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 Hsiao 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.
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”.

Table 5. Standard names for cultivars in Australia.

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

(“Kwai May Pink” grown in Australia is not known as a separate cultivar in China. “Tai So” is similar to “Mauritius” in many countries).
4.4.4 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”.
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.

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

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 discolor, 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” (“Muzzaffarpur”, “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 subtropical 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.

Bibliography


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°C to 30°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° to 25°C and roots at 30° to 32°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).

Bibliography


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°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.
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 “Kuai 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.

<table>
<thead>
<tr>
<th>Tree</th>
<th>No. leaves per tree</th>
<th>Total leaf area (m² per tree)</th>
<th>Canopy surface area (m² per tree)</th>
<th>RLAI</th>
<th>SLW (g m⁻²)</th>
<th>No. fruit per tree</th>
</tr>
</thead>
<tbody>
<tr>
<td>One</td>
<td>2730</td>
<td>11.8</td>
<td>23.6</td>
<td>0.50</td>
<td>120</td>
<td>474</td>
</tr>
<tr>
<td>Two</td>
<td>3135</td>
<td>15.3</td>
<td>31.7</td>
<td>0.48</td>
<td>134</td>
<td>558</td>
</tr>
<tr>
<td>Three</td>
<td>3453</td>
<td>15.4</td>
<td>32.0</td>
<td>0.48</td>
<td>125</td>
<td>563</td>
</tr>
<tr>
<td>Four</td>
<td>4021</td>
<td>20.5</td>
<td>31.3</td>
<td>0.66</td>
<td>113</td>
<td>252</td>
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<td>Five</td>
<td>4603</td>
<td>18.7</td>
<td>33.3</td>
<td>0.56</td>
<td>121</td>
<td>518</td>
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<td>Six</td>
<td>4753</td>
<td>20.9</td>
<td>28.9</td>
<td>0.72</td>
<td>135</td>
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<td>Seven</td>
<td>6168</td>
<td>25.6</td>
<td>33.1</td>
<td>0.77</td>
<td>135</td>
<td>712</td>
</tr>
<tr>
<td>Eight</td>
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<td>51.1</td>
<td>0.76</td>
<td>123</td>
<td>956</td>
</tr>
<tr>
<td>Nine</td>
<td>8227</td>
<td>40.4</td>
<td>48.4</td>
<td>0.83</td>
<td>110</td>
<td>1321</td>
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<td>Ten</td>
<td>9138</td>
<td>33.6</td>
<td>53.2</td>
<td>0.63</td>
<td>134</td>
<td>1274</td>
</tr>
</tbody>
</table>

(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 halfway 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; NO₃-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 NO₃-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 CO₂ 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).

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

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 m². 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 m² 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.

<table>
<thead>
<tr>
<th>Nutrient</th>
<th>Product</th>
<th>Soil application (g per m²)</th>
<th>Foliar application (g per litre)</th>
</tr>
</thead>
<tbody>
<tr>
<td>B</td>
<td>Solubor</td>
<td>2</td>
<td>2.0</td>
</tr>
<tr>
<td>Zn</td>
<td>Zinc sulphate</td>
<td>25</td>
<td>1.0</td>
</tr>
<tr>
<td>Cu</td>
<td>Copper sulphate</td>
<td>4</td>
<td>2.0</td>
</tr>
<tr>
<td>Fe</td>
<td>Ferrous sulphate</td>
<td>10</td>
<td>5.0</td>
</tr>
<tr>
<td>Mn</td>
<td>Manganese sulphate</td>
<td>5</td>
<td>2.5</td>
</tr>
</tbody>
</table>

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).

<table>
<thead>
<tr>
<th>Time of year</th>
<th>Years 4-6</th>
<th>Years 7-15</th>
<th>Years 15+</th>
</tr>
</thead>
<tbody>
<tr>
<td>May-June (pre-flowering)</td>
<td>120</td>
<td>200</td>
<td>400</td>
</tr>
<tr>
<td>July-September (flowering)</td>
<td>400</td>
<td>600</td>
<td>1,200</td>
</tr>
<tr>
<td>October-February (fruit growth)</td>
<td>500</td>
<td>800</td>
<td>1,500</td>
</tr>
<tr>
<td>March-April (leaf growth)</td>
<td>400</td>
<td>600</td>
<td>1,200</td>
</tr>
</tbody>
</table>

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.

Bibliography


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 *Argyroplece 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 *Trichogrammatoidae 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. *Platyplus 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, *Uracanthis 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 overwinter 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 *Ooencyrtus* 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 *Ooencyrtus 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,
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 debilitating 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 mercaptophion. 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° to 25°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 gloeosporioides*, 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.

### Bibliography


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 \( \text{O}_2 \) and 3 to 5 percent \( \text{CO}_2 \) 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° 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 \( \text{O}_2 \) and 3 to 5 percent \( \text{CO}_2 \) 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

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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 O₂ and 3 to 5 percent CO₂ 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.

Bibliography


