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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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FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS
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TABLE OF CONTENTS

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.

R.B. Singh
Assistant Director-General
and FAO Regional Representative
for Asia and the Pacific

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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^{o}S) at 400 to 700 m. The area has average temperatures of 22^{o} to 31^{o}C, 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^{o}S) 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^{o}S). 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

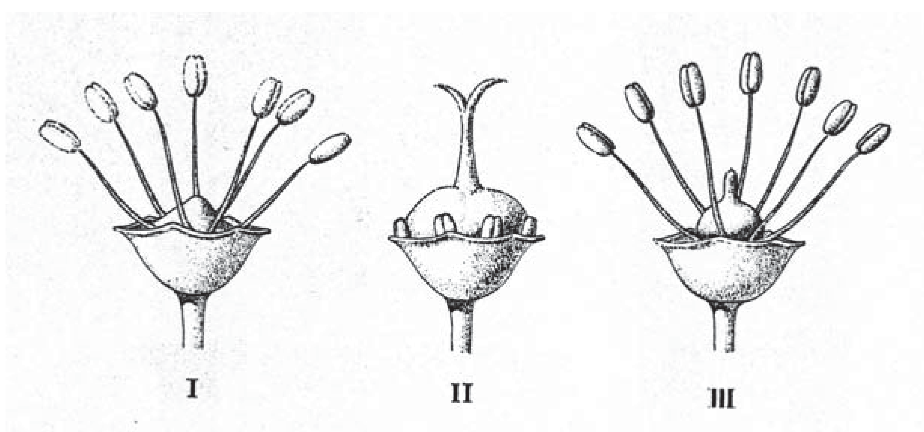
Lychee is a long-lived, evergreen tree up to 30 m tall in old specimens, with a short stocky trunk. In some cultivars, the branches are crooked or twisting and spreading forming a crown broader than high, while in other cultivars, the branches are fairly straight and upright forming a compact, rounded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

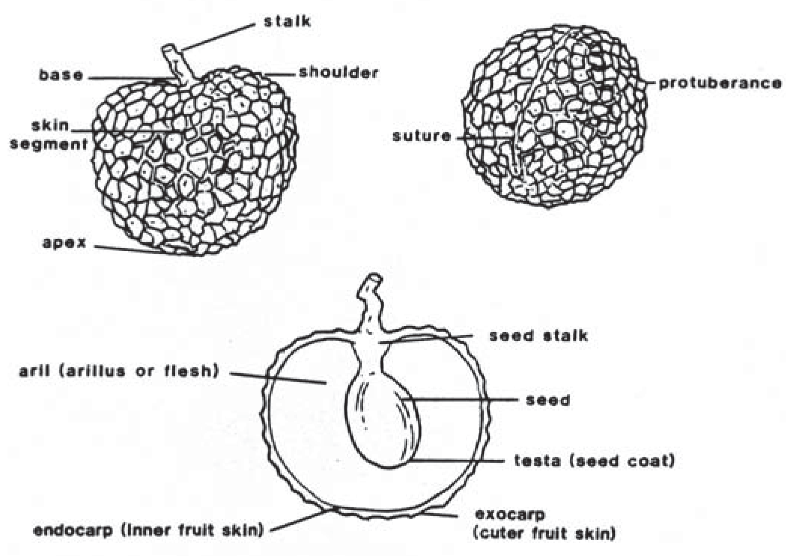
Figure 2. Flower types (♂,♀ and ♂).



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^{o}C 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.

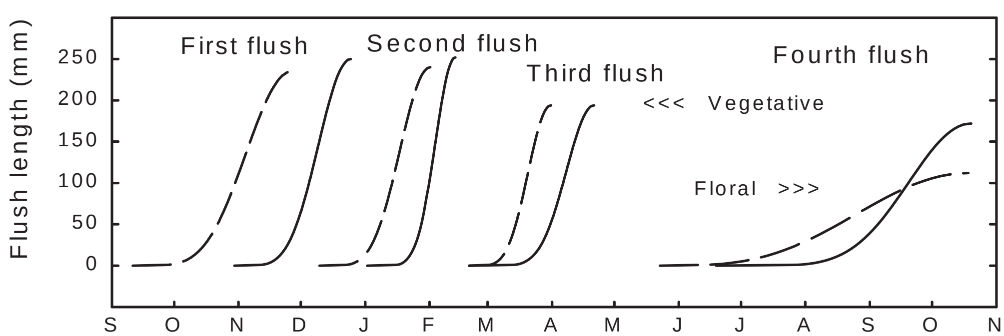
High-yielding trees typically have one or two leaf flushes after harvest, followed by a floral one in winter, if cool weather occurs during early bud development. In southern Queensland, the main period of leaf growth occurs from January to March for early cultivars such as "Tai So" and from March to 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.

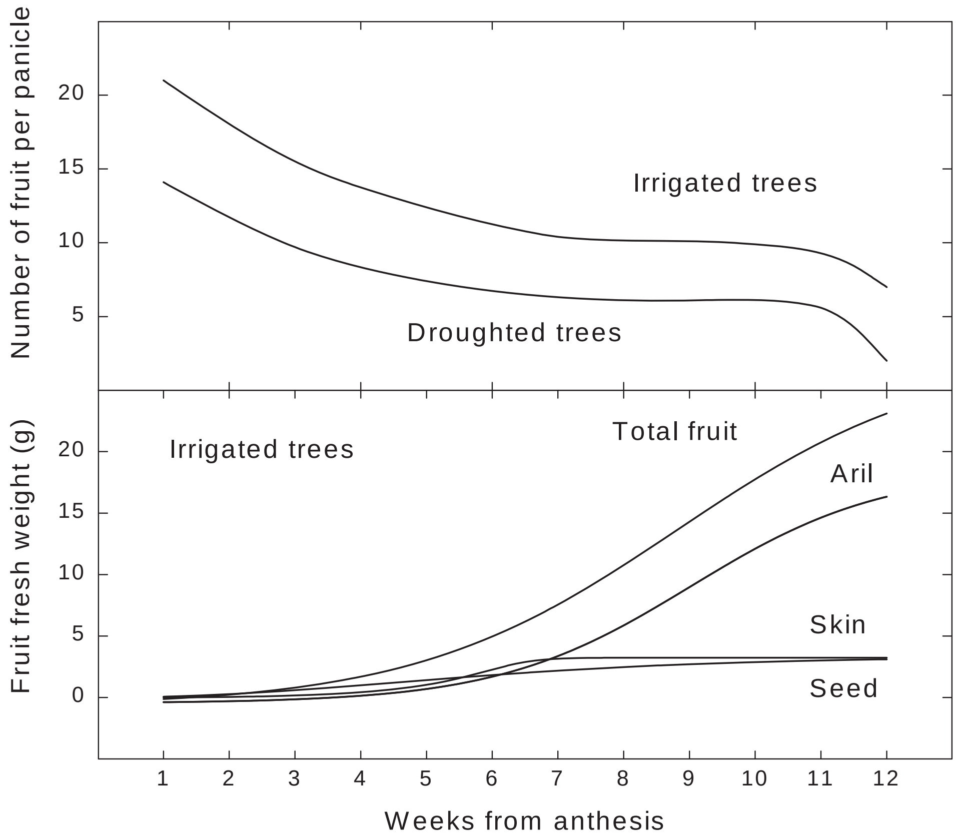
3.1.6 Fruit disorders

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^{o}C and rainfall 49 mm compared with 20.5^{o}C and 43 mm for the middle 10 days of the month and 21.9^{o}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^{o}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^{o}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^{o}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^{o} to 33^{o}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^{o} to 22^{o}C, with maximum fertilization obtained after seven days. At 15^{o}C, pollen tube elongation was strongly inhibited. However, from 15^{o} to 27^{o}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^{o}C, all female flowers abscised, suggesting a limitation for good yields when days are above 30^{o}C for long periods.

In southern Queensland, the proportion of female flowers that set was greater with later flowering when the maximum was 30^{o}C than with earlier flowering when the maximum was 24^{o}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^{o}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^{o}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^{o}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^{o}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^{o} (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^{o}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).

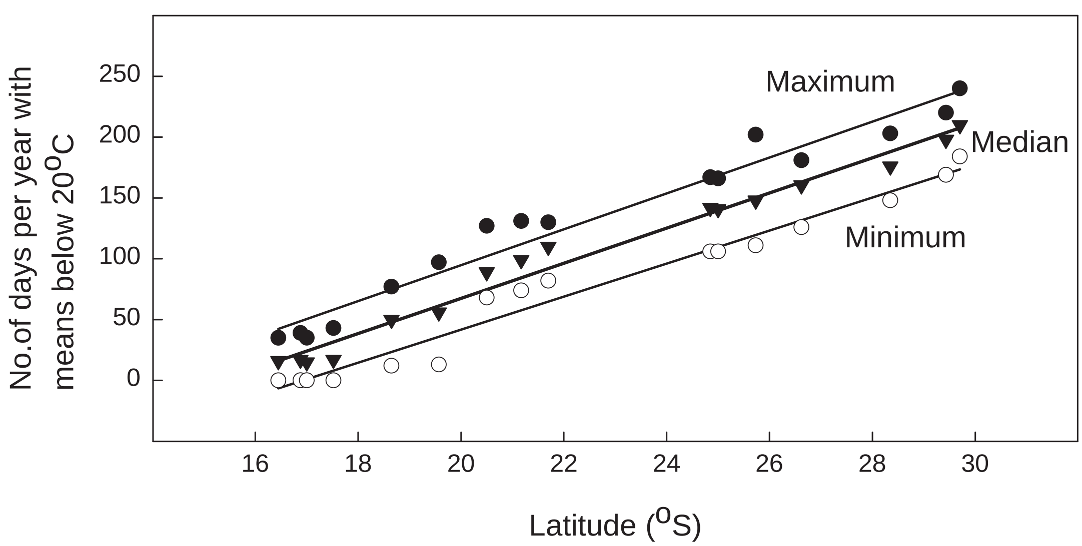


Figure 7. Relationship between average temperatures in July and latitude along eastern Australia.
(Latitude varies along 2,000 km of coastline. Data from Menzel et al. 2000).

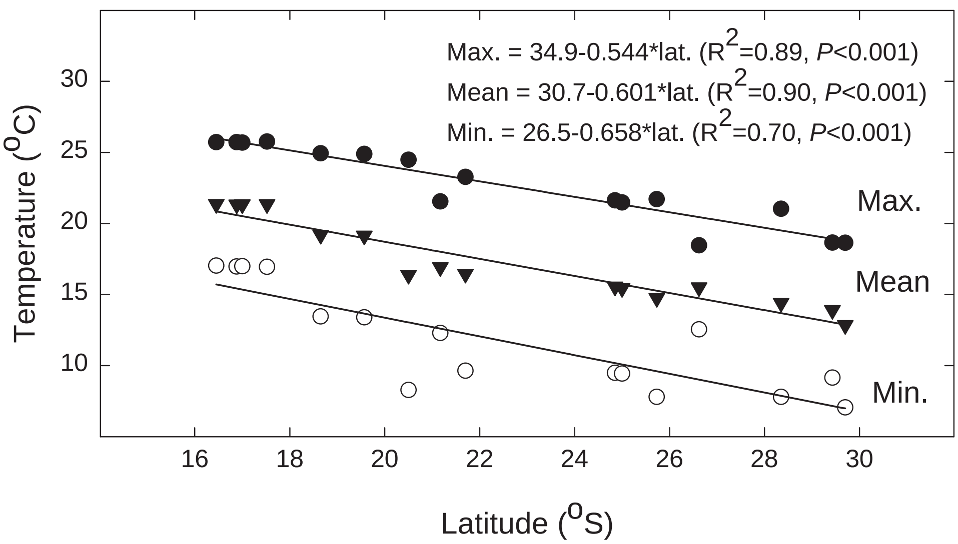


Figure 8. Relationship between number of days per year with means below 20°C, and mean daily temperature in July in eastern Australia.
(Data from Menzel et al. 2000. Mean temperatures in July have been calculated from Figure 7).

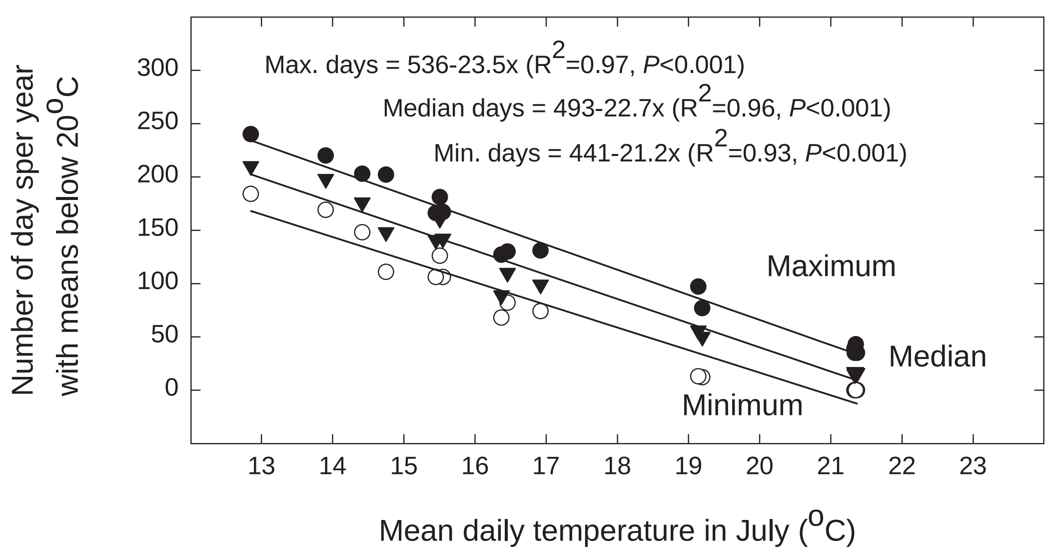


Figure 9. Relation between temperature in January and elevation at a tropical location (latitude 12^o).
(Analyses from McAlpine et al. 1983).

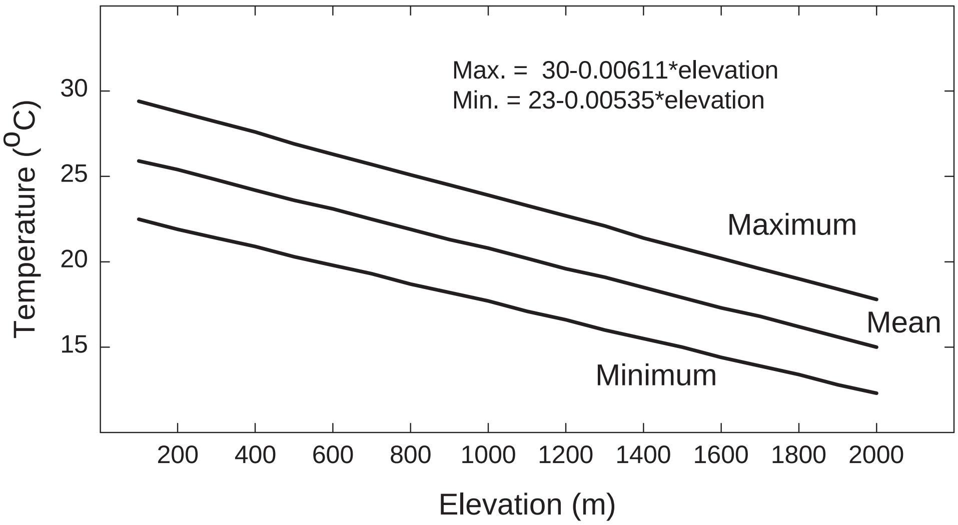
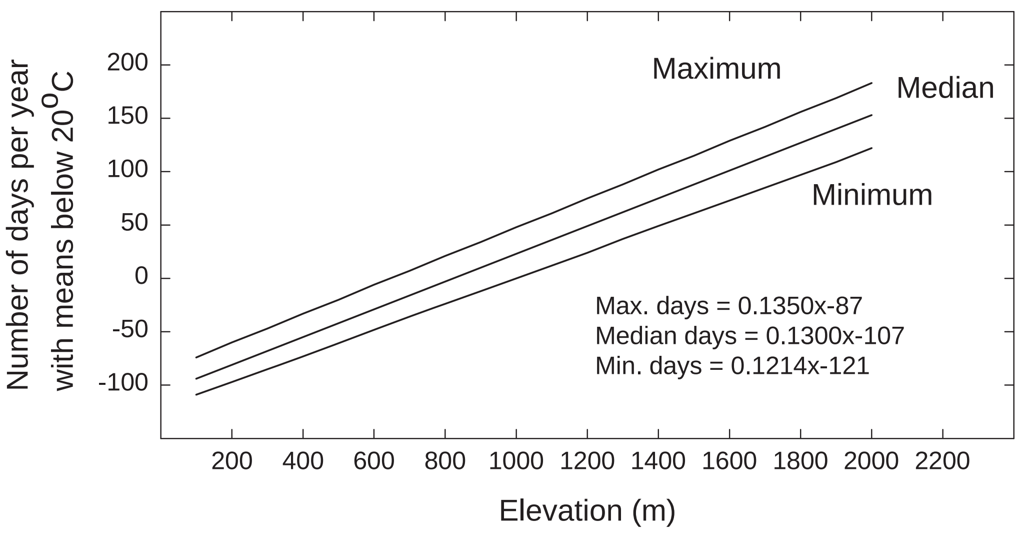


Figure 10. Relationship between number of days per year with means below 20^{o}C, and elevation at 12^o latitude.



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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