In that these restrictions change as new laws are enacted, the state department of agriculture or forestry should be recontacted to determine the latest regulations that are in effect. Several state laws concerning *Ribes* are under reconsideration or revision in 1990. New Jersey's revisions are retaining strict control. Wisconsin may repeal their regulation. These tables are presented as guidelines in an effort to make the reader more aware of regulations concerning *Ribes* germplasm movement.

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Performance and Improvement of Lychee Cultivars: A Review

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Abstract

The lychee (*Litchi chinensis* Sonn.) is native to southern China where it has been cultivated for thousands of years and undergone intensive selection. The main cultivars in China include Wai Chee, Souey Tung and Haak Yip. In other countries, the lychee industries are generally based on only a few cultivars, which are nearly all of Chinese origin, e.g. Haak Yip in Taiwan; Tai So and Wai Chee in Thailand; Tai So in South Africa, Mauritius, Malagasy Republic and Reunion; Tai So and Brewster in Hawaii and Florida; and Tai So, Bengal (from India), Kwai May Pink and Wai Chee in Australia. The only exceptions are in India and in southern Thailand, where local seedling selections of Chinese cultivars are exploited. Seedling cultivars developed in the last 50 years which are becoming increasingly important include Sah Keng (Taiwan), Kaimana (Hawaii) and Salathiel (Australia).

Lychee cultivars differ greatly in vegetative flushing patterns, flowering, yields and fruit quality. Opportunities exist for improving lychee productivity by selecting seedlings from controlled pollination to combine superior characteristics of individual cultivars and possibly closely related members of the *Sapindaceae* family.

The lychee (*Litchi chinensis* Sonn.) which belongs to the *Sapindaceae* or soapberry family originated in southern China and possibly in northern Vietnam and the Malay Peninsula. Lychee trees grow wild in abundance on Hainan Island near northern Vietnam mainly at an elevation of 600-800 m, and below 500 m in hilly areas in Leizhou Peninsula, in the west of Guangdong and the east of Guangxi. The natural distribution of wild lychee is from south of Shiwan Mountains, Liu Wan Mountains, Yunkai Mountains

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to Hainan Island. Wild lychees are a major species in several lowland rainforest areas on Hainan Island and may account for 50% of the virgin forest composition (14, 25, 29).

The first official recording of lychee in China appeared in the 2nd century BC, while unofficial records date back to 1766 BC (22). A "Lychee Register" indicated that there were 16 cultivars in Guangdong by 1034 and 30 in Fujian by 1059 (1). These figures had climbed to 100 by 1076 in Guangdong and a similar number, somewhat later (1597) in Fujian. There is mention of cultivars in scientific literature before this time (3rd, 4th and 9th century), but morphological description were not provided until the 11th century (1, 22), and the first detailed description did not appear until 1612 (1). The Chinese lychee growers could distinguish the best types for cultivation on the plains, hills or levee banks by the 2nd century BC, but there is no indication of how, when or why they selected certain selections. Certainly, better cultivars could not be disseminated before clonal propagation became available (air-layering in the 4th century and grafting in the 14th century). Propagation by seed, however, continued for sometime, but was eventually eliminated by the 16th century.

Some cultivars in China have a very long history of cultivation, while others are relatively new (1). It is reported that cultivars such as Sum Yee Hong, Haak Yip, Kwai May, No Mai Chee, Wai Chee and Seong Sue Wai have a history of 500-600 years or more, while others such as Bah Lup, Heong Lai and Tim Naan date back 200-300 years ago. Souey Tung is a relatively young cultivar (about 100 years old).

The lychee was introduced to the tropical and subtropical world from the end of the 17th Century and now is found situated within 15-35° latitude in most countries (9, 21, 45, 72). Large commerical industries have developed in Taiwan, Thailand, India, Malagasy Republic and South Africa. There is substantial interest in the crop in Australia, Mauritius, Reunion, Spain, Bangladesh, Vietnam and The United States. There are collections of lychee cultivars in several of the lychee-growing areas of the world. The major collections are in China, Taiwan, Thailand, Australia and U.S.A. (Florida and Hawaii).

The Chinese claim that lychee has more cultivars than any of their fruits. A monograph on lychee cultivars written by Ts'ai Hsiang in 1059 is considered the first publication in the world devoted to fruit culture (1). Despite the large number of lychee cultivars available, only about 15 are exploited commercially in the lychee growing districts in China (2), while in other countries such as South Africa and Mauritius, commercial plantings are based on a single cultivar (35). The lychee crops best in warm subtropical climates with short cool, dry frost-free winters and long warm, wet and humid summers (51, 52). It has a narrow environmental range, and most cultivars do not bear successfully in a range of environments. Because of this narrow ecological adaptation, lychee cultivars must be closely matched to their environmental range to obtain consistent yield (23).

This review describes the performance of the major lychee cultivars in different countries. It indicates that opportunities exist for increasing lychee production by the development of new cultivars. Traditional methods of chance seedling selection for improved genotypes and multiplication of new cultivars are likely to be replaced in the near future.

Standardization of Cultivar Names

A large number of lychee cultivars are grown around the world. However, the same cultivar may be known under several different names in different places (even within a given country). This leads to confusion amongst re-

Table 1. Recommended standardized names for lychee cultivars grown in Australia and names used in other lychee growing countries (6, 12, 35, 59, 64, 76, 82, 84). Other Australian cultivars are Bengal (ex Fla), Hong Kong (origin ?), Salathiel (local selection) and Gee Kee (origin ?).

Recommended name in Australia*	Current official Pinyin name	Taiwan	Thailand	South Africa	U.S.A.
Sum Yee Hong (Third month red)#	San Yue Hong	Sun Yueh Hong			
Souey Tung (East of waterways)	Yuan Zhi	Kwang Tung			
Bah Lup (White wax lychee)	Bai La				
Tai So (Big crop)	Da Zao		Hong Huey Maw Mong	H.L.H Mauritius	Kwai Mi (Charley Tong)
Jin Feng (Tribute)	Jin Feng				
Fay Zee Siu (Concubine laughing)+	Fei Zi Xiao	Yu Her Pau			
Haak Yip (Black leaf)	Hei Ye	Hak Ip			Hak Ip
Kwai May Red (Cinnamon flavour)+	Gui Wei	Kwai Mi			
No Mai Chee Glutinous rice grain)	No Mi Ci	No Mai Tsz			
Heong Lai (Fragrant lychee)	Xin Xing Xiang Li				
Tim Naan (Sweet cliff)	Tian Yan				
Kwai Lok (Hanging green)	Zheng Cheng Gua Lu				
Wai Chee (Cherished lychee	Huai Zhi	Kwai Li	Kim Cheng	Sweetcliff	
Secong Sue Wai (President of the board embraces)	Shang Shu Huai				
Soot Wai Zee (Snow white lychee)	Xue Huai Zi				

*Names used in this paper (meaning of name in parenthesis). In order of fruit maturity.
#Known previously in China and Australia as Yook Ho Pow.
Known previously in Taiwan and Australia as Yook Ho Pow.
+Kwai May Pink grown in Australia is not known as a separate cultivar in China.

Table 2. Reasons for low lychee yields in different countries.

Country	Reasons for low yields	Reference
China	poor floral induction due to mild winters (Guangdong). poor fruit set due to cool damp springs (Fujian). excessive fruit drop and biennial bearing due to poor nutrition.	5, 57, 78
Thailand	poor floral induction due to mild winters (mainly tropical areas).	11
India	poor fruit set/retention in hot dry springs. biennial bearing due to poor nutrition.	62, 78
Australia	poor floral induction due to mild winters (all districts). excessive male flowering (S. Qld). poor fruit set in hot/dry springs (S. Qld). poor fruit set in cool/damp springs (NSW).	59
USA	poor floral induction (Fla. and Hawaii). frost damage (Fla.)	63, 82

searchers, advisors, growers and nurserymen (6). The spelling or standardization of lychee cultivars has been recently reviewed in Australia (6, 76). The spelling of cultivars cited in this review and equivalent names in various countries are indicated in Table 1.

Classification of Lychee Cultivars

Chinese researchers have discovered that the shape of skin segments and protuberances are a reliable and stable genetic characteristic and less variable with changes in climate, soil type or tree management than fruit size, shape or taste (1). They have suggested that the wild lychee is similar morphologically to the commercial cultivars, in particular the Jin Feng types. Wild lychee may have evolved in two directions, the skin segments becoming flat (eg. Sum Yee Hong, Haak Yip, No Mai Chee and Wai Chee), or protruded and lengthened (Tai So and Kwai May). An index to the taxonomy of Chinese lychee cultivars based on the type of skin segments and protuberances is given in Table 3.

Productivity of Lychee Cultivars

Vegetative Growth and Flowering

Lychee cultivars vary greatly in their vegetative flushing patterns and flowering abilities. In subtropical Australia, high vigour cultivars such as Tai So, Brewster and Bengal tend to flush vegetatively more than once after harvest at the expense of panicle and flower initiation (56). In contrast, low vigour cultivars such as Kwai May Pink, Salathiel and Wai Chee tend to be less vegetative and flower more consistently. These field observations have been confirmed by results of contolled-temperature experiments which showed that there was an inverse relationship between the flowering ability of the cultivars at 15°C day/10°C night and 20/15°C and their vegetative growth at 25/20° and 30/20°C (58).

The importance of vegetative flushing on panicle initiation and flowering is also emphasized in the Chinese, Hawaiian and Florida literature (51, 57, 78). In China, lychee trees can initiate floral buds on either the first or second flush produced after harvest provided the second flush does not occur after mid-October (78). Once again, vigorous cultivars are more likely to flush after this critical period. The timing of flushing is critical because it determines the time of flowering in spring (78). Early flowering during cold damp weather may reduce fruit set.

Menzel and Simpson (58) also showed that lychee cultivars varied in the type of panicles produced under inductive and marginal flowering tem-

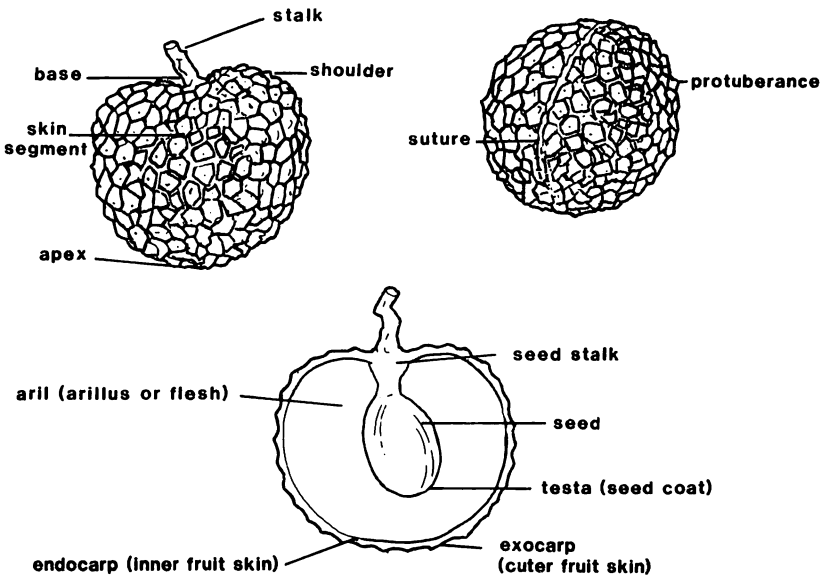

Figure 1. Internal and external features of lychee fruit (1).

perature conditions. More leaves were formed on the panicles of trees growing at 20°C day/15°C night than at 15/10°C, and cultivars that were vigorous at high temperatures produced more leafy panicles at low temperatures. The extreme case was a single flower at the end of a vegetative flush shoot.

Differences in the length and spread of panicles and the number of floral branches amongst lychee cultivars have also been recorded in the field (52). Long and multiple branched panicles generally have more flowers. In fact, there was a good correlation between flower number and panicle weight in lychee cultivars in subtropical Australia (C. M. Menzel and D. R. Simpson, unpublished data, 1987).

Fruiting

Anthesis in China and Hawaii corresponds with the rainy season, while in South Africa, Florida and Queensland, the reverse is true (52). Under very dry conditions, the young flowers may dehydrate and fail to develop. In subtropical Queensland, these dry conditions mainly affect the early maturing cultivars such as Tai So. The later maturing cultivars such as Salathiel and Wai Chee normally flower during more humid weather (13, 56).

Chadha and Rajpoot (8) demonstrated that initial fruit set in several Indian cultivars was high, although varietal differences were marked. There was a definite correlation between fruit set and sex ratio. Calcutta Late, which had the highest proportion of female flowers (48.7%) had the highest fruit set (23.2% of flowers setting fruit), while Dehradun, which had the lowest fraction of female flowers (19.8%), had the lowest fruit set (8.0%). When the difference in sex ratio was taken into account there was only a slight effect of cultivar on fruit set (47.6 and 40.3% for Calcutta Late and Dehradun, respectively). In other studies in India (19), there was no consistent relationship between fruit

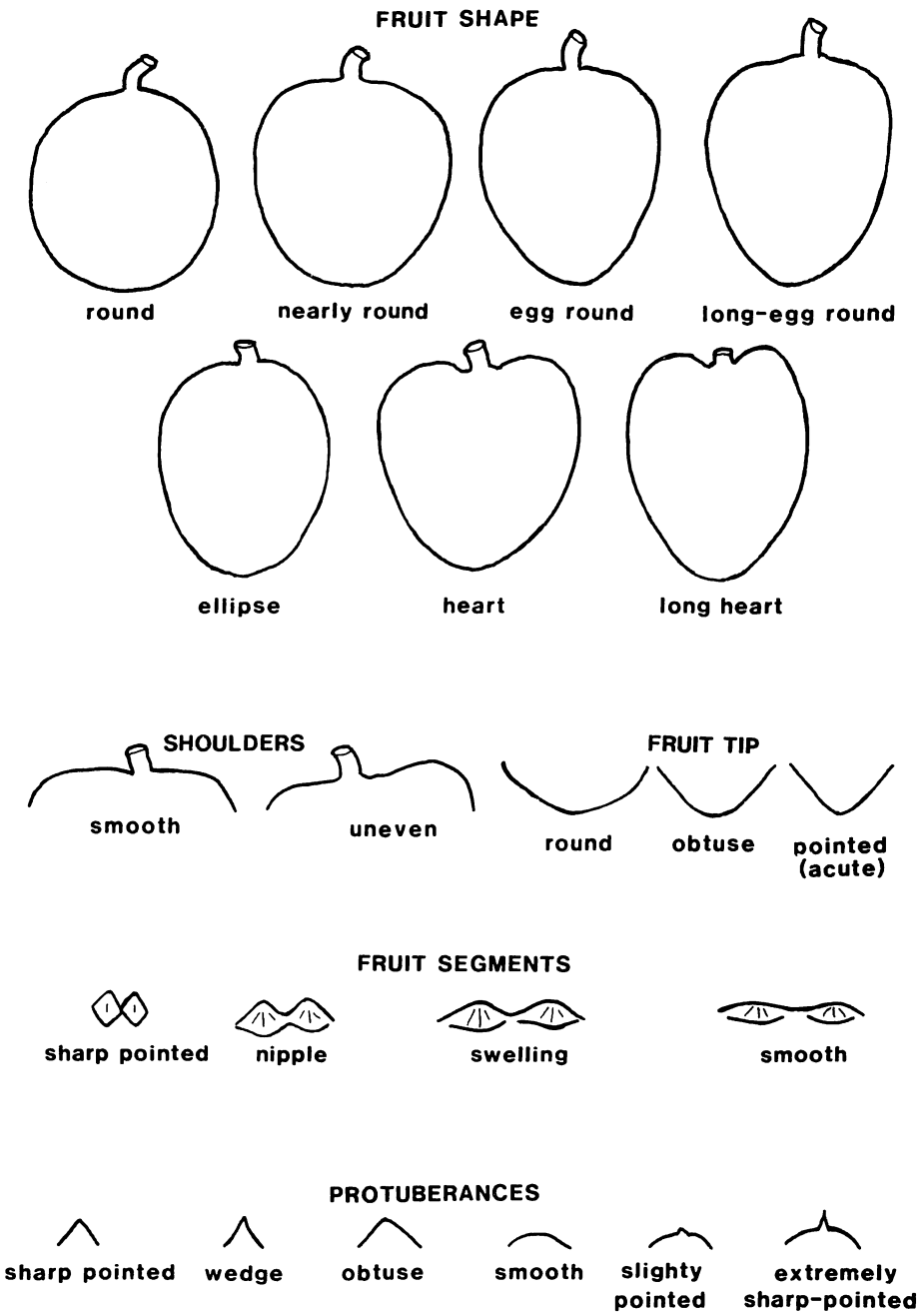

Figure 2. Variation in shape of fruit, shoulder and tip of fruit, fruit segments and protuberances of lychee cultivars (1).

set and number of flowers (male and female) on a panicle in 5 varieties. Sex ratios were not presented. Menzel and Simpson (58) showed that the cultivar with the highest proportion of female flowers (Salathiel) has the most consistent fruit set in subtropical Australia, while the one with the lowest proportion of female flowers (Kwai May Red) is notorious for setting few fruit per panicle (56).

Joubert (32) in South Africa, who probably worked with the H. L. H. Mauritius strain of 'Tai So' described 3 stages of fruit growth in lychee that were based on average fruit composition according to fresh weight: (1) development phase of the skin, embryo and testa of about 7-8 weeks after fertilization; (2) development phase of the cotyledons and beginning of aril development of approximately 2-3 weeks; and (3) development phase of the aril of about 5-6 weeks. Investigations with other cultivars (13, 30, 52) have been compatible with Joubert's findings. The only exception was found by Yen (83) who studied the fruit growth in normal and small seeded fruit of the Taiwanese cultivar Sah Keng. The seed grew rapidly in the early stages of fruit growth and the normal and small seeded fruit could not be distinguished macroscopically until about 30 days after full bloom. The volume and weight of normal seed increased continually and attained full size about 50 days after full bloom, whereas the aborted seed grew slowly and ceased about 40 days after full bloom.

In lychee, far more fruit are set than develop to maturity, and quite a number of investigations on this subject have been reported (36, 52). In India, Calcutta retained 43.1% more fruit on a panicle than 'Early Seedless,' and this was associated with a greater total production in the former (Singh and Lal, 1980 cited in 52). In Florida, fruit drop was less severe in Brewster compared to Haak Yip, Kwai May and Wai Chee (52). The early-maturing and more vigorous Tai So seemed to drop more fruit than the late-maturing and less vigorous Wai Chee in dry weather in southern Queensland, because it sets fruit earlier during the driest conditions (C. M. Menzel and B. F. Paxton, unpublished data, 1982).

Yuan and Huang (85) studied the pattern of fruit drop in Wai Chee (full seeded) and No Mai Chee (aborted seed) lychee. There were four waves of fruit drop. Wave I occurred one week after full bloom and was associated with lack of fertilization of the ovary. Wave II occurred around the third week after full bloom before liquid endosperm had fully developed. Wave III occurred 6-7 weeks after full bloom before the start of embryo development. Wave IV was specific to aborted-seeded cultivars and occurred prior to harvest. They concluded that a so-called critical period beyond which fruit do not abscise only applies to normal seeded fruit.

Fruit cracking is common in many lychee growing areas. eg. India (37, 39), South Africa (32) and Australia (56). Any stress that induces a check in growth of the fruit during the early period of cell division in the skin is likely to be followed by a period of skin cracking as the fruit rapidly increase in size before harvest (52). Most of the cultivars in India are susceptible to skin cracking (64, 66-69). The absence of cracking in the cultivar Hong Kong was attributed to delayed fruit initiation and late development outside the critical period of high temperature that induced cracking in other cultivars. The incidence of cracking in other cultivars was less in those with round flat shaped fruit, thin skin and fewer protuberances (40). In Australia Tai So is more susceptible to cracking than Bengal, Kwai May Pink, Haak Yip and Wai Chee (56).

Table 3. A key to the major classes of Chinese lychee cultivars (modified from 1).

A. The protuberance are protruding and hard.

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

2. The protuberances are large, sharp and short pointed. The skin segments are small and regularly arranged .... 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 .... 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. .... 4. Sum Yee Hong type.

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

C. The protuberances are smooth or not evident.

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

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

Yield

The average yield of lychee orchards in China is only 1.6-2.9 t/ha (78). Not all the trees are of bearing age and many of the orchards are neglected. A well managed orchard can produce 10-45 t/ha in an 'on year.' Mature trees may produce 150-250 kg of fruit.

There is a paucity of published records of the yields of lychee cultivars from replicated trials. Jawanda and Singh (31) indicated that average yields of 10 lychee cultivars in India ranged from 12-130 kg/tree (2-6 trees for each cultivar). The highest yields were obtained from Calcutta followed by Seedless Late, although the former cultivar is prone to biennial bearing. These authors did not indicate why certain cultivars were high yielding.

Menzel et al. (54) grew four lychee cultivars in a replicated trial in Nambour in subtropical Australia. Yields after eight years varied from 0.1-28.5 kg/tree (equivalent to a maximum of 6.6 t/ha at a density of 230 trees/ha). Wai Chee was superior to Gee Kee under all conditions and to Bengal and Tai So when flowering was reduced after warm wet winters or when fruiting was reduced during hot, dry springs. In other trials (C. M. Menzel and D. R. Simpson, unpublished data, 1989) yields of 6-10 year-old Tai So and Bengal trees (vigorous cultivars) were 28.8-40.0 kg/tree in "dry" sites (eg. Caboolture, Beerwah and Childers) in southern Queensland compared to less than 5.0 kg/tree in a "wet" site (eg. Nambour), because the trees in the "wet" site were prone to remain vegetative during winter.

Low and irregular production is a major problem in commercial lychee orchards around the world, possibly with the exception of Taiwan and South Africa (see Table 2). The reasons for low average yields varies with country and district. Biennial bearing is not normally a problem, except in

parts of China and India where orchards are neglected. Consequently, the main physiological reasons for low production are: poor floral induction (mild winters), poor fruit set in cool damp weather (poor pollination) or hot dry weather (fruit drop), or excessive male flowering.

Important Characteristics Used to Identify Lychee Cultivars

Harvest Season

The harvest season normally last 5-10 weeks for a range of cultivars in any one location (56). Cultivars can be broadly classified as early-, mid- or late-season. Cultivars with similar fruit-maturity may vary slightly in relative order from year to year, depending on seasonal conditions. There is also some variation in the relative order of maturity of cultivars in different countries, presumably due to differences in environmental or cultural conditions (56).

Tree Characteristics

A person can learn to identify cultivars using tree characteristics alone (4, 56). However, vegetative characteristics are very susceptible to environment and can change with climate, soil or cultural practices (22, 23). Some of the useful vegetative characteristics are tree size and shape, and length and spread of branches (34). For example, Brewster is vigorous, erect with very wide strong crotch angles (56); Tai So is vigorous with a spreading habit and sharp weak crotch angles; and Wai Chee is slow growing, compact and dome-shaped.

Leaf Characteristics

Some of the useful characteristics are leaf size, leaf shape, and colour of the new and mature growth flushes (22, 56). As examples, Tai So has large, glossy dark green leaflets that have an upward curl from the midrib to almost canoe-shaped. Bengal leaflets are large, mid-green in colour and have a distinctive twist along their length (56). A characteristic feature of Haak Yip is the dark glossy green colour of the leaflets. Leaflets are also long, narrow, pointed and slightly curled at the tip. The small leaflets of Wai Chee are oval-shaped and curve upwards from the midrib and down along their length. Colour of the new flush ranges from red in Wai Chee and Kwai May to green-bronze in Tai So.

Fruit Characteristics

The fruit shape of some cultivars is very distinctive (1, 22). The round shape of Kwai May Pink distinguishes it from the egg shape of Tai So or the heart shape of Haak Yip (56). The shoulders of the fruit can be smooth or flat (Wai Chee and Kwai May Pink) or uneven (Souey Tung and Bengal). The apex or tip of the fruit can be round (Kwai May Pink and Wai Chee), obtuse or blunt (Souey Tung and Brewster) or pointed (Bengal).

Skin Colour and Texture

Typical colours are bright red (Bengal), dull red (Wai Chee), purple red (Haak Yip) or pinkish red (Brewster). Skin thickness ranges from thick (Wai Chee, Bengal and Kwai May Pink) to thin (Haak Yip and Souey Tung) (1, 2, 22, 56). Skin segments at full maturity can vary from smooth (Haak Yip) to swelling (Wai Chee) to sharp pointed (Kwai May Red). Similarly, the protuberances on each segment can be smooth (Haak Yip), sharp pointed (Kwai May Red and Bengal) or hair-like and sharp (Tai So). The presence or absence of an obvious suture line can distinguish some cultivars, for example Haak Yip and Souey Tung (4).

Flesh Texture and Flavour

The texture, juiciness, taste and aroma of the flesh can aid the description of lychee cultivars, although experience is needed to make distinctions

(4, 22, 56). For example, the watery texture of Wai Chee, the firmer flesh of Kwai May Red, the spicy flavour of Kwai May Pink and the sweet flavour of Bengal can each be distinguished with experience.

Seed

The proportion of small or shrivelled seeds is an important characteristic, although it varies from season to season and orchard to orchard (56). Cultivars with a high proportion of chicken tongue seeds are favoured. In Australia, Salathiel consistently produces a high percentage of fruit with small seeds, while Bengal, Souey Tung, Haak Yip and Wai Chee produce hardly any shrivelled seeds. Other cultivars such as Tai So, Kwai May Pink and Kwai May Red vary in the amount of chicken tongues.

Major Cultivars in Lychee Growing Countries

The major lychee cultivars in different countries are indicated in Table 4.

China

Lychee trees are distributed in 7 provinces in southern China of which Guangdong and Fujian are the main producing areas followed by Guangxi, Sichuan and Yunnan. Guangdong produces about 65% of the crop. There are over 80 counties growing lychees in Guangdong, but lychee production is centered, in and around Guangzhou (1). The lychee ranks second after citrus as the most important fruit crop in Guangdong (12, 78). In Fujian, citrus and longan are more important. Yields of 10 t/ha are possible in well-managed orchards in Guangdong (78). Average yields are about 2 t/ha. Yields are lower in Fujian, where lychee is considered a poorer proposition.

There are more than 100 lychee cultivars in China probably because of the long history of cultivation and propagation of the crop by seed (11). Descriptions of lychee cultivars in China have been provided by Groff (21), Anon. (1) and Anon. (2). The last mentioned book indicated 26 major commercial varieties and presented a short description for each cultivar both in Chinese and English including geographical distribution, biological characteristics and economical evaluation. Each description is accompanied by a full colour plate. The most important cultivars in Guangdong and Fujian are Sum Yee Hong, Tai So, Chen Zi (Brewster), Souey Tung, Haak Yip, Fay Zee Siu, Kwai May, Wai Chee and No Mai Chee. Wai Chee accounts for over 50% of plantings in Guangdong and bears consistently because it flowers late and avoids the low temperatures of early spring. In Fujian, Haak Yip and Souey Tung dominate plantings (12, 14, 78). Other cultivars grown commercially include: Bah Lup (Pinyin: Bai La), Jin Feng, Chong Yun Hong (Zhuang Yuan Hong), Heong Lai (Xin Xing Xiang Li), Tim Naan (Tian Yan), Kwa Lok (Zheng Cheng Gua Lu), Seong Sue Wai (Shang Shu Huai) and Soot Wai Zee (Xue Huai Zi) (2).

In general, No Mai Chee and Kwai May are very highly regarded for excellent eating quality and a high proportion of chicken tongue (or aborted seed) fruit. Fay Zee Siu is also popular because of its excellent eating and its large size (24-32 g) fruit (12). Some culitvars are best eaten fresh, others are more suitable for canning or drying. Cultivars for export include Sum Yee Hong, Fay Zee Siu, Haak Yip, Kwai May, Wai Chee and No Mai Chee (14).

Taiwan

Lychee marcots, mainly Haak Yip and Chong Yun Hong (Pinyin: Zhuang Yuan Hong) were introduced into the northern part of Taiwan from mainland China in 1760 and again in 1860. However, commercial production did not begin until the late 1920's when further introductions of the main Chi-

Table 4. Major lychee cultivars in different countries (1, 7, 10, 11, 35, 59, 62, 64, 78).

Country	Production (tonnes)	Main growing areas	Major cultivars
China	61820	Guangdong	Wai Chee, Haak Yip, Sum Yee Hong, Kwai May and No Mai Chee
		Fujian	Souey Tung, Haak Yip, Tai So and Brewster
Taiwan	131000	Tai Chung	Haak Yip and Sah Keng
Thailand	8401	Chiang Mai, Lamphun and Fang	Tai So, Wai Chee and Baidum
India	91860	Bihar State	Shahi, Rose Scented and China
Malagasy Republic	35000	Wet coastal belt	Tai So
South Africa	5687	Transvaal-Lowveld Region	Tai So
Reunion	5000	Wet coastal/subcoastal areas	Tai So
Mauritius	1000	—	Tai So
Australia	15000	Eastern coastal strip	Tai So, Bengal, Wai Chee, Kwai May Pink and Salathiel
U.S.A.	40	Hawaii	Tai So and Kaimana
		Fla.	Brewster

nese cultivars were grown in southern areas away from strong winds of the Pacific Ocean (10).

Since the 1920's, lychee plants have been distributed to every district in Taiwan except the north where the weather during winter and spring is cold and wet. The major area of cultivation is the central and southern districts of the island, where there are large areas of alluvial sandy loam (Chung-Ruey Yen, personal communication, 1988). Yields are higher on these soils compared to those on the mountain slopes. Temperature and moisture conditions are ideal for satisfactory flowering during winter and mature trees may carry 500 kg of fruit in a season.

Haak Yip is the most popular cultivar and accounts for over 80% of plantings (11). Other important cultivars are Sum Yee Hong, Chong Yun Hong, No Mai Chee and more recently Sah Keng (83).

Thailand

Lychee ranks eleven in the list of economic fruit crops in Thailand (12). The main production centre is in the north at elevations of 300 to 600 m between Chiang Mai, Lamphum and Fang in a monsoonal climate with a distinct dry season (11, 12). Plantings have also been established in the more tropical humid high rainfall areas north of Bangkok, but flowering is more consistent and yields higher in the cooler elevated areas.

Although the lyche has a long history in Thailand, better cultivars from China were only introduced in the early 1950's (12). The main cultivars in the Chiang Mai area are Tai So and to a lesser degree Wai Chee, Baidum and Chacapat (12). A different set of cultivars has been developed for production in the tropical areas, including Luk Lai, Sampao Kaow, Kaloke Bai Yaow, Kom and Red China. Quality

of these seedling selections does not compare favourably to the cultivars grown in northern districts.

India

Lychee reached India through Burma about the end of the 17th century, and India now produces more lychees than China (38, 48, 61, 70). During the last 200 years, it has spread to several areas. More than 70% of the crop is produced in northern Bihar. Other lychee growing states include West Bengal (15%) and Uttar Predesh (6%).

Most of the lychee cultivars in India have been developed locally from seedlings from Chinese selections (18). Although a large number of lychee cultivars are grown (Singh, 1954 lists 33 cultivars), most of them are not widely planted. The same cultivar may be known under several different names in different places. However, few of the Indian cultivars appear to be renamed Chinese cultivars as has happened in Thailand, Hawaii and Australia. Hot and desiccating winds is the main factor limiting lychee cultivation in several districts and cultivars have been selected which can reputedly set and carry fruit under these adverse conditions (37, 62).

Of the 10 commercial cultivars growing in Bihar, Shahi (Muzaffarpur), Rose Scented and China are the most popular, due to their large fruit size and excellent quality (62, 62, 65, 74). Other important cultivars are Deshi, Kasba, Purbi, and Early and Late Bendana. The most popular cultivars in the Punjab are: Saharanpur (Early Large Red), Dehr Dun, Calcutta (Calcutta, Kalcuttia or Calcuttia Late), Shahi, Seedless Late (Late Seedless or Late Bedana) and Rose-Scented (48).

South Africa

There is evidence that lychee trees were imported into South Africa from Mauritius in the early 1870's (Davis 1928 cited in 49). From 1886 onwards, the Durban Botanical gardens distributed air-layers of those introductions within the country, mainly for planting in Natal (49). Commercial orchards are currently spread on the eastern boundary of South Africa from Levubu in the northern Transvaal, The Central and Southern Lowveld, Underberg/Malelane down to the North and South Coast of Natal (7, 33).

The commercial lychee industry in South Africa is exclusively dependent on a single cultivar, H.L.H. Mauritius, so named because practically all the trees throughout the country are clonal propagules from an original tree imported from Mauritius by H. L. Hood. This culitvar resembles the Chinese cultivar Tai So, and any differences in tree or fruit characteristics are very minor and not agronomically significant; it may be a seedling or sport of Tai So (35, 56). The main disadvantage with Tai So is its large seed. Because the industry is dependent on a single cultivar, the production season is unduly short at any location. However, fruit are normally available from the end of November to mid-February due to differences in environmental conditions in the different lychee-growing areas (49). Chinese and Indian cultivars have also been imported into South Africa but their performance and yield have been disappointing and none have been released for commercial cultivation (35).

Malagasy Republic (Madagascar)

The lychee arrived in Malagasy Republic from Mauritius in 1770. Production in 1987 was estimated to be about 35000t (Bertin, 1987 cited in 17) and is centered in the wet coastal belt (60). Mauritius (or Tai So) is the most important cultivar.

Mauritius

Lychee planting material was first introduced from the orient in 1764 and production in 1985 was about 1000t (17). The Mauritius lychee was selected from a seedling on the island

in the 1870's (43). Practically all the trees in Mauritius, Malagasy Republic and South Africa are clonal propagules from this tree.

Reunion

The lychee arrived in Reunion over 200 years ago from Mauritius. Annual production is about 5000t, of which about 10% is exported to France (16, 17). The main cultivar is Tai So (Mauritius).

Australia

The lychee was introduced into Australia by Chinese migrants over 100 years ago. They originally came to work the goldfields in northern Queensland and ate fruit and threw the seeds away. They did not go directly into agriculture or plant crops. Isolated trees of 80-100 years are found in these areas. Lychee plants (seedlings?) were growing in the Sydney Botanical Gardens in 1854 and in Brisbane by the late 1850's. Air-layers (Wai Chee) were not introduced until the 1930's. Plant material was subsequently distributed further along the coast and production now extends from Cairns and The Atherton Tableland in northern Queensland to Coffs Harbour in northern New South Wales (59). Tai So and Bengal are the main cultivars. This is because they were the only planting material readily available during the expansion of the industry in the early to mid 1970's (59). These cultivars have now lost favour and current expansion is mainly based on cultivars such as Kwai May Pink, Salathiel and Wai Chee (41, 56).

Hawaii

The first lychee (cv. Tai So) was brought to Hawaii in 1873 and was still growing in 1972 (28, 82). Other introductions were made by the Department of Agriculture and private individuals during the first half of the 20th century (73). Lychees are grown up to an elevation of about 500m and occasionally up to 1000m on the five major islands of Hawaii. Commercial plantings peaked during the late 1960's with about 25,000 trees and production of about 250t (average yield of 10kg/tree). About 20% of the crop was exported to the mainland. Production declined during the next decade because of low yields and quarantine restrictions with exported fruit (82). Since 1980, there has been renewed interest in the crop, mainly due to the availability of better cultivars and improvements in post-harvest technology.

Tai So is the only cultivar grown on wide scale (27, 28, 82). Fruit ripen from May to June. Because of the irregular bearing habit and short cropping season of Tai So, other cultivars have been tried, including Brewster, Haak Yip and Sweetcliff (similar to Wai Chee but different to Tim Nann or Sweetcliff from China) which were imported earlier in this century, and Kaimana which is a seedling selection of Haak Yip.

Florida

Southern Florida is well known as the centre of tropical fruit production in the U.S.A. (26). This is the result of an active plant introduction and research program. Florida's commercial lychee plantings reached a peak of about 130ha in 1957 but declined to less than half these figures in 1966 because of cold damage and urban expansion (63). Lychee production has been on a steady increase since 1975 when plantings shifted towards the less frost-prone southern areas. Many factors have contributed to the interest in lychee production including the search for alternative crops to avocado and limes, greater demand for exotics and the opportunity for higher returns.

Brewster has been the main lychee cultivar in Florida since the Reverend W. M. Brewster obtained air-layers of Brewster (or Chen Zi) from Fujian Province in 1903 (24, 25, 42, 63). There

are many orchards with mature trees 12m across. Brewster matures from mid-June to mid-July and has good colour and flavour.

Tai So (Mauritius) has become very popular in recent years and is more consistent in bearing compared to Brewster. However, it suffers from wind-damage. There is also the problem of limb breakage after ice-loading. Tai So matures about two weeks before Brewster. Other cultivars under evaluation include Sweetcliff (small fruit and susceptible to micronutrient deficiencies, especially Fe), Bengal (irregular yielding) and Haak Yip (47, 63).

Plant Improvement

The chromosome number of lychee has been reported as 2n = 28, 30, 32, or 34 (3, 15, 19). There is no information on the inheritance of any morphological or physiological character. Yang and Chen (79), however, did indicate that shrivelled seed was inherited in longan, *Euphoria longan*.

The genetic improvement of lychee to date has been by selection amongst existing cultivars, or selections amongst the open-pollinated seedlings from such cultivars. Most of the modern cultivars have been selected under Chinese conditions, although there have been small selection programs in Taiwan (84), Thailand (12), India (11, 62), South Africa (35), Florida (41), Hawaii (73, 82) and Australia (53). Most of these programs have been limited to small populations in the field, not exceeding 200 (53). The industries in India and southern Thailand are based on selections from seedlings of cultivars that were imported from China (11, 12).

Lychee breeding objectives include regular high yields, good tree structure, large fruit size, bright red skin colour, small seed size or seed abortion, and acceptable flavour and texture (39, 41). Other important characteristics include resistance to pest and diseases and extremes of environment, acceptable fruit ripening pattern, good storage life, and early or late fruit maturity to extend the production season.

New cultivars can normally be developed only from the selection of seedlings with improved characteristics (23, 53). Lychee seedlings from a single cultivar often resemble the parent tree in vegetative characteristics, but most are characterized by a long juvenile period (usually 5-10 years or more), irregular bearing and poor fruit quality (53).

Only a few cultivars have been developed in the last 60 years. These include Salathiel in Australia (56), Sah Keng from Haak Yip (?) in Taiwan (84), Peerless from Brewster (Chen Zi) in Florida (41, 75), Bengal from Purbi in India/Florida (47) and Groff and Kaimana from Haak Yip in Hawaii (27, 73). However, only Salathiel, Sah Keng and Kaimana warrant further attention. Peerless has watery flesh, Bengal has a very large seed and consequently poor flesh recovery, and Groff has very small fruit (12-15 g).

It is generally accepted that lychee flowers possess nectaries and require insects for pollination (52). Bagging inflorescences or screening trees virtually eliminates pollination and fruit set. Unpublished data by C. McConchie (1989) indicate that lychee cultivars are self fertile and most combinations of cultivars are cross compatible. There is usually a good supply of pollen within an orchard due to the overlap of male and female flowers and the release of pollen from individual male flowers over a 3-day period. Certainly, isolated trees or blocks of a single cultivar can set and carry large crops (35).

The development of better cultivars by traditional methods of plant improvement is very slow, because of the long juvenility of most seedlings and because less than 1.0% of those grown to date are worthy of selection.

Storey *et al.* (73), for instance, selected Groff out of a population of 500 open-pollinated Tai So, Brewster and Haak Yip seedlings, but these are not premium cultivars. Future efforts in plant breeding need to involve the cross pollination of selected cultivars with the most desirable traits. Yen et al. (84) had a population of 2500 seedlings from open- and controlled pollination. However, he did not indicate whether all the male flowers from panicles on the mother tree were removed to exclude the possibility of self-pollination. Controlled pollination was utilized to combine superior characteristics of individual cultivars and to overcome differences in flowering times between early and late cultivars that could not hybridize naturally. Haak Yip, Kwai May, Sah Keng and Wai Chee set the most fruit after controlled pollination and were considered more suitable as mother plants than other cultivars. However, no new cultivars have yet been released to the lychee industry in Taiwan. Experience from Australia indicates that even cultivars producing aborted or chicken tongue seed can be used as mother plants as it is possible to culture the young embryo in tissue culture (C. McConchie, unpublished data, 1989).

Menzel and Paxton (55) showed that the rate of shoot growth in 7 open pollinated lychee seedling lines (Bengal, Haak Yip, Kwai May Red, Gee Kee, Tai So and Wai Chee) was similar to the flushing ability of the parent cultivars in the field. This indicates that selfing of lychee cultivar which has undergone intensive selection in China is tolerant without inbreeding depression. Although the maternal trees were available for cross pollination, the overlap of flowering amongst the cultivars was probably small, so that most trees were probably self-pollinated.

Although the number of potential crosses may be the same in open and controlled pollination, the practical limitation of controlled pollination is a barrier to adequate progeny population size. However, the goals of the breeding program are likely to be achieved earlier with controlled pollination because the parentage of improved progeny can be identified for future crossing. The problem with open pollination, is that the parent lines of improved types that may be preferred for future breeding work cannot always be recognized from attributes of the seedling without a technique like izoyme analysis.

Seedling populations can use a lot of land on research stations. It has been suggested that the progeny of breeding/selection programs should be grown out on grower's properties, possibly as windbreak trees. To conserve space, the seedling trees can also be grown at close spacings but would still require large areas for an adequate population size. Storey et al. (73) planted their seedlings 2 m apart, in rows 2.9-2.5 m apart (equivalent to a density of 2000-2500 trees/ha). Standard densities are normally 70-280 trees/ha.

Top-working, growth retardant sprays and cincturing have been mentioned as possible ways to shorten the juvenility period (53, 84), but no recommendations are available. New methods of tissue culture also speed the multiplication rate of new cultivars (20, 46).

Wild plants have been sought for new germplasm in other subtropical trees (eg. avocado and mango), particularly as sources of disease resistance or dwarfing (65, 71); this approach may have potential to lychee improvement, as well. The *Sapindaceae* family contains more than 1000 species from 125 genera, mostly trees and shrubs, rarely herbs, with wide distribution in the tropics and warm subtropics (17, 21, 50, 67). The majority of species are native to Asia, although there are a few in South America, Africa and Australia.

Other cultivated species from the same family and sub-family (Nephelieae) in order of economic importance are longan *(Euphoria longan)*, rambutan *(Nephelium lappaceum)* and pulasan *(Nephelium mutabile)* (81). Lychee is related morphologically more to longan than any other species, but the former differs morphologically with the flowers not having petals and the fruit having distinct tubercles or protuberances on the skin. Lychee fruit are also generally larger have larger fruit and and smaller seeds, and are aromatic and more acid in flavour (50).

Groff and Liu (25) suggested that there was considerable scope for uitlizing the characteristics of some of the other members of the *Sapindaceae* family. Longan has been suggested as a useful source of cold/drought tolerance or resistance to erinose mite (41). The existence of a lychee x longan hybrid was once reported in China (22). Similar crosses have been attempted recently in Australia, but no successful hybrids developing to flower and fruiting stage have been reported.

The *Litchi* genus contains two other sub-species, *L. chinensis subsp. philippinensis* (kumingi), which developed in the Philippines and Papua New Guinea at high elevation and *L. chinensis subsp. javensis* which been recorded in the Malay Peninsular and Indonesia (44, 80). Neither of these wild forms is exploited commercially. Philippines lychee has long oval shaped fruit with long thorn-like protuberances. Fruit split in the middle when ripening. The aril only partly covers the seed and is not edible. *L. chinensis subsp. javensis* is a rare specimen in Chinese gardens in West Java and has fruit similar to the cultivated lychee, but the aril is thinner.

Conclusion

The lychee has a long history in southern China where it has undergone intensive selection. New cultivars have been selected from seedlings of these Chinese cultivars to exploit production in northern India, and more recently in southern Thailand. There has also been limited selection in Florida, Hawaii, Taiwan and Australia. With the possible exception of Taiwan (and more recently in Australia), most of these plant improvement programs have used seedlings from open- rather than controlled-pollination and results to date have been very discouraging. Controlled-pollination should be used in future breeding studies to combine superior characteristics of individual cultivars.

Market acceptance varies with the quality of the different lychee cultivars and fruit quality should be paramount in any breeding program. The aim is for large bright red fruit with small seeds and crisp sweet flesh. Fruit should also have an acceptable ripening pattern and storage life. The second aim of lychee improvement is high regular yields. However, there is a scarcity of published information on yields of lychee cultivars, either experimental or commercial. A priority of any research effort should be the collection of yields of cultivars across different environments over several seasons. In the few cases where yields have been collected, it is not always obvious why one cultivar outperforms another. Experience from southern China and to a lesser degree in Australia indicates that most lychee cultivars have limited environmental adaptation and very few cultivars will crop successfully in a range of environments. Research in Australia has also shown that high-yielding lychee trees follow a set pattern if vegetative flushing, flowering and fruiting during the year. The timing and level of these activities varies greatly with cultivar, orchard and year. Researchers and growers need to keep a record of vegetative flushing, flowering and fruiting cycles to gain an understanding of the performance of different lychee cultivars in different environments. It can be

concluded from Table 2 that vegetative vigour and timing of flower and fruit set are the main tree characteristics which determine yield in lychee and should have a high profile in a lychee breeding program.

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Spur vs. Standard 'Delicious' in Slender Spindle

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'Red Prince' (Standard) and 'Millersturdee Spur Delicious' on M.9 were compared over 12 years trained as slender spindles. 'Red Prince' had a 22% larger trunk cross sectional area than 'Millersturdee Spur' and produced 33% more fruit/tree. 'Red Prince' exceeded its 1.5m in-row spacing and required significant containment while 'Millersturdee Spur' never filled its alloted space. This study emphasized the importance of matching tree spacing with the growth potential of the scion-rootstock combination. It is estimated that 30% closer spacing of the spur type may be more efficient than coping with the significant containment pruning of the standard habit strain.

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