to changes in nutrition management.

6.3.5 Crop removal

Indian and Australian scientists have determined the concentrations of nutrients in fruit. These data can be used to estimate the removal of the different nutrients by the crop. Average concentrations in the fruit were as follows: N, 0.85 percent; P, 0.19 percent; K, 1.04 percent; Ca, 0.10 percent; Mg, 0.18 percent; Mn, 29 ppm; Zn, 34 ppm; Cu, 36 ppm; B, 15 ppm; and Cl, 0.01 percent. It was calculated that a 50 kg crop would remove the following nutrients in the fruit (g per tree): N, 98; P, 22; K, 120; Ca, 12; Mg, 21; Mn, 0.3; Zn, 0.4; Cu, 0.4; B, 0.2; and Cl, 28. Thus, the fruit use more potassium than nitrogen. The amounts of nutrients needed for new leaves, stems, roots and flowers were not included in these calculations. Some of the nutrients from the tree would be recycled as leaf litter and fallen twigs, flowers and fruit. These data can be used as a guide for fertilizer applications to avoid over fertilization and leaching of nutrients off-farm.

6.3.6 Time of fertilizer applications

The time of fertilizer application during the crop cycle generally has no impact on yield or fruit quality. An example is given for nitrogen applied at different times in Australia.

Nitrogen was applied over four years to six year old "Bengal" trees growing in southern Queensland. The soil was a sandy loam with low reserves of soil N (2.8 mg NO_3-N per kg). Applications equivalent to 750 kg N per ha in year 4 were made after panicle emergence in July, after harvest in January, or split between the two periods. Control trees received no nitrogen.

Leaf N concentrations in April to June were on average 0.1 percent lower after a single application in winter than application in summer or split applications. Leaf N concentrations in November to February were about 0.1 percent higher after winter application or split applications than after summer. In other words, the time of nitrogen application had little impact on leaf nitrogen concentrations.

The time of fertilizer application had no effect on yield, and in fact, it took four years without fertilizer to show significant reductions in yield compared with fertilized trees. In year 4, yield increased as leaf N in August increased from 0.95 to 1.56 percent. Lower yields in control trees were associated with poor leaf growth in the previous two years, and lower CO_2 assimilation after fruit set compared with trees receiving nitrogen.

6.3.7 The effects of phosphorus and potassium on production

The fertilizer requirements of field trees have not been well studied. South African workers examined the response in "Mauritius" over eight years. There was a 50 percent increase in leaf P from 0.12 to 0.18 percent, but only a 10 percent increase in leaf K from 0.91 to 1.06 percent. Yield increased with phosphorus fertilization from 38 to 46 kg per tree, but not with potassium (41 to 44 kg per tree).

The effects of phosphorus and potassium applications were studied in sub-tropical Queensland. The Scientists were interested to see if deficiencies would appear after three years without fertilizer, and if excessive rates of application had any detrimental effect on production. The trees were growing on a sandy loam, red clay loam and a heavy clay soil, and thus differed in their ability to buffer against sudden changes in external nutrient supply.

The sites were selected on the basis that they had soil nutrient concentrations common to many orchards in Australia.

Fertilizer applications were equivalent to 0 to 2.4 tonnes per ha for phosphorus, and 0 to 3.2 tonnes per ha for potassium. In the first two years, there was no effect of fertilizer on leaf phosphorus and potassium, while in year three, leaf phosphorus was related to phosphorus application at two out of two sites and leaf potassium to fertilizer potassium at one out of three sites. Thus, phosphorus and potassium accumulated at some sites at high rates of fertilization. In contrast, concentrations in unfertilized control trees fell only slightly over time.

Fruit production was similar over the range in leaf phosphorus of 0.18 to 0.44 percent, and leaf potassium of 0.75 to 1.10 percent, compared with the Australian standards of 0.14 to 0.22 percent and 0.70 to 1.10 percent, respectively. The buffering capacities of the soil and tree were thus indicated. These results suggest that annual applications of phosphorus and potassium may not be required, indicating savings for growers. This would provide a saving in operating costs of US$70 per ha for 15 year old trees for phosphorus, and a saving of US$80 per ha for potassium. These results also suggest that the leaf standards for phosphorus and potassium need to be reviewed.

6.3.8 Fertilizer guide

Tables 8 and 9 outline the suggested applications for well-grown, high-yielding trees in Australia. These rates are a guide only and should be supported by the results of leaf and soil analyses. Depending on cropping patterns and soil, they can easily be modified to suit other environments. In many parts of Asia, most of the nutrients are supplied from organic fertilizers. The suggested applications of the different nutrients can be amended as necessary. The major nutrients are best applied to the soil. Responses to foliar applications have been reported in some countries, but tend to be short-lived. Leaf nutrient concentrations are increased only temporarily.

For nitrogen, don't apply fertilizer if leaf concentrations are above 1.8 percent and the trees are vigorous and have not set a crop. If the range is 1.5 to 1.8 percent, apply the rate recommended. If the range is 1.2 to 1.5 percent, apply 25 percent more, if it is 1.1 to 1.2 percent, apply 50 percent more, and if it is less than 1.0 percent, apply 100 percent more.

For phosphorus, interpret the results in conjunction with soil analysis, and don't apply if the leaf test is more than 0.22 percent or if the soil test is above 300 ppm. Annual applications are not likely.

For potassium, trees carrying a heavy crop, with less than 0.50 percent K in the leaf test, will require twice the amount of fertilizer listed for their size or age. If the leaf test is 0.5 to 0.6 percent, use another 50 percent than the recommendation. If the leaf potassium is 0.70 to 1.10 percent, use the recommendation, but if it is above 1.10 percent, add nothing.

Table 8. Annual fertilizer requirements (kg per tree).

Tree age (years)	Canopy diameter (m)	Urea	Super-phosphate	Sulphate of potash
4-5	1.0-1.5	0.4	0.8	0.7
6-7	2.0-2.5	0.7	1.0	1.1
8-9	3.0-3.5	0.9	1.3	1.3
10-11	4.0-4.5	1.1	1.7	1.7
12-13	5.0-5.5	1.3	2.0	2.0
14-15	6.0-6.5	1.8	2.5	2.9
>15	>6.5	2.2	3.0	3.4

Dolomite is recommended for the correction of soil pH below 5.5, when magnesium concentrations are low, but the response can be slow. Where leaf magnesium is low, magnesium sulphate (9.6 percent Mg) can be applied to the soil at the rate of 40 g per m^2. Magnesium oxide (54 percent Mg) can also be used, but is fairly insoluble. Another strategy is to apply the magnesium sulphate as a foliar spray (20 g per litre), although the results can be short-lived.

For low calcium concentrations, apply gypsum at 500 g per m^2 if the pH is above 6. If the soil pH is below 6, use lime or dolomite at the rate recommended by your chemical laboratory.

For micronutrients, if the range is within the optimum values, use the recommended rate (Table 9), but if it is below the optimum, apply a second application. If the leaf test is above the standard value, apply nothing.

Table 9. Micronutrient recommendations.

Nutrient	Product	Soil application (g per m^2)	Foliar application (g per litre)
B	Solubor	2	2.0
Zn	Zinc sulphate	25	1.0
Cu	Copper sulphate	4	2.0
Fe	Ferrous sulphate	10	5.0
Mn	Manganese sulphate	5	2.5

Timing of fertilizer application is not likely to influence tree performance. Most nutrients can be applied between spring and summer. If using foliar applications, apply boron, copper and manganese to the mature summer and autumn leaves. Zinc should be applied to the expanding summer and autumn flushes.

Similar rates of fertilization are suggested in China, although there is emphasis on split applications during the year. For a ten year old tree with a 100 kg crop, it is suggested growers apply 600 g N, 40 g P and 250 g K prior to flowering; 200 g N, 50 g P and 700 g K at full bloom; and 600 g N, 40 g P and 250 g K prior to harvest. Foliar fertilizers can be used instead of the soil applications at flowering. The fertilizer is normally applied in a trench around the tree. The amount of phosphorus applied appears much higher than that recommended in Australia.

In India, the suggested approach for 12 to 15 year old trees is to broadcast 600 to 800 g N, 150 to 200 g P and 300 to 500 g K in two or three applications. There is generally an emphasis on organic fertilizers. Applications of foliar zinc, copper, manganese and boron are suggested.

6.4 Irrigation management

Lychees have a deep root system and can survive long dry periods, although leaf, flower and fruit production are usually reduced. The period from flowering to early fruit development is particularly sensitive to water supply. Most orchards in the Region are not irrigated because of costs or lack of infrastructure, but it is generally agreed that yield and fruit quality would be improved with supplementary watering. It is recommended that new orchards should be irrigated. In the absence of irrigation, an annual rainfall of 1,200 to 1,500 mm is required for satisfactory production.

There has been only limited research on the irrigation requirements of commercial orchards. Work in South Africa showed that drought from panicle emergence to harvest reduced yield and fruit size in “Tai So”. Gross returns dropped from US$125 to US$18 per tree. This work has relevance to many areas in Asia, which experience dry winters and springs. Different results were recorded in Australia, although the drought was less severe and applied later in the reproductive cycle. Plants dried out after flowering had higher yields than well-watered plants, although this was at the expense of fruit size. Fruit in droughted plants were 10 percent smaller than those from plants watered regularly. These two studies showed that trees are capable of extracting water at considerable depths in most soils, and can produce acceptable yields with fairly long intervals between waterings. Some orchards in Australia are watered two to three times per week, but this is excessive.

An acceptable cycle in a sandy loam would be two weeks, and considerably longer in a clay, with greater water-holding capacity. Irrigation in a sandy loam before 50 percent of the available soil water is used, would maintain tree water status in the acceptable range. The profile should be brought back to field capacity with every irrigation. This strategy is dependent on the trees being well grown with a deep root system and the soil having a good structure. Trees growing on compacted sites, with limited roots at depth will need more frequent watering.

Suggested water applications for trees in southern Queensland are shown in Table 10. It may be much drier in some areas of Asia. The only efficient way to irrigate is to monitor changes in soil water under the trees. Various instruments are available, but they are too expensive for most farmers. Experience is the best approach. Evaporation from a Class A pan can be used as a guide, although the relationship between actual water use and evaporation from the pan varies with the weather and crop cycle. Local horticulturists can give you advice on irrigation systems and application rates for your orchard.

Table 10. Suggested irrigation rates (litre per tree per week) in southern Queensland.
(Some areas in Asia may be drier).

Time of year	Years 4-6	Years 7-15	Years 15+
May-June (pre-flowering)	120	200	400
July-September (flowering)	400	600	1,200
October-February (fruit growth)	500	800	1,500
March-April (leaf growth)	400	600	1,200

6.4.1 Irrigation in different countries

Most of the orchards in China are not irrigated, although some trees planted along the rivers and streams have access to water. Only a few of the new orchards planted away from the rivers at elevation on red clays are irrigated. Water resources are normally reserved for rice. It is usually dry from October to March (flowering and fruit set) in Guangzhou and wet during the rest of the year. Orchards in Viet Nam are also reliant on rainfall, since there is no water available in the elevated areas. It is felt that rainfall is normally sufficient for good production.

Most of the orchards in Thailand are found in the northern hills on steep slopes, and thus are not readily irrigated. Flood irrigation was sometimes used in the low areas, but has now been replaced by mini-sprinklers in the larger commercial plantings.

Experiments in India showed that irrigation every second day was required for good yields and fruit quality. This watering regime also helped to reduce the incidence of skin cracking which can be quite severe in some districts. Most orchards are watered by basin or flooded, even though drippers are more efficient. Irrigation is generally not available in Nepal or Bangladesh, with some trees suffering water deficits during fruit development. Orchards in the Philippines are also dependent on rainfall.

Irrigation is normally required to produce commercial crops in Australia, but care must be taken with the water to make sure it is not too saline. About two to four megalitres of stored water is required for each hectare of trees. Under-tree sprinklers are recommended. Drippers are rare. Some growers base their applications on experience, while others reply on estimates of water use calculated from evaporation from a Class A pan. The use of tensiometers and other soil water sensors is less common. Irrigation is more important in northern Queensland at elevation in Mareeba, and in Rockhampton and Bundaberg in central Queensland, and less of an issue in southern areas with more uniform rain during the year such as Nambour and Ballina.

6.5 Use of growth regulators and cincturing to improve flowering and fruit set

Synthetic auxins were used in the 1950s and 1960s to control growth and flowering in Florida and Hawaii. Typically, the chemicals were applied before flowering to prevent late vegetative shoots developing. There were many instances where the treatments increased yield, however, often the responses were unpredictable. This was possibly because cool weather needed for flower initiation did not always follow the sprays.

More recently, Australian horticulturists showed that ethephon could be used to control early red leaf flushes when applied in May or June in sub-tropical areas. New buds emerge behind the damaged shoots within a few weeks, and flower if the weather remains cool enough. Mechanical pruning of the red flushes also induces the same response, but is difficult with large trees. If too much leaf is removed at this time, the crop will be very poor. This is because fruit are dependent on assimilates produced by leaves behind the fruiting clusters. Many similar strategies have been developed in Guangzhou and Chiang Mai.

Girdling or cincturing can be used in the same way as the auxins or ethephon to improve flowering as shown in China, Thailand and Australia. Girdling is normally carried out after the post-harvest flush has matured which would be in late March in sub-tropical Australia. This prevents new shoot growth for about three months, so that the next activity of bud growths occurs when conditions are favourable for flowering. In essence, it manipulates the growth cycle so that new buds develop during cool weather, and so is similar to the drought treatments used in Hawaii and Israel. However, it cannot substitute for cool weather at the time of flower initiation. Chemicals applied at this time are also not likely to increase flowering unless followed by cool weather.

Growth regulators and girdling have also been used to improve fruit retention. Chinese and Israeli workers showed that synthetic auxins reduced fruit drop and increased the yield of several cultivars when applied to trees soon after fruit set, when the fruit weighed about 1 or 2 g. Work in China, South Africa and Australia indicated that girdling soon after fruit set gave similar increases in yield. Girdling presumably redirected assimilates that normally supported stem and root growth. However, the long-term effects of these treatments on tree health are unknown.

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7. MAJOR PESTS AND DISEASES

Overview

Many insect and mites attack trees in Asia. Although some affect production in nearly all locations, many others are of only local significance. Relatively few species cause significant crop loss in their own right, and are only a problem when the population exceeds damaging thresholds. The less important species may at times require special attention, especially if their natural enemies have been disrupted by chemical sprays.

There are a few diseases affecting leaves, flowers and fruit, and some others causing tree deaths or decline. However, no major disease currently limits production in the Region. Brown blight (Peronophythora litchii) infects leaves, panicles and fruit in China and Thailand, but can be controlled with metalaxyl. Anthracnose (Colletotrichum gloeosporoides) and similar diseases also attack fruit in China, India and Australia. Parasitic algae and nematodes affect some orchards, but can be readily controlled with available chemicals. Various organisms have been associated with tree deaths or decline in Asia and Australia, although their pathogenicity is yet to be proven.

7.1 Major pests

Regardless of where lychee is grown, several insect groups attack the flowers, fruit, leaves and branches. Lepidopterous fruit borers are generally the most important pests affecting production. Other important species include various leaf- and flower-eating caterpillars and beetles, bark borers, scales, leaf mites, fruit-sucking bugs, fruit-piercing moths and fruit flies.

7.1.1 Fruit borers

Conopomorpha sinensis Bradley, known as the lychee stem-end borer in China and the lychee fruit borer in Thailand, is the major pest in most seasons. This pest was previously recorded as *Acrocercops cramerella* (now *Conopomorpha cramerella* Snellen). *C. sinensis* and the related *C. litchiella* Bradley both attack lychee, the latter preferring leaves and shoots, while *C. cramerella* is restricted to rambutan and cocoa (Bradley, 1986).

C. sinensis lays yellow, scale-like eggs 0.4 x 0.2 mm long on the fruit any time after flowering, as well as on new leaves and shoots. Both lychee and longan are affected. The eggs hatch in three to five days, with the larva immediately penetrating the fruit, leaf or shoot. They tunnel through the flesh of the fruit that often fall from the tree.

In Thailand, fruit are inspected weekly from fruit set to detect eggs of *C. sinensis*, which are very small and almost invisible to the naked eye. Infested fruit should be picked and destroyed, at infestation levels of 1 to 2 percent. When the pest becomes more active, permethrin is applied weekly, up to two weeks before harvest. In Taiwan Province of China, cypermethrin, deltamethrin, carbofuran or fenthion during early fruit set is recommended to prevent damage later in the season. Moths can be excluded by enclosing the fruit panicles in nylon mesh bags, but is uneconomic in areas with high labour costs. If the parasitoids *Phanerotoma* sp. and *Apanteles* sp. are not active, fallen fruit should be removed to reduce the build-up of moths.

All stages of the leaf-miner, *Conopomorpha litchiella* Bradley, are similar to those of the fruit borer. The female lays its eggs on new shoots and the small, light-yellow eggs hatch three to five days later. The newly hatched larva is creamy white, and bores into shoots and leaf blades, usually into the mid-rib and veins. The moths are attracted to leaf flushes that emerge during the rainy season from June to October in Thailand. Affected shoots often wilt.

Bearing trees should be inspected during early flush development and sprayed if necessary. The leaf flush before flower initiation is very important as it supplies the carbohydrates needed for fruit development. If 30 to 40 percent of the larvae are parasitised, spraying is not recommended. Young, non-bearing trees do not need to be sprayed either. This also allows the parasitoids to build up in the orchard.

The insect originally referred to as *Argyroploce illepida* Butler (= *Cryptophlebia carpophaga* Walsingham) in India (Butani, 1977), is actually *Cryptophlebia ombrodelta* Lower (Bradley, 1953). It also occurs in Thailand, China, Japan, Taiwan Province of China and Australia, but only in the latter area is it regarded as a significant pest.

The creamy white eggs of these species are oval and flat with a reticulate surface, and are about 1.0 x 0.8 mm. They are laid singly or in groups of up to 15 on the fruit surface. The newly hatched larva feeds on the fruit skin and then tunnels towards the seed. In immature fruit, the young larva bores directly into the seed, which is completely eaten. A single larva may damage two or three fruit, if the fruit are small. However, they prefer mature colouring fruit with larger seeds.

In South Africa, the insect growth regulator, triflumuron as a single, full cover spray 40 days before harvest, or two sprays of teflubenzuron a fortnight apart commencing when the fruit are 10 mm in diameter, are recommended. Alternatively, the panicles can be covered with paper bags. The bags also improve fruit colour and overall quality. In Queensland, carbaryl and azinphos-methyl have been used with varying success. Several sprays commencing at fruit colouring are applied on a calendar basis, with monitoring for the presence of eggs less common. Newer insecticides including the insect growth regulator, tebufenozide, provide better control, with less disruption to natural enemies.

The various species of *Cryptophlebia* are attacked by their own complex of egg, larval and pupal parasitoids; however, these do not always keep borers below economic thresholds. Egg parasitoids such as *Trichogrammatoidea fulva* Nagaraja from India and *T. cryptophlebiae* from South Africa and Australia, offer the best prospects for biological control.

7.1.2 Fruit-piercing moths

Fruit-piercing moths such as *Eudocima (Othreis) fullonia* (Clerck), *Eudocima salaminia* (Cramer) and *Eudocima jordani* (Holland) are important throughout Asia, Australia and the South Pacific. The larvae of these moths develop on a variety of host plants such as the coral tree, *Erythrina*, and vines of the Menispermaceae (*Legnephora*, *Stephania*, *Fawcettia*, *Tinospora*, *Carronia*, *Sarcopetalum*, *Pleogyne* and *Hypserpa*).

The moths have a proboscis that drills a neat hole in the skin of the fruit allowing them to suck the juice from the flesh. Contamination of the wound with yeasts and bacteria carried on the proboscis destroys the fruit. *Drosophila* spp. attracted to the fermenting juice hastens deterioration. Within a few days, a frothy exudate seeps from the fruit and stains undamaged fruit close by. In Australia and Thailand, farmers go to their orchards at night with spotlights and attempt to catch the moths. However, this is futile.

Australian farmers also make traps by draping shade cloth loosely over a frame of wire and baiting it with fermenting citrus and bananas. The moths feed on the fruit and become entangled in the folds of the shade cloth when they attempt to fly off. Several traps are required to protect an orchard and even then, substantial damage is sustained. In Thailand, ripe bananas and pineapples are dipped in insecticide and hung in the trees to poison the feeding moths. In some countries, panicles are covered with paper bags. In recent times, parrots and fruit bats have become a severe problem for growers in Australia. Fine nets erected over the orchard control fruit-piercing moths as well as the vertebrate pests.

7.1.3 Leaf-feeding caterpillars

Oxyodes scrobiculata F. and *Oxyodes tricolor* Guen. occupy similar niches in Thailand and Australia. In Australia, *O. tricolor* attacks trees in southern Queensland, but is not a pest in the north. The castor oil looper, *Achaea janata* (L.), is a voracious feeder in Australia and often infests trees in large numbers at the same time as *O. tricolor*. The caterpillars can cause severe defoliation.

In Thailand it is recommended that carbaryl be applied when there are two to three young larvae per leaflet. Shaking the tree to dislodge larvae onto the ground improves the effectiveness of the sprays. If 40 percent or more of larvae are parasitised, sprays should not be necessary. In Australia, *Bacillus thuringiensis* Berliner (Bt), endosulfan or methomyl may be used when damaging populations of *O. tricolor* appear.

7.1.4 Leafrollers

Olethreutes perdulata Meyr. is an occasional pest in Queensland. *Platypeplus aprobola* (Meyrick) has also been recorded in Australia, China and India. *Adoxophyes cyrtosema* Meyr. and *Homona coffearia* Nietner attack trees in Guangzhou and Fujian. The latter species along with *Homona difficilis* is recorded in lychee, longan and rambutan in Thailand. The orange fruit borer, *Isotenes miserana* (Walker), is another leafroller that also attacks flowers and fruit in Queensland.

P. aprobola is a minor pest in China and India where it attacks leaves and flowers. However in Australia, it is part of a complex of species contributing to a significant loss of flowers. In China, *A. cyrtosema* and *H. coffearia* also feed on leaves, flowers and fruit.

In Australia, the damage caused by leafrollers is tolerated so long as it is restricted to the foliage and unlikely to affect flower initiation. If necessary, methomyl or carbaryl can be applied when 20 percent of leaf flushes are infested, to minimize damage to young trees or at critical periods of leaf growth in older trees. In India, rolled leaves that contain larvae are removed manually during light infestations, but phosphamidon, fenitrothion or endosulfan are applied for heavy infestations.

7.1.5 Beetle borers

The longicorn beetle, *Aristobia testudo* (Voet), is a serious pest of lychee and longan in Guangdong (Zhang, 1997). The beetle has one generation per year, with adults emerging from June to August. The females girdle branches by chewing off 10 mm strips of bark, with the eggs laid on the wound and covered with exudate. The larvae hatch from late August and live under the bark until January when they bore into the xylem and create tunnels up 60 cm long. In Taiwan Province of China, the white-spotted longicorn beetle, *Anoplophora maculata* (Thomson), has a one-year life cycle. Adults emerge in spring and females insert about twenty eggs individually into T-shaped incisions in the bark, 0.5 m above the soil surface. The larval period lasts about ten months. In Australia, the longicorn beetle, *Uracanthus cryptophagus*, causes similar damage (Plate 7).

Tunnelling by the larvae may kill branches, but rarely whole trees. Ring-barking of twigs by ovipositing adults causes the shoot tips to die and snap off. In China, regular inspections of trees during adult activity enable orchard workers to remove the beetles. Eggs and young larvae can also be removed at the same time. Established larvae can be located from the appearance of their frass, which is packed into the ends of tunnels. They can then be ‘fished out’ with wire hooks and knives. Alternatively, dichlorvos is injected and the tunnels sealed with clay (Zhang, 1997).

7.1.6 Scarab beetles

The elephant beetle, *Xylotrupes gideon* (Linnaeus), is important in all areas of Australia. The larvae develop in the soil or mulch where they feed on plant roots and humus. The large, heavily-sclerotised and sexually-dimorphic adults emerge in spring. Later, they are attracted to the fruit as they ripen, especially those that have split or been damaged by parrots and fruit bats. They then start attacking sound fruit and can cause significant economic losses in the week or so leading up to harvest. Chemical control is unsatisfactory. Manual removal is effective in small trees, but difficult in large trees. Labour is relatively expensive in Australia, so this operation adds significantly to growing costs.

7.1.7 Soft scales

Pulvinaria (*Chlorpulvinaria*) *psidii* (Maskell), the green shield scale, infests trees in China, Taiwan Province of China, Australia and India. In Queensland, crawlers are produced in spring by adult scales that infest the leaves and twigs. Some of these crawlers move onto the flowers and young fruit. The female scales are sometimes mistaken for mealybugs because the egg masses that are covered in waxy filaments cover the ends of the scale.

Soft brown scale, *Coccus hesperidum* Linnaeus, is an occasional pest in Queensland, where chemicals have disrupted its parasitoids or it is protected by ants. *Parasaissetia nigra* (Nietner) and *Saissetia coffeae* (Walker) infest trees in India along with *C. psidii*, but they are not important.

These scales cause no damage as they feed, but the fruit become unmarketable when significant populations develop on the surface, as they often do in China, Taiwan Province of China and Australia. The scales also produce honeydew, which supports the growth of sooty mould on infested fruit and panicles, and those below. These discoloured fruit are downgraded or rejected in the market-place.

Severe infestations may be controlled with methidathion, although applications of mineral oil are preferred so that effective predators, the mealybug ladybird, *Cryptolaemus montrouzieri* Mulsant, and the green lacewing, *Mallada signata* (Shneider) are not affected.

7.1.8 Bugs

Several bugs belonging to Tessaritomidae attack lychee and longan throughout Asia and Australia. *Tessaritoma papillosa* Drury occurs in southern China, Vietnam, Thailand, Myanmar, the Philippines and India, although Butani (1977) notes that *Tessaritoma javanica* Thunberg and *Tessaritoma quadrata* Distant, are the main species in India. In Australia, *Lyramorpha rosea* Westw. is known as the lychee stink bug, but rarely causes damage.

In China, *T. papillosa* has one generation per year. Adults tend to aggregate and over-winter mostly on lychee and longan, but may also be found on other hosts in warm protected areas. In spring, the females are attracted to trees with new flowers and shoots. They mate and lay up to 14 egg masses, each containing about 14 eggs, on the back of leaves. Peak egg-laying occurs in March in Guangdong, but continues through to September. The first nymphs mature in June, while there are still old adults in the trees. These old adults may have lived for up to a year, and generally die by August. The new adults do not mate immediately, but mature over winter and mate and lay eggs the following spring.

Adults and nymphs feed on terminals, which may be killed, and also on flowers and fruit, causing these to fall. Liu and Lai (1998) claimed that up to 30 percent of fruit in commercial orchards are damaged despite chemical applications.

In Guangdong, the main natural enemies are the egg parasitoids, *Encyrtus* (*Ooencyrtus*) sp., *Anastatus* sp. and *Blastophaga* sp. which parasitise 70 to 90 percent of eggs laid late in the season. Similar results were recorded by Liu and Lai (1998) when parasitised egg cards were hung in trees during March. In orchards under integrated pest management, combined parasitism rates by *Anastatus* sp. and *Ooencytus* sp. may reach 50 percent in June, but may be less than 3 percent in orchards that rely on chemicals. During the 1970s, biological control in Guangdong was initiated using the egg parasitoid *Anastatus japonicus* Ashmead, the flat venter wasp, after field trials had demonstrated its value. Since only 10 percent of eggs are parasitised by April when most of the eggs are laid, natural control is ineffective. In contrast, very good control with up to 90 percent parasitism is achieved after mass release of wasps.

In Thailand, the egg parasitoids *Anastatus* sp. nr. *japonicus* and *Ooencrytus phongi*, operate in a similar manner to their counterparts in China. Low levels of control are achieved during the critical early fruit production period, building up to good levels later. Mass rearing of the parasitoids in the wild silk worm, *Philosamia ricini* Hutt., and releasing them early, produced results similar to those in China. *Anastatus* sp. and *O. phongi* parasitised 79 percent and 21 percent of eggs, respectively (Nanta, 1992).

If chemicals are used, the timing of sprays is critical because the bugs vary in their susceptibility to trichlorfon at different times of the year, depending on body fat content and its nature.

Amblypelta nitida Stål, the fruitspotting bug, and *Amblypelta lutescens lutescens* (Distant), the banana spotting bug, are major pests of tropical fruit in Queensland (Waite, 1990). The adults over-winter on citrus or non-crop native or exotic ornamentals, and start to move into lychee and longan orchards in spring when the trees flower. They prefer to feed on green fruit, and so are very common just after fruit set. Orchards near rainforests where the bugs breed are particularly susceptible (Waite and Huwer, 1998).

The bugs feed on the developing seed and this causes the fruit to fall a couple of days later. The puncture mark is invisible on the fruit surface and the only way to distinguish damage from natural drop is to dissect the fruit. Fruit that has been attacked typically have a tan lesion on the seed testa. Endosulfan should be applied if more than 10 percent of fallen fruit have been stung. Usually, a maximum of two sprays applied two weeks apart, during the first six weeks after fruit set is sufficient.

7.1.9 Mites

Erinose mite, *Aceria litchii* (Keiffer), also known as hairy mite, hairy spider, or dog ear mite, occurs throughout China, Taiwan Province of China, India, Pakistan and Australia. Females lay eggs singly on the leaf surface amongst the erineum induced by their feeding. The eggs are only 0.032 mm in diameter, spherical and translucent white. The mites are also small, only 0.13mm long and pinkish-white. All stages have only four legs, but are quite mobile and move easily from old leaves to infest new flushes. Their feeding stimulates the production of the erineum where they shelter and feed. Numbers vary with the cycle of shoot growth, and are highest in summer and lowest in winter. Planting material obtained as marcots may be infested if they have been taken from trees with the mites. Later infestations occur when the mites are moved around the orchard by direct contact between trees, or carried around by orchard workers, wind and bees (Waite and McAlpine, 1992).

The mites attack new leaves causing a felt-like erineum to be produced on the under-surface. This forms as small blisters but may eventually covers the entire leaf, causing it to curl. In severe cases, whole terminals may be deformed. The young erineum is silver-white, changing to light brown and dark reddish-brown, and eventually black. The greatest numbers of mites are found in the intermediate stages.

Many leaves are ruined if infestations are severe (Plate 8). This generally causes no problems in established trees, but can debilitate young orchards. There can also be a problem if the mite moves from leaves onto the developing flowers and fruit. Fruit set can be disrupted or the fruit deformed. Such fruit are unmarketable.

Numerous species of predatory mites, particularly those from the Phytoseidae, have been recorded with *A. litchii* (Wu *et al*., 1991; Waite and Gerson, 1994). *Agistemus exsertus* Gonzalez (Stigmaeidae), has been used for control in Guangdong, Guangxi and Fujian.

Branches infested with the mite should be cut off and burnt. The mites can be controlled by applying insecticides when they move from the older leaves to a new flush. The leaves should be checked regularly for symptoms over summer and autumn. Not all trees in an orchard will be flushing or infested at the same time. In Australia, three sprays of dimethoate or wettable sulphur every two to three week during leaf emergence and expansion generally provide adequate control. Chemicals recommended in China include dichlorvos, dimethoate, dicofol, chlorpyrifos, omethoate and isocarbophos (Zhang, 1997).

7.1.10 Gall flies

The leaf midge, *Dasyneura* sp., is a major pest in China (Zhang, 1997). *Litchiomyia chinensis* Yang and Luo was described from specimens reared from galls on lychee leaves collected in Guangdong. The larvae over-winter in the galls produced as a result of their feeding. They pupate in the soil, with the adult flies initiating the first of eight overlapping generations from March. The midges prefer damp, closed canopies and dry out in exposed areas. The adults lay eggs in lines on young leaves. The larvae then mine the leaf, causing 'watery dots' that later become the "galls". These turn brown and eventually drop out, giving the leaf a "shot-hole" appearance.

In susceptible orchards, monitoring is not effective and preventive procedures are required. As with erinose mite, infested leaves can be removed after harvest and burnt. Later in the spring, methyl parathion (2.5 percent) at 75 kg per ha can be distributed under the trees, or isofenphos (0.001 percent) can be sprayed on the ground just prior to emergence of the adults. In autumn, isocarbophos (0.001 percent) should be sprayed twice over two weeks during early leaf development (Zhang, 1997).

7.1.11 Fruit flies

In Queensland, *Bactrocera tryoni* (Froggatt) occasionally attacks lychee, but is not considered economically significant. Females lay their eggs through the skin of the fruit, often utilizing cracks and wounds made by other pests. Although the eggs can hatch, the larvae rarely survive (de Villiers, 1992), probably because of the juice in mature fruit drowns them. The flies in Queensland, and related species in Africa and Hawaii, are capable of ovipositing through the skin of lychee, although some cultivars may be too thick. The only real fly problem appears to be in South Africa, with *Ceratatis rosa*. However, the level of damage is still quite low. In South Africa, pheromone-baited traps can be used for monitoring populations. Control is achieved with bait sprays of protein hydrolysate mixed with trichlorfon or mercaptothion. Alternatively, the panicles can be covered with paper bags after the November fruit drop.

7.2 Major diseases

No major disease currently limits commercial production in Asia. Diseases are more important after harvest, although undoubtedly many of the fruit are infected before picking. There are a few organisms that infect the leaves, flowers and fruit, and a few others associated with tree decline and tree deaths. Chemicals are generally available for controlling diseases on the flowers and fruit. In contrast, more efforts need to be made to control the loss of trees.

7.2.1 Brown blight

Brown blight, *Peronophythora litchii*, is a major disease in both lychee and longan in China and Thailand, although more important in the former. It is also reported to affect lychee in India. It is well described in Guangdong, and attacks leaves and panicles, as well as fruit that can be infected right up to harvest. These infections all reduce production and shelf life. Flower panicles are particularly susceptible. Immature fruit turn brown, while those infected before harvest have a white mildew growing on the skin.

The fungus over-winters in the soil or on old infected fruit, with the spores spread by wind, rain and insects. Continuous wet weather and temperatures of 22^{o} to 25^{o}C favour infection. It is suggested that growers clean up their orchard by removing shaded, infected and dead branches after harvest. Copper oxychloride during winter and copper sulphate in spring also help to reduce inoculum levels. These chemicals are replaced by fosetyl-Al or metalaxyl during flowering and fruit development.

7.2.2 Anthracnose

Anthracnose, *Colletotrichum gloeosporoides*, is a major disease in Guangdong, and also occurs in India. Although it attacks leaves and branches, along with flowers and flower stalks, infected fruit are unmarketable. Lesions on the leaves may appear as small round light grey areas, or irregular brown marks at the tips. In contrast, infections are much more obvious on the flowers and fruit. Outbreaks are common after warm wet weather. The fungus may not always cause immediate disease, which sometimes only becomes apparent after harvest. Fungicides are used during an initial outbreak, but are not always effective.

A form of anthracnose caused by *Colletotrichum gloeosporioides* (*Glomerella cingulata* in the sexual state) also affects trees in Australia. Pepper spot causes superficial skin blemishes to the fruit, but does not effect production, fruit quality or shelf life. More than half of the crop may be unmarketable in some orchards. The disease has been recorded on all cultivars, but is most severe on the popular “Kwai May Pink”.

The disease first appears as brown pinhead freckles, usually on the top of semi-mature fruit, in areas with overhanging branches. The spots do not increase in size, but rapidly turn black. More spots appear on the top and sides of the fruit and may, by harvest, cover up to half of the fruit surface. Infections over-winter on the leaves, with the fungus potentially spread from nurseries to new orchards.

Until the appearance of pepper spot, lychee was generally free of diseases affecting fruit or foliage in Australia. However, the occurrence of the disease has resulted in attempts to control it using copper oxychloride and copper hydroxide. Calendar sprays of copper are costly and could lead to unacceptable residues if used close to harvest. Other chemicals such as mancozeb are being evaluated.

7.2.3 Tree decline

A slow decline and a sudden death have been recorded in China, Viet Nam and Australia, especially in poorly drained soils. It can affect the whole tree or just one or two branches. The symptoms include a sudden branch wilt that is followed by the decline of new growth on the affected branch over a period. In other situations, the tips die without wilting. The tree or branch may recover temporarily, but subsequently dies. Parts of the tree flush and grow, while other sections die.

A number of organisms including *Phytophthora*, *Pythium* and *Fusarium* have been isolated from the roots of trees, but it is not known where they cause the disease. A root rot caused by *Clitocybe* is reported to kill trees in the Philippines. Growers are advised not to plant on waterlogged soils.

Armillaria occasionally attacks roots and the base of trees of any age causing death or slow decline. The fungus may survive in the soil, or on stumps and roots of various trees for many years. The planting sites need to be fumigated before establishing new trees in the orchard.

7.2.4 Parasitic algae and nematodes

A parasitic algae, *Cephaleuros virescens*, occasionally attacks trees in Australia causing loss of vigour. Cultivars such as "Souey Tung" and "Haak Yip" are very susceptible. It can be controlled with two sprays of copper, before and after the wet season.

Nematodes such as *Xiphinema*, *Paratrichodorus* and *Helicotylenchus* are a problem in South Africa, but whether they are significant in Australia and Asia is not yet clear. Post-plant nematicides are used in South Africa, but have not been evaluated elsewhere.

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8. HARVESTING AND STORAGE

Overview

Lychee fruit are classified as drupes, and have a large seed, edible aril (flesh) and thin, tough, corky pericarp (skin). The pericarp of the mature fruit varies from pink-red to plum, depending on the cultivar, while the aril is succulent, translucent cream or white, exotic and sweet. The fruit is highly prized, especially in Asia, and is a valuable international commodity. It is, however, also very perishable. This limits marketing in many countries without good storage facilities. The fruit must also be marketed and consumed quickly.

The fruit are particularly prone to water loss. In the first instance, dehydration only causes cosmetic injury with most of the initial water lost from the pericarp, causing it to lose colour and turn dull brown. The aril is largely unaffected at this stage. Eventually, the aril also loses water and the fruit become flaccid and bland (Underhill and Critchley, 1993; Underhill and Simon, 1993). Without specialized treatment, the skin browns within a day, whereas the flesh deteriorates more slowly.

Water loss can be overcome with packages that maintain high humidity around the fruit, however, these increase the risk of rots (Scott et al., 1982). A number of measures can help to control these rots, with refrigeration, the most effective. Fungicides can also be used, but are more effective when combined with refrigeration. With precautions against dehydration and rots, along with sensible orchard management and post-harvest handling, fruit may keep for two to three weeks.

8.1 Post-harvest physiology

8.1.1 Fruit maturity

As lychee fruit mature, the concentrations of sugars, principally those of sucrose, glucose and fructose increase (Chan *et al.*, 1975; Paull *et al.*, 1984), while the concentrations of organic acids, predominantly malic acid decrease (Chan and Kwok, 1974; Paull *et al.*, 1984). The most reliable guide to maturity is titratable acidity (TA) or the ratio of total soluble solids (TSS, degree Brix) to titratable acidity (Batten, 1989). Recommendations vary, but a TSS:TA of 40 or greater is recommended for commercial fruit. In practice, most orchards in the Region are harvested on the basis of taste and general appearance. The flattening of the fruit segments on the skin is a good way of telling when the fruit are mature. Over-ripe fruit are sweet, but bland.

Fruit quality declines after harvest. Concentrations of ascorbic acid, phenols, sugars and organic acids decrease during storage (Holcroft and Mitcham, 1996; Chen *et al.,* 2001). However, significant post-harvest ripening can be achieved with dips in ethephon, an ethylene precursor. A 5 minute dip in a 2.5 g per litre ethephon solution resulted in a 50 percent increase in total sugars, a 20 percent increase in ascorbic acid and an increase in the TSS:TA from 20 to 30-40 over three days (Sadhu and Chattopadhyay, 1989). However, despite such experiments, ethephon has not been commercialized. The focus of current activities is to maintain rather than improve the quality of harvested fruit.

8.1.2 Browning

Pericarp browning is the first visual sign of fruit decline. Browning that occurs during the first few days after harvest is usually caused by dehydration of the pericarp. Fruit start to brown once they lose a few percent of the harvested pericarp fresh weight (Jiang and Fu, 1999). Below 50 percent of its initial fresh weight, the pericarp is entirely brown.

The biochemistry of browning is only vaguely understood. The colour of mature fruit is largely due to a range of anthocyanins located in the mid- to upper mesocarp (Underhill and Critchley, 1993). The anthocyanins are stable at pH below 3, but are converted to colourless chromenols, in an acid-reversible reaction, as the pH rises. Anthocyanins are also prone to enzymatic and non-enzymatic oxidation, often leading to melanin by-products (Kaiser, 1994).

The expression of colour in hydrated tissue seems to be related to the compartmentalization of the cells. The anthocyanins are located in the vacuole (Underhill and Critchley, 1993), which is expected to be highly acidic because of the proton gradient across the tonoplast that, amongst other things, drives the accumulation of organic acids (Ratajczak and Wilkins, 2000; Tomos *et al.*, 2000). In addition, anthocyanin oxidative enzymes tend to be sequestered elsewhere. For example, polyphenol oxidase is found in chloroplasts or other plastids (Underhill and Critchley, 1995). Dehydration may act to disrupt the compartments, increasing the permeability of the membranes, causing the pH of the vacuole to rise, and accelerating the oxidation of anthocyanins and other cell components. As a result, the distinctive lychee pigments fade, and a range of brown pigments appear. In this regard, Jiang and Fu (1999) found that the rate of water loss was correlated with membrane permeability, the rate of browning, polyphenol oxidase activity and tissue pH, and negatively correlated with anthocyanin content.

Other factors also cause the fruit to brown, including: mechanical stresses of various sorts (tugging the pedicel at harvest, sliding the fruit down a rough picking bag, dropping fruit from short heights); microbial and insect attack; and extremes of temperatures. In short, anything likely to accelerate cell breakdown is likely to increase fruit browning.

8.1.3 Controlling dehydration

Packing fruit into moisture-proof (plastic) bags and punnets can substantially reduce water loss and slow the rate of browning. For example, Scott *et al.* (1982) found that fruit kept in unperforated polyethylene bags at 20°C for 10 days lost less than 2 percent of their fresh weight, while control fruit lost between 18 and 30 percent. More permeable barriers such as paper, wicker baskets and cardboard, offer less protection. Surface coatings are another possibility. Zhang and Quantick (1997) found that a solution of chitosan and L-glutamic acid reduced water loss at 4°C by about 20 percent and significantly slowed browning compared with untreated fruit. However, this technology has not been adopted commercially. This is in contrast to other fruit such as apples and citrus that are routinely coated with waxes.

Cool temperature storage also slows browning (Paull and Chen, 1987). Low temperatures slow evaporation as well as respiration (Tongdee, 1998) and probably slow tissue senescence. Jiang and Chen (1995) found that fruit treated with polyamines, suspected anti-senescence agents, then wrapped and stored at 5°C, had lower membrane permeabilities and less browning than controls. This work implicated senescence as a significant co-determinant of the life of well-packed, cool-stored lychee.

A controlled atmosphere of 3 to 5 percent O_2 and 3 to 5 percent CO_2 has also been shown to slow water loss. Fruit stored under such an atmosphere for 30 days at 1°C lost only a quarter of the water lost by the controls (Jiang and Fu, 1999). However, the mechanism of the response is not clear. Such an environment may affect the metabolism of the fruit as well as that of the pathogens.

8.1.4 Controlling rots

Lychee is host to a range of post-harvest pathogens, often with quite different modes of infection (Coates, 1995; Johnson *et al.*, 2002). For example, germinating appressoria of *Colletotrichum* spp. produce infection pegs that can penetrate the cuticle (Coates and Gowanlock, 1993), while *Penicillium* spp. are more dependent on pericarp lesions for colonization (Johnson and Sangchote, 1993). Low temperature storage is the most successful means of slowing rot development. For instance, Johnson *et al.* (2002) found that fruit stored at 22°C rotted three times more quickly than fruit stored at 5°C.

Synthetic fungicides are also effective. For example, Wong *et al.* (1991) and Johnson *et al.* (2002) found that hot benomyl dips at 48^{o} to 52°C slowed rot development compared with undipped fruit. By applying a log transformation to their rot coverage data, the rates of rot development were compared. The control fruit had about 170, 110, 40 and 30 percent higher rates of rot than the best dipped fruit for the cultivars “Bengal”, “Tai So”, “Kwai May Pink” and “Wai Chee”, respectively. These data show that rots still affected the dipped fruit, although the fungicides slowed the spread of the diseases. This technology has not been used by the Australian industry for quite some time. There are health concerns surrounding synthetic fungicides, with benomyl no longer registered (Johnson *et al.*, 2002).

Straight hot water dips or sprays are alternatives to fungicides (Olesen *et al.*, 2001). For “Kwai May Pink” stored at 5°C for the first seven days after harvest, and then at 22°C, the control fruit reached 50 percent rot coverage, 15 percent more quickly than the best 52°C dipped fruit, or 20 percent more quickly based on degree-days. This is approximately 50 percent of the effect of the 52°C benomyl dip on rot development on “Kwai May Pink” outlined above.

A great range of other possibilities exists for controlling rots, such as the 3 to 5 percent O_2 and 3 to 5 percent CO_2 mixture mentioned above (Jiang and Fu, 1999). However, these need to be studied in a commercial environment.

8.1.5 Cosmetic solutions to browning and rots

Sulphur and acids, or combinations, can be used to stabilize the red colour of the pericarp. Both treatments increase the permeability of the cells and acidify the sap (Tongdee, 1998; Tongdee *et al.*, 1998), but sulphur also results in the formation of a colourless anthocyanin-sulphite complex (Kaiser, 1994). Consequently, sulphur-treated fruit are somewhat bleached relative to controls, while the “redness” of the acid-treated fruit is enhanced. Sulphur is also anti-fungal if applied correctly (Coates, 1995).

Sulphur dioxide fumigation has been used extensively in South Africa and Israel. There have also been many experiments in China and Thailand. However, sometimes the fruit are tainted. There are also concerns about high sulphite residues in relation to sulphur-sensitive individuals (Tongdee, 1998). Israel has recently promoted a hot water brush/acid/prochloraz treatment (Lichter *et al.*, 2000), but acid treatments sometimes give an artificial and persistent red colour to the fruit that masks poor eating quality (Olesen and Wiltshire, 2000).

8.2 Low-technology handling protocols

8.2.1 Pre-harvest

The quality of the fruit at harvest determines subsequent shelf life and market performance. Blemishes at harvest are only magnified during handling and marketing. Trees require a good supply of nutrients and water to produce sound fruit. Fruit splitting, for example, has been correlated with low concentrations of calcium in the pericarp (Huang *et al.*, 2001; Li *et al.*, 2001) and uneven watering during fruit development (Kumcha, 1998). Insect control is also important, as fruit damaged prior to harvest deteriorate rapidly. The use of pesticides or bags in the field minimizes damage and increases the proportion of sound, marketable fruit. Bagging may even enhance fruit colour under certain circumstances (Tyas *et al.*, 1998).

Sensible orchard hygiene needs to be practiced to reduce the risk of rots during storage. Trees pruned to open canopies are better ventilated than non-pruned trees, and provide a less favourable environment for rots, while skirting lowers the risk of infection from the soil. Removing dead wood from the orchard eliminates a source of pathogens. Field sprays with registered fungicides can also reduce post-harvest diseases in some circumstances (Johnson and Sangchote, 1993).

8.2.2 Harvesting

Indices used to judge maturity include fruit size, skin colour or texture, the aril sugar:acid ratio, and flavour (Greer, 1990). There is little information on the effects of fruit maturity on storage life. Sittigul *et al.* (1994) examined three colour classes of “Hong Huay” (“Tai So”) from 31 percent surface redness to 100 percent surface redness and found negligible differences in browning or rotting. Wu *et al.* (2001) examined four colour classes of “Fay Zee Sui” from less than 33 percent surface redness to 100 percent surface redness. The youngest fruit (<33 percent red) and the oldest fruit (100 percent red) had lower aril concentrations of total soluble solids and higher pericarp superoxide dismutase activity than intermediate fruit. The youngest fruit also had higher rates of water loss than older fruit. Overall, there seems to be a large range of fruit maturities, with similar physiological characteristics and storage potential.

Harvesting may be carried out by removing whole panicles using secateurs, or by cutting or twisting the stems of individual fruit. If fruit are harvested by twisting, care needs to be taken to avoid tearing the skin, caused by pulling rather than twisting. Careful handling of fruit in the field is also required to avoid mechanical injury (Plate 9). Drops of greater than 30 cm onto hard surfaces, or 60 cm onto other fruit, can cause cracking, particularly if the fruit are turgid (Bryant *et al.,* 2001). Packing bin or basket heights of 30 cm or less are recommended (Batten and Loebel, 1984). The bins should be clean since soil and debris can increase rots during storage.

The water content of fruit on the tree fluctuates throughout the day. Harvesting early in the morning or late in the afternoon maximizes fruit water content (Olesen, 2001), and reduces the risk of desiccation. Once harvested, exposure to the sun and air can increase water loss by a factor of ten (Ward, 2000). A tarpaulin can be used to protect the fruit, but must be kept clean to prevent the build-up of pathogens. Lightly spraying the fruit with water may help to maintain fruit quality in hot, dry weather. The transfer of fruit to the packhouse soon after harvest minimizes the opportunity for water loss in the field. Transporting the fruit dry and fairly tightly packed reduces the risk of vibration damage.

8.2.3 Packhouse operations

Sorting, grading and packing are often carried out in a packhouse or shed, to protect workers and fruit from the elements. Where shelter is not available, operations are best located in a cool, shady area. This is more common in China and Thailand, and other parts of Asia. Good hygiene in the packhouse is required to avoid the spread of diseases during handling. Pathogens can build-up on packing surfaces and fruit crates. These surfaces should be washed with sanitizing agents such as chlorine every day. Water and fungicide dips also require frequent replacement or sanitizing. Waste fruit need to be regularly removed from the packing area to reduce the spread of spores.

8.2.4 Sorting

Product quality is maintained by removing damaged and inferior fruit during sorting. Close attention to detail and good lighting are required at this stage. Sorting can be carried out on a table (common in Asia), or preferably as fruit move along a series of rollers (common in Australia). The entire surface of each fruit must be observed to ensure that damaged specimens are not packed. Damage extending to the aril rapidly leads to rots, which may spread to sound fruit within the package. For this reason, fruit with pulled stems, splits, cracks and insect damage should be rejected at this stage.

In Australia, fruit damaged by piercing moths the night before harvest show little damage initially, but will show signs of weeping and tissue darkening within 24 hours. For this reason, some growers store fruit overnight in high humidity cool-rooms, to ensure that all stung fruit are detected. If cool-rooms are not available or a quick turn around is preferred, recently stung fruit can often be identified by leakage of aril juice when the fruit is squeezed. Immature fruit and fruit showing any signs of rot are also removed during sorting. Some markets have low tolerance for cosmetic defects, such as scale infestation, small fruit, severe pepper spot (anthracnose) infection or superficial browning. Fruit showing these defects are generally downgraded and not sent to the central markets, but can be processed or sold at roadside stalls.

8.2.5 Grading

Grading separates fruit into different grades to suit different markets. Most producers have at least two grades of fruit. Grading is normally carried out during or after sorting. Grading systems depend on market requirements, but are normally based on fruit size and colour, and the area of blemish. Export markets usually have higher standards than domestic markets, requiring uniform, unblemished fruit. There can also be differences within different sections of the domestic market.

8.2.6 Fungicides

Post-harvest treatments with fungicides can slow rot development, but the required equipment and chemicals are expensive. Although several chemicals are effective, few have been registered for commercial use. There are also increasing concerns about residues in fruit.

8.2.7 Disinfestation

Some export markets require disinfestation of fruit for insect pests. For example, marketing of lychees from Australia to Japan and the USA is limited because these countries consider lychees to be a host of fruit flies in Australia. There are several methods available to kill the insects (Holcroft and Mitcham, 1996), but fruit are often damaged in the process. There are also health concerns regarding treatments such as ethylene dibromide and gamma irradiation. Further research is required to develop a safe and effective strategy for these pests.

8.2.8 Packing

Lychees can be packed in panicles, or as individual fruit. Fruit are often sold on panicles in Asia, whereas loose fruit are more common in Australia, Europe and North America. De-stalking is required when fruit harvested on panicles are packed individually. Fruit can be twisted to break the stem at the natural abscission zone, or a short length of stem cut using secateurs. Mechanical de-stalkers based on stiff bristled brushes are available in Australia, but often cause damage, particularly when fruit are wet.

Selection of packaging depends on market preferences and availability. The ideal package protects fruit from damage and minimizes water loss and condensation. Research in Queensland has focussed on plastic packaging combined with cool storage or fungicides (Scott *et al.*, 1982; Coates, 1995). However, without good temperature control, plastic covers result in condensation and an increased risk of rots.

Much of the fruit marketed in Asia is transported in bamboo baskets. Square baskets less than 30 cm high give good protection against injury. Circular baskets can be improved by tying strings in two or three directions across the top, with padding underneath (Hilton, 1994). The outer layers of fruit in these baskets are prone to rapid water loss. This can be alleviated by lining the baskets or by covering them with a tarpaulin. Many of the larger commercial operations now consign their fruit in plastic trays or cardboard boxes, which provide better control of water loss. Some growers in Asia dip their fruit in cold water or cover their fruit with ice. However, very low temperatures can injure the fruit (Huang and Wang, 1990). Free water around the fruit as the ice melts can also increase the risk of diseases.

8.2.9 Transport

Poor transport conditions are a major problem in Asia. The main limitations, including rough roads, lack of refrigeration and poor truck suspension, are out of the control of growers. Fruit are often damaged when baskets are overfilled, dropped, stacked or packed on their sides (Hilton, 1994). Shelves can be used in the truck to avoid stacking of baskets, and reduce damage to fruit. Padding and strapping the baskets can restrict movement during transport. Exposure to warm air can dry out the fruit very quickly, so transport during the warmer part of the day is best avoided, if possible. Fruit can be protected by covering the baskets with a clean tarpaulin or similar material.

8.2.10 Marketing

During marketing, quality can be preserved by shading or covering the fruit or by sprinkling them with water. To reduce browning, the packaging is best left in place until the display needs restocking.

8.3 High-technology handling protocols

8.3.1 In the orchard

A range of farm machinery can be used for general orchard management, including fertigation, irrigation, spraying and pruning. Trees can also be netted to protect the fruit from birds, bats and the large insects. There is, as yet, no accepted mechanized means of harvesting fruit. Cherry pickers and other elevated picking platforms, along with ladders are generally used.

8.3.2 Processing, transport and marketing

Lychee is delicate, so minimal handling is preferred. It is also highly perishable, with a short storage life, so that a rapid turn around will deliver the best quality to consumers. Ideally, fruit should be shipped on the day of harvest.

Research into the best handling practice for lychee is still in its infancy, and no accepted protocol exists. It is likely to begin with some form of anti-fungal treatment in the orchard prior to harvest. The harvested fruit would be initially placed in a cool-room to remove the field heat, and then sorted on a roller conveyor in the packhouse. It might then be subjected to a small suite of anti-fungal measures, for example, a hot water spray with a dissolved fungal inhibitor, then packed dry into punnets, gassed with a modified atmosphere and heat sealed with an anti-condensation film. The punnets would be transported and marketed under refrigeration.

Yet in this simple outline there are an extraordinary number of unknowns. The optimum temperature recommended for the storage of lychee seems to depend on the method of assessment. The optimum temperature for storage of lychee is approximately 5°C (Huang and Wang, 1990), although fruit stored at 10°C can last almost as well (Olesen and Wiltshire, 2000), with less risk of condensation in the pack. A modified atmosphere of 3 to 5 percent O_2 and 3 to 5 percent CO_2 was mentioned earlier, but other mixtures, and gases such as nitrous oxide (Qadir and Hashinaga, 2001), deserve attention.

The incorporation of a hot water spray into the packing line does not bring with it the problem of packing fruit wet, which increases the incidence of rots, because the water evaporates quickly from the treated fruit, but raises concerns about packing fruit warm. There is a vast array of pre-harvest and post-harvest fungicides that need to be assessed, along with various technologies for disinfestations of fruit. There may also be efficiencies to be gained by developing new sorting and grading equipment. These issues require resolution if lychee is to be marketed with confidence throughout the Region.

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9. ECONOMICS OF PRODUCTION

Overview

Average yields in the Region are about 4 tonnes per ha, although some orchards in Australia, China and elsewhere can produce 15 tonnes per ha, under close spacings and intensive tree management. The price for fruit varies with year, season and cultivar. Early fruit in Guangdong fetch US$2 per kg, whereas the bulk of the crop is sold at half this price in the middle of the season. Premium cultivars with small seeds such as "No Mai Chee" and "Kwai May" can sell for US$10 or more per kg in a light year. Prices for export fruit are normally higher than those sold locally. In both markets, lychees are also more expensive than the related longan. Little information is available on the profitability of enterprises within the Region. An analysis in Australia showed that trees could be as profitable as alternative crops such as avocado, macadamia and mango. Picking, packing and marketing are the most expensive part of the operation, and account for 65 percent of total costs. There is little benefit in trying to reduce growing costs, whereas there are financial rewards to be gained by improving the efficiency of harvesting and packing. It is not known whether similar improvements are possible in Asia, with lower labour costs.

9.1 Productivity

Yields vary widely with cultivar, season and country. In China, a ten year old tree can carry 100 kg of fruit. Average yields range from 2 to 5 tonnes per ha, although well-managed, high-density plantings can yield 15 tonnes per ha. Production is generally more consistent in Guangdong than in Fujian or Guangxi. Over-crowding, inadequate watering and fertilizing, stink bug and fruit borer lower productivity in neglected orchards. Warm temperatures during winter can also reduce flowering across the production areas.

Average yields in Viet Nam are a low 2 tonnes per ha, but only about half the plantings are of bearing age.

Average production in Thailand is 3.5 tonnes per ha, with the highest yields in Chiang Mai and Chiang Rai in the north, and the lowest in Samut Songkhram in the south. Longan generally has higher yields than lychee, but fetches a lower price.

Lychee is quite productive in India, especially under irrigation. Average yields have increased by 50 percent in the past ten years to 7 tonnes per ha. Productivity is highest in Bihar, followed by West Bengal. Some well-grown orchards in Bangladesh can be just as productive, however, average yields here are lower than in India. Production in Nepal ranges from 40 to 100 kg for ten year old specimens. The higher yields are usually associated with more intensive tree management, including irrigation.

In Australia, ten year old trees can produce 80 kg of fruit, although average yields are half that. An early economic analysis of production on the Atherton Tableland with "Fay Zee Siu" assumed average yields of 55 kg for ten year old trees, but this was too optimistic. A recent economic analysis in the same region used average yields of 24 kg per tree. In southern Queensland, yields are 40 kg per tree or 11 tonnes per ha for "Kwai May Pink". Some orchards are more productive. Protection from bats and birds can double yields in many areas.

9.2 Prices

Early cultivars such as “Sum Yee Hong” from Guangdong fetch US$2 per kg, even though fruit quality is only average. When production is heavy, the price in the middle of the season falls to US$0.50 per kg, although sought after cultivars such as “No Mai Chee” and “Kwai May” may fetch US$15 per kg. Growers in Guangxi generally receive US$1.50 per kg for lychee and a little less for longan. For comparison, apples are US$1 per kg and bananas US$0.25 per kg. Prices in the export markets are much better, normally US$5 to 15 per kg.

Lychee is a lucrative crop in Viet Nam. In Luc Ngan District, each farmer has about 100 trees with half of these of bearing age. Average income is US$1,400 to 2,200 or US$700 to 1,100 per labourer. This is a high income compared with Local Government workers who earn US$400 per annum.

The average farm price in Thailand is US$1.50 per kg, with longan receiving only half of this. In 1997, fresh exports of 11,000 tonnes sold for US$13 million, while 27,000 tonnes of canned fruit sold for US$38 million.

The Philippines is a net importer of lychees that normally sell for only US$0.30 per kg. The price has fallen in the last year or two, but is still higher than that obtained for some of the more common local fruit.

Prices in Australia range from US$1 to 6 per kg, depending on quality, demand and time of year. Average prices are US$2.50 per kg, somewhat above US$1.50 predicted in 1986 when the industry was just starting to expand. The highest prices are normally received for early-season “Fay Zee Siu” from northern Queensland.

9.3 Profitability

Thew examined the profitability of orchards in southern Queensland, with average yields of 4.6 tonnes per ha and a price of US$1.50 per kg. These yields and returns are on the low side for orchards in southern districts. Nevertheless, his analysis is useful for examining the effect of picking rate, price, and variable costs. He found that a 10 percent increase in price improved profitability more than a 50 percent reduction in growing costs. This analysis suggests that there are more gains to be had in improving the handling of fruit than in reducing growing costs.

Hassalls and Associates studied the profitability of an 11 ha “Kwai May Pink” orchard in southern Queensland over 20 years, assuming yields of 11 tonnes per ha (275 trees per ha), a price of A$5 per kg and netting costs of A$16,500 per ha. Picking, packing and marketing were the most expensive part of the operation, and accounted for 65 percent of total costs. These data further illustrate that there is little benefit in trying to reduce the costs of watering, fertilizing and spraying, while there are potential benefits to be gained by improving the efficiency of harvesting and marketing. Gross margin was A$34,000 per ha, after subtracting recurring costs of A$21,000 per ha from revenue of A$55,000 per ha.

Table 11. Effects of netting, pruning and plant spacing on yields and returns in Australia.

	Potential yield (kg/tree)				
	10	20	30	40	50
	Low-density planting without pruning or nets				
Actual yield (kg per tree)	6	12	18	24	30
Actual yield (tonne per ha)	0.90	1.80	2.70	3.60	4.50
Returns ($'000 per ha)	4.50	9.00	13.50	18.00	22.50
	Low-density planting with pruning and nets				
Actual yield (kg per tree)	7	14	21	28	35
Actual yield (tonne per ha)	1.05	2.10	3.15	4.20	5.25
Returns ($'000 per ha)	5.25	10.50	15.75	21.00	26.25
	High-density planting with pruning and nets				
Actual yield (kg per tree)	7	14	21	28	35
Actual yield (tonne per ha)	2.10	4.20	6.30	8.40	10.50
Returns ($'000 per ha)	10.50	21.00	31.50	42.00	52.50

(The analysis assumes 30 percent loss of fruit to birds and bats and a 10 percent extra loss to insect pests in the traditional orchard. Yields of pruned trees are 30 percent lower than the yields of non-pruned trees (similar yields on a canopy area basis). There are 150 trees per ha in a traditional planting and 300 trees per ha in a high-density planting. The price for fruit is A$5 per kg. Data from Menzel et al. 2000).

Hinton examined costs and returns for a 13 ha "Fay Zee Siu" orchard in northern Australia, assuming yields of 3.7 tonnes per ha (154 trees per ha) sold at A$8 per kg. Nets were hung over the trees at a cost of A$6,000 per ha. The gross margin was A$19,000 per ha after subtracting recurring costs of A$11,000 from the gross revenue of A$30,000 per ha. Harvesting and marketing accounted for 87 percent of variable costs. The two most critical factors affecting profitability were yield and price. At yields of 12, 24 and 36 kg per tree, farms were profitable above A$10.20, A$6.00 and A$4.60 per kg, respectively. Capital outlays were not included in the analysis, but were A$1,200 per ha for each year of the 30-year project. Land was only A$3,000 per ha, about a third of the cost in southern Queensland.

The costs of production are much lower in South-East Asia than in Australia. There are also differences in capital outlays for land and equipment. However, some of the principles discussed in Australia have application elsewhere.

9.4 Profitability of high-density plantings

Menzel *et al*. (2000) undertook an analysis of returns for three different orchards in Australia. They compared:

- a traditional non-netted orchard with 150 trees per ha and trees not pruned,
- a netted and pruned orchard with 150 trees per ha, and
- a netted and pruned orchard with 300 trees per ha.

The analysis assumed 30 percent loss of fruit to birds and bats and a 10 percent extra loss to insect pests in the traditional orchard. Yields of pruned trees were 30 percent lower than the yields of non-pruned trees. However, yields were similar when expressed on a canopy surface area basis. The price for fruit was A$5 per kg.

Returns were greater after pruning and netting, especially when trees were planted at close spacings (Table 11). Some existing orchards suffer losses of up to 60 percent due to birds and bats, so the net impact of pruning/netting would be substantially greater. There are of course additional costs associated with this system, including A$1,650 per ha for extra plants, A$1,875 for extra irrigation and A$16,500 for nets. Not taken into account in this analysis were the savings associated with harvesting smaller trees. Harvesting is very expensive in Australia, due to the high costs of labour.

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10. PROSPECTS FOR INDUSTRY EXPANSION

Overview

Although lychee has a long history in Asia, it is a relatively new species in most countries, and efforts to increase production have been relatively small compared with the more established tropical fruit such as citrus, banana, pineapple and mango. There are many recipes for growing the crop, although not all agronomic recommendations have been based on the results of research. There has also been much speculation on the factors controlling growth and cropping. The main reason for low yields is failure to flower, although in some seasons, the trees may flower heavily, but carry few fruit at harvest. The yield of cultivars varies greatly from district to district, so cultivars must be evaluated for their cropping in different areas.

There are opportunities to increase production with new cultivars, and appropriate watering, fertilizing and pruning. Girdling and growth regulators can also increase flowering and fruit retention under some circumstances. Improvements in integrated pest and disease management, post-harvest treatment and marketing are required. These developments are more likely to succeed if countries across the Region remain united in their vision for the future of this crop.

10.1 Cultivar improvement

The industry in Asia has a narrow cultivar base. Most countries apart from China use one or two cultivars, even though many more are available. A single cultivar may become popular because of its consistent cropping, easy management or good quality. There are few cultivars that have developed in tropical parts of Thailand and Indonesia; however, the bulk of production is in the sub-tropics. Cropping is much more consistent in cooler areas, with winters below 20°C.

Future expansion of the industry in the Region is dependent on the development of new ecotypes with better production and fruit quality. New cultivars are still being released to the industry in China; however, most other countries cannot afford a large breeding effort. The main focus of a breeding programme would be to produce cultivars with regular and heavy yields, good tree shape and small seeds, and earlier or later harvests. In the short-term, it might be advantageous to link existing programmes from different countries, or at least exchange some of the better cultivars. It would also be useful to evaluate the performance of existing cultivars in a systematic way.

10.2 Canopy management

Many countries are moving towards close plantings of 3 to 5 m between trees and 6 to 8 m between rows, whereas older orchards were up to 12 m x 12 m. Desktop calculations indicate that close plantings are more profitable, especially in the early life of an orchard. There is probably no advantage in very close plantings where the trees start to crowd each other before they begin to bear. Guidelines are available on the optimum time to prune trees after harvest along eastern Australia and these could be applied to much of Asia. In contrast, optimum tree shape and canopy size have not been established. Many of the existing cultivars have a considerable number of shaded leaves that contribute little to overall productivity. Studies in this area have increased yields in temperate deciduous fruit orchards, but are rare in tropical trees.

10.3 Water and nutrition management

General guidelines are available for water and nutrient management. Most orchards in Australia are irrigated, whereas those in Asia are dependent on rainfall. Yields and fruit quality are undoubtedly affected in some seasons. It is recommended that new plantings be irrigated if possible.

Drought could be used to control flushing patterns and improve flowering in localities with dry winters such as India and Thailand; however, the timing and duration of the water deficit for success are not known. There is also some evidence from Australia that a light drought after flowering could increase fruit production, but commercial recommendations are not available.

Growers generally irrigate their orchards on the basis of long-term evaporation data from a Class A pan, or just from experience. This easily translates into under- or over-watering. Research indicates that irrigation once a week is more than adequate for established trees in most areas. Maximum water use would be about 60 mm per week. Soil water can be monitored with the various electronic devices, but these are expensive and impractical for most growers. They also need to be calibrated. Water management is much easier on deep well drained soils.

Australian growers base their fertilizer applications on soil and leaf tests; however, these are less common in Asia. Samples could be collected by Government horticulturists and used to monitor potential nutrient problems in a particular growing area. It is unlikely that the standard values will change significantly with new cultivars or growing areas. It is possible that increases in yields could occur with higher tree nitrogen concentrations, above 1.8 percent, whereas there is probably little benefit in increasing the application of other nutrients. Both organic and chemical fertilizers are effective. In contrast, there is no evidence that the rate or time of nitrogen applications affect flowering. Foliar applications are less effective than soil applications. Most nutrients are probably best applied to the soil.

10.4 Manipulating flowering and fruit set

Research on flower and fruit physiology was active in the 1980s and early 1990s, with glasshouse and field experiments conducted in Australia and elsewhere. Vegetative growth is greater at 30°C than at lower temperatures. In contrast, flowering is poor with days above 25°C and nights above 15°C. Flowering is usually best with at least three weeks of low temperatures. Small buds only a few millimetres long flower when exposed to a few weeks of cool weather, whereas longer buds remain vegetative. Australian workers also showed that the number of days suitable for floral induction in an average year was about 200 in sub-tropical districts such as Ballina (latitude 29°S) and below 20 in tropical areas like Cairns (latitude 17°S). This analysis can be used to predict relative cropping at different elevations in parts of Asia. There is no evidence that strategic pruning, girdling, drought or withholding fertilizers can induce flowering in the tropics.

Auxins have been shown to increase fruit retention and yield in Israel and China. It would be interesting to evaluate this technology in other countries, although there could be problems with registering the chemicals. It is quite possible that other chemicals have similar benefits, without the risks to human health. The long-term effects of girdling on flowering, fruit set and tree health should also be explored.

10.5 Control of pests and diseases

The main insect pests are erinose mite, fruit-sucking bugs and fruit borers. There can also be problems with scales, stem borers, leaf- and flower-eating caterpillars and beetles, and fruit-piercing moths in some areas. Current strategies generally employ calendar sprays with little monitoring, although there is some effort to control stink bug in China and Viet Nam with parasitoids. There has also been a change in the chemicals used with strong interest in the use of insect growth regulators. In the future, there will probably be a shift to monitoring and strategic applications, with possible biological control for some pests. There also needs to be a change in pesticide label directions for tree crops, which are currently based on application rates rather than on dose per tree.

Exclusion nets are the most effective control for birds and flying foxes in Australia, but orchards must be productive for the system to be economically viable. This can be a problem in tropical areas with irregular flowering. These pests are less of an issue in Asia. With a small aperture, the netting can control fruit-piercing moths and possibly even macadamia nutborer.

Strategies need to be developed to control brown blight, *Peronophythora litchii*, and anthracnose, *Colletotrichum gloeosporoides*, which affect orchards in China, India and Australia. Current systems of control are not always successful. There are a few diseases killing individual trees or whole orchards in the Region, but the causal organisms have not been identified. No chemicals are currently registered for these diseases.

10.6 Post-harvest technology and marketing

Research into extending shelf life has been active since the 1980s. Fruit deteriorate rapidly after harvest. Several strategies have been developed to reduce the considerable wastage that occurs through the marketing chain. Fruit dipped in hot benomyl and stored in punnets with PVC wrap keep for several days at room temperature, but the technology is not practicable. Many countries just cool the fruit with cold water or ice.

Experiments have been conducted with sulphur, acid dips, hydrocooling, heating and other techniques to maintain the red skin, but none of this research has improved eating quality. New approaches based on a better understanding of fruit physiology need to be developed. The emphasis needs to be on reducing water loss, and then the build-up of diseases under the higher humidity. This work will become more important as trade within Asia expands. It can be concluded that research into extending the shelf-life of fruit is a priority for the Region.

Most of the fruit produced in Asia is sold on the domestic markets. There is also some trade within the Region to Hong Kong and Singapore, and some exports to North America and Europe. The majority of the crop is sold fresh, with a little drying and canning as well.

Table 12. Factors limiting expansion of production in different countries.

Country	Factors limiting expansion
China	Short shelf life, inefficient marketing system, variable fruit production and quality from small orchards, irregular flowering and fruit set, and frost and wind damage.
Viet Nam	Irregular flowering, narrow cultivar base, and lack of equipment for maintaining shelf life after harvest.
Thailand	Alternate bearing, short shelf-life, poor marketing system, high cost of fertilizers and other chemicals, and strong competition from longan in the market.
India	Narrow cultivar base, poor growing techniques, high incidence of insect pests, poor post-harvest management, shortage of planting material, and lack of irrigation.
Bangladesh	Narrow cultivar base, short production season, variable quality of planting material, inappropriate pruning, and lack of technical information.
Nepal	Large seed in current commercial cultivars limits marketing, shortage of planting material, inappropriate pruning, harvesting and post-harvest management, and inadequate industry research and extension.
Indonesia	Narrow cultivar base, variable yields, poor quality fruit, short harvest season, and lack of planting material and growing technology.
Philippines	Irregular production in existing cultivars, high cost of planting material, high growing costs, lack of technical information for new growers, lack of irrigation, and limited research and extension.
Australia	Many orchards in northern districts are inherently low yielding, harvesting and packing expensive, and fruit susceptible to browning and rotting and thus have a relatively short shelf life.

Marketing groups are well established in Australia, and are now the largest exporters from that country. They typically have a market coordinator, rigorous grade standards and quality assurance training, and pack their fruit into distinctive cartons that are readily identifiable in the marketplace (Plate 10). The groups achieve a premium of US$1 per kg above the average market price. These ideas need to be developed throughout the rest of the Region, especially for the lucrative export trade. Quarantine issues associated with fruit fly also need to be resolved.

10.7 Factors constraining production in various countries

Profitable lychee growing starts with the identification of a market opportunity either internationally or locally. The site and cultivar determine the time of production and hence average prices. There are also important agronomic decisions associated with site selection. The site should be frost-free and yet have a dependable period of cool weather to induce flowering. There should be a reliable supply of good quality water and suitable soil. The slope of the land should allow safe use of vehicles for tree maintenance and harvesting. Selection of regular heavy-yielding cultivars, with good quality fruit is essential. In establishing orchards, closer planting to produce high early returns should be considered, but sufficient space for access should be maintained.

Planning for netting of trees when production commences should be considered in some locations such as Australia. High-density orchards need to be pruned regularly to keep trees small and allow space for machinery. Trees have a range of serious pests that must be controlled, and require regular water and fertilizer applications. However, these do not appear to be major costs. All cultivars have a short production season and short shelf-life so that picking and packing need to be efficient. Marketing decisions will determine the success or failure of an enterprise. Marketing groups in Australia have improved returns to growers, but their full potential will only be reached with the development of better post-harvest technology. These strategies need to be considered by the expanding industry in Asia.

Table 12 lists some of the factors constraining the expansion of cultivation in Asia. Production in most countries is limited by the narrow cultivar base, with a lack of suitable planting material an issue in some areas. There are concerns about the regularity of cropping throughout much of the Region related to irregular flowering or fruit set. This can be due to poor growing techniques especially on the smaller farms, or just due to weather. Some growers do not have ready access to advice on the best watering, fertilizing or pruning programmes for their area. There is much wastage of fruit after harvest, even in countries like Australia where hydrocooling and post-harvest technology are available.

Many growers are hampered by a lack of capital and access to finance. There is inadequate Government support for research and extension in many countries, considering the potential value of the fruit in the Region and the number of families involved in growing, marketing and supporting the crop.

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Plate 1. Cultivar "Tai So"

Plate 2. Cultivar "Wai Chee"

Plate 3. Cultivar "Kwai May Pink"

Plate 4. Cultivar "Salathiel

Plate 5. Marcots or air-layers

Plate 6. Pruned orchard in Australia

Plate 7. Fruit borer in Australia

Plate 8. Erinose mite

Plate 9. Fruit harvest in China

Plate 10. Quality assurance in Australia