Lychee Biology and Biotechnology

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Abstract

Lychee (*Litchi chinensis* Sonn.) is one of the revered members of the soapberry family Sapindaceae which includes 150 genera and 2000 species. It is a tropical and subtropical fruit tree which is native to Fujian and Guangdong regions of China and is cultivated as an important commercial fruit crop in many parts of the world. It is famous for its fragrant and sugary flavour. After China, India is at the second position in the production of lychee in the world. The varieties with large pulp, small seeds and noteworthy flavour are of great interest among the consumers and farmers. Lychee fruit took tremendous attention of scientists as it contains ample amounts of anti-oxidants, vitamins and fibre. Moreover, the plant parts possess considerable anti-pyretic, anti-inflammatory, anti-cancer, anti-diabetic, anti-tumour and anti-oxidant properties. Propagation of lychee from seeds is difficult and not practicable because of longer juvenile period and non-viable, abortive and genetically diverse nature of the seedlings. However, the techniques such as cell, tissue and organ culture (micropropagation) can overcome the difficulties of lychee propagation. Very limited efforts have been made in its varietal improvement through hybridization and modern breeding techniques. In a nutshell, lychee is an important commercial fruit crop, and there is a need to develop technical research so as to sustain and enhance its yield, postharvest management, medicinal value and marketing. This chapter comprises of botanical description, cultivation, medicinal uses, micropropagation and trading of *Litchi chinensis*.

Keywords

Lychee • Subtropical fruit • Anti-oxidant • Lychee propagation • Hybridization

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5.1 Origin and History

Lychee (*Litchi chinensis* Sonn.) is one of the precious and economically important fruit crops of the world. The species belongs to the family Sapindaceae, which comprises about 2000 species of tropical and subtropical trees, shrubs and vines that have been classified into 140 genera (Chapman 1984). Lychee has been shown to possess variable diploid chromosome numbers where 2n = 28, 30, 32. The variation in chromosome number is thought to be because the modern species had more than one wild progenitor. Lychee cultivation was reported since 1500 BC by the people of Malayan descent and has been growing for thousands of years in southern Guangdong province of China. The first reference to this fruit is available in the literature of the Han dynasty (140 BC to 86 BC). It is sure that lychee is native of South China, but, according to Blume, Cochin-China and the Philippine islands are the lands of its origin (Popenoe 1920). It is also reported to have originated in China's Kwangtung and Fukien provinces and have been cultivated in China for about forty centuries (Ochse et al. 1961). A monograph written by Tsai Hsiang in 1059 AD is considered to be the first publication in the world devoted to this fruit. However, according to Walter T. Swingle, the first published work of fruit culture was written by a Chinese scholar in 1056 AD, on the varieties of lychee.

From China it reached Burma (Myanmar) by the end of the seventeenth century and was introduced in India about 100 years later. Lychee reached Madagascar and Mauritius around 1870 and was introduced in Hawaii in 1873 by a Chinese trader. It arrived in Florida, from India, between 1870 and 1880 and was introduced in California in 1897. Lychee was reported to be brought to Australia by Chinese migrants in 1954 and arrived in Israel sometime between 1930 and 1940. Presently, lychee is grown in Central and South America, parts of Africa and throughout Asia. China, India, South Africa, Australia, Mauritius, Madagascar and Thailand are now the major lychee-producing countries in the world.

5.2 Production

Lychee plantation requires a warm subtropical to tropical climate (Rivera-Lo'pez et al. 1999). Besides China and India, lychee fruit is also grown as a commercial crop in subtropical Asia, Hawaii, Israel, Mexico, Australia and South Africa (Jiang et al. 2001). India is the second largest producer of lychee after China with an annual production of 428,900 metric tons from 56,200 ha (Fig. 5.1). Lychee is mostly grown in Eastern India, and Bihar state alone contributes to 74% of Indian lychee production (Fig. 5.2). As lychee is an introduced fruit crop, it has great potential of yield in India. Figure 5.3 reveals a trend in the year-wise expansion in the area under lychee cultivation which has increased from 58,100 to 84,200 ha in 1991–1992 to 2013–2014 with a similar trend in the production from 355,900 MT to 585,300 MT in the last decades.

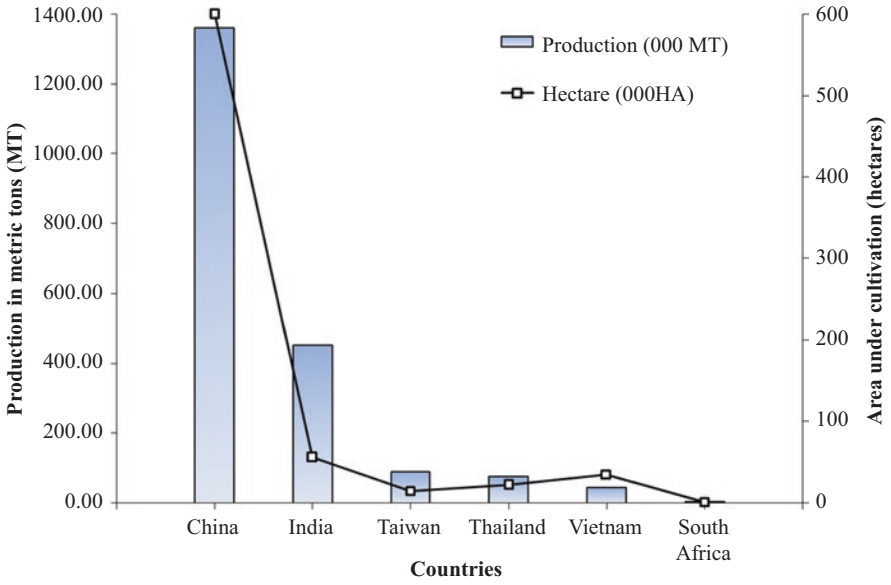


Fig. 5.1 World lychee production

5.3 Classification of Major Lychee Cultivars

The lychee (*Lychee chinensis* Sonn.) is a non-climacteric fruit of Southeast Asian origin (Nakasone and Paull 1998). It is covered by a pink or red leather-like pericarp due to the presence of anthocyanins (Lee and Wicker 1991; Rivera-Lo'pez et al. 1999) as shown in Fig. 5.4. When distinguishing the cultivars, the shape of fruit skin segments and protuberances are reliable and stable genetic characteristics (Fig. 5.5). Fruit size, shape and taste are also variables but are influenced by other than genetic factors. Chinese researchers report that the shape of the skin segments and protuberances are more reliable characteristics than fruit size, shape or taste, to identify cultivars. The lychee cultivars vary greatly in vegetative flushing patterns, flush colour and flowering ability. The leaf of the Rose Scented is boat shaped, while China has a distinctive twist along the length curved upwards from the midrib and down along its length. Small leaflets in Bedana are oval shaped. The fruit shape of lychee is very distinguishing. The round shape of Bedana is distinguished from oblong shape of China or Shahi. The fruit is smooth and pulp is even or uneven. The apex of the fruit can be round, obtuse, blunt as in Shahi or pointed as in China (Fig. 5.5).

The varieties can also be distinguished depending on the colour of new flush and season of flowering. Shahi produces very light-coloured flush, while China has pinkish flush. Bedana produces bright red or copper-coloured flush and short compact panicles. The fruit colour varies in different varieties and is also influenced by growing conditions. Skin thickness depends on cultivars. Bedana and China have

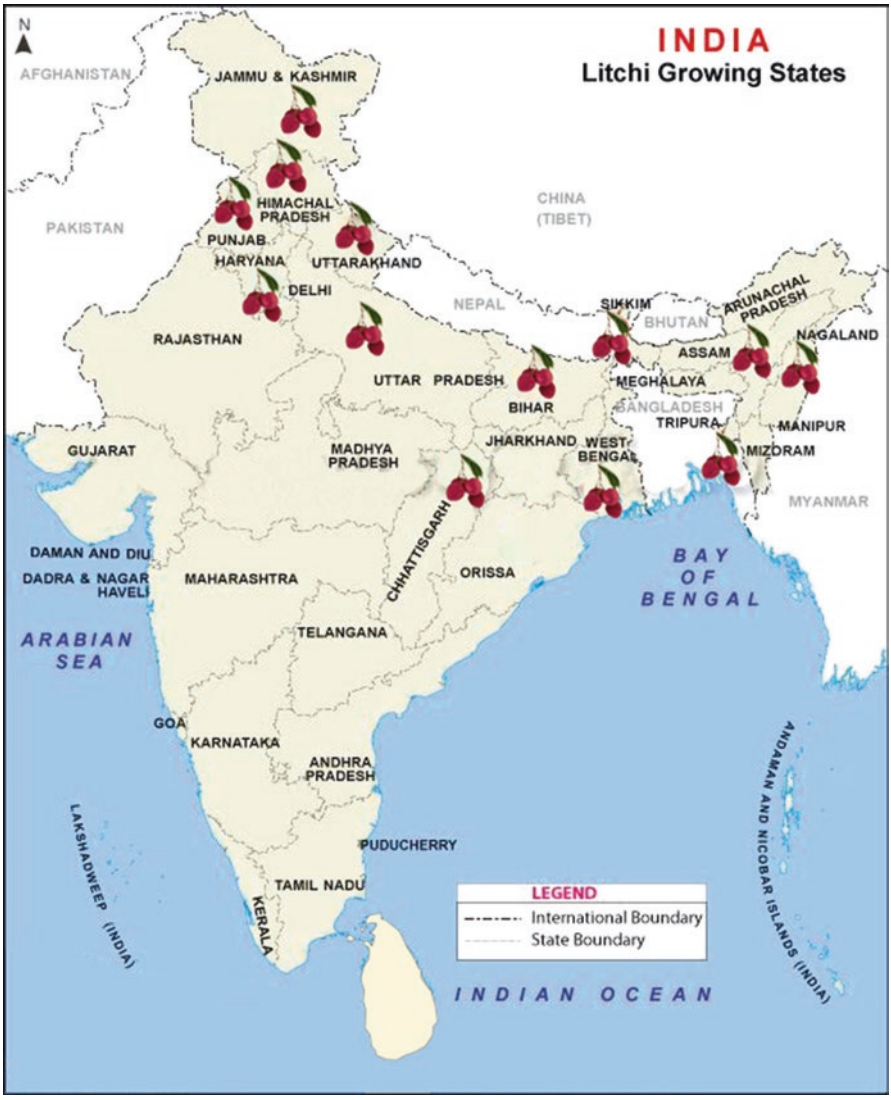


Fig. 5.2 Map showing lychee-producing states in India

very thick skin, whereas Rose Scented and Shahi have thin skin. Skin surface at maturity also varies being smooth, swelling and sharp pointed. Protuberances of pericarp (skin) can be smooth as in Bedana or sharply pointed as in China. The presence and absence of seed as well as structure and size of seeds also vary from cultivar to cultivar, but it is also influenced by the environmental conditions. In Rose Scented and Bedana, a high proportion of chicken-tongued seeds is observed, while China has bold seeds.

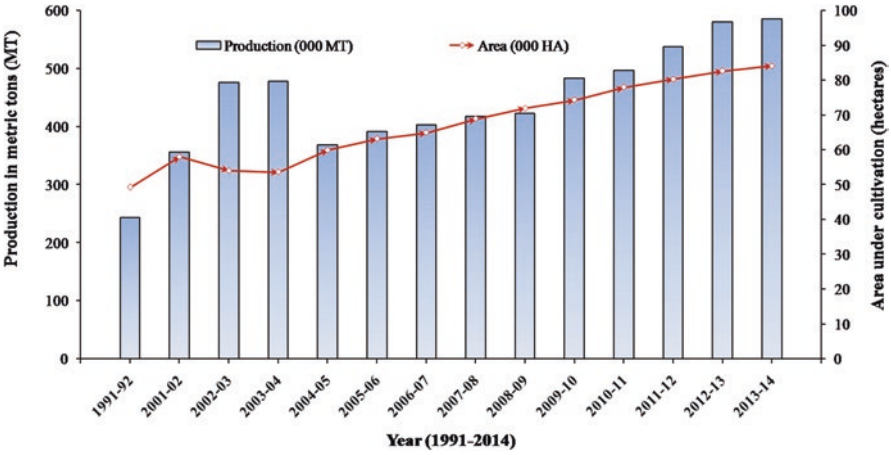


Fig. 5.3 Production of lychee in India (Indian horticulture database 2014)

Fig. 5.4 Lychee tree with ripened fruits

The harvest season lasts 5–10 weeks for a range of cultivars in any one location. Lychee cultivars can be broadly classified as early, mid or late maturing, although the order varies from year to year, depending on seasonal conditions. Table 5.1 enlists the lychee cultivars grown in different countries. According to the Indian Horticulture Database (2014), Indian lychee is exported to China (87 MT), Thailand (19 MT) and Mauritius (1MT).

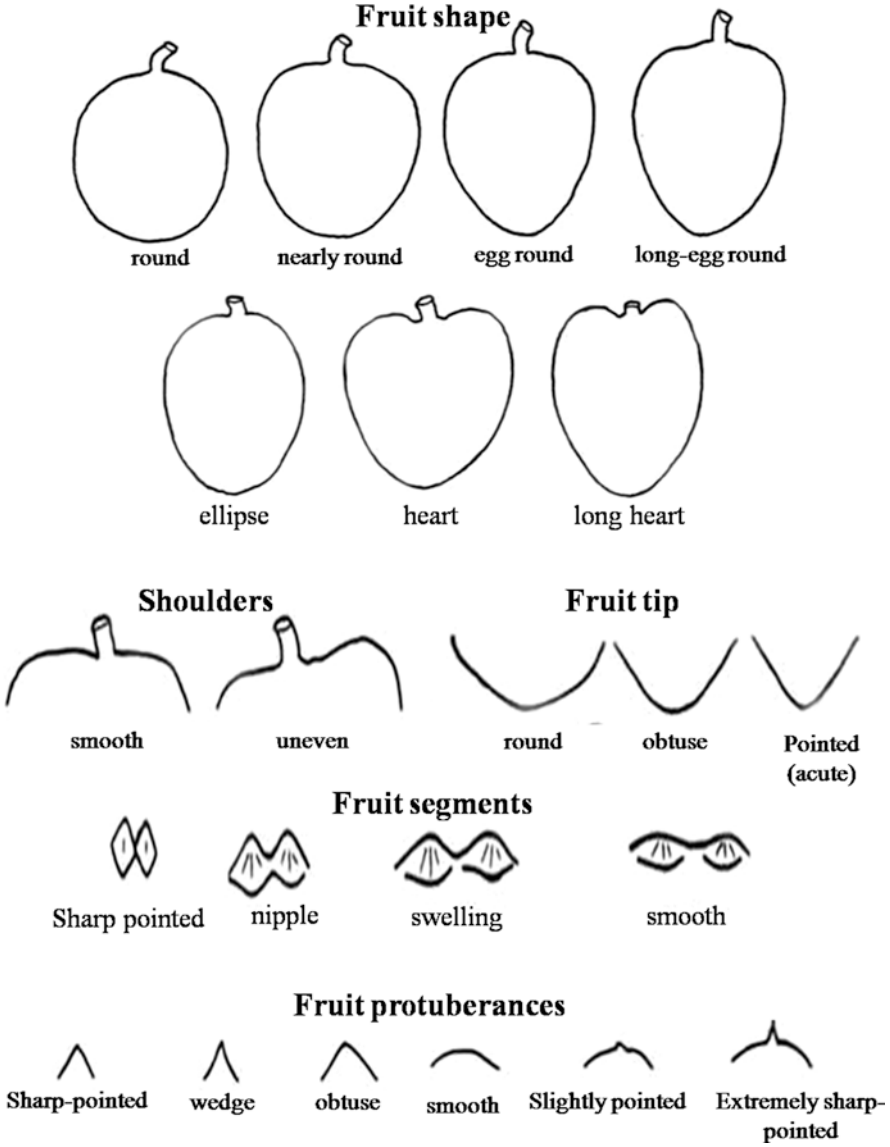


Fig. 5.5 Lychee fruit characteristics

Table 5.1 Major lychee cultivars grown in different countries

Country	Cultivars
Australia	Kwai May Pink, Tai So, Souey Tung, Fay Zee Siu, Salathiel, Wai Chee
Bangladesh	Bombai, Muzaffarpur, Bedana, China 3
Brazil	Bengal
China	Early: Sanyuehong, Baitangying
	Mid: Dazao, Heiye, Baila, Feizixiao and Shuidong, Tianyan, Chenzi
	Late: Xiangli, Guiwei, Noumici, Huaizhi, Xuehuaizi, Lanzhu, Bobaitangbo, Yuanhong, Xiafanzhi, Nanmuye
Florida, USA	Mauritius and Brewster
India	Bihar/Jharkhand: Deshi, Purbi, China, Kasba, Bedana, Early Bedana, Late Bedana, Dehra Rose, Shahi, Manragi, Maclean, Longia, Kaselia and Swarna Rupa, Ajhauli, Green, Mandraji, Rose Scented
	Uttar Pradesh/Uttrakhand/Himachal Pradesh: Early Large Red, Early Bedana, Late Large Red, Rose Scented, Late Bedana, Calcuttia, Extra Early, Gulabi, Pickling, Khatti, Dehra Dun, Piyazi
	West Bengal/Assam: Bombai, Ellaichi Early, China, Deshi, Purbi and Kasba, Kalyani Selection
	Haryana/Punjab: Early Seedless, Late Seedless, Seedless-1 and Seedless-2, Calcuttia, Muzaffarpur
	Chhattisgarh: Sarguja-1, Sarguja-2
Indonesia	Local Selections
Israel	Mauritius, Floridian
Madagascar	Mauritius
Nepal	Mujafpuri, Raja Saheb, Dehradun, Calcuttia, China
Philippines	Sinco, Tai So, Ulpb Red
South Africa	Mauritius, Mclean Red
Thailand	Tai So, Chacapat, Wai Chee, Haak yip, Khom
Vietnam	Thieuthauhha

5.4 Botanical Description

Tree Lychee is a long-lived, evergreen tree up to 30 m tall in old specimens, with a short stocky trunk. In some cultivars, the branches are crooked or twisting and spreading forming a crown broader than high, while in other cultivars, the branches are fairly straight and upright forming a compact, rounded crown. The varieties can be identified by using tree characteristics. However, they change with weather, soil and culture. Differences in the tree size and shape, length and spread of branches are commonly seen. For example, Brewster is vigorous and erect, with very wide strong crotch angles; Tai So is vigorous, with a spreading habit and sharp crotch angles, while Wai Chee is slow, compact and dome shaped.

Leaves The leaves are alternative and compound, with two to five leaflets. The leaflets are oblong and 5–15 cm long. The foliage comprises 2–4 pairs of leaflets, which are 3–6 in. long, coriaceous, elliptic-oblong to lanceolate, shortly acute, glabrous and shining above and glaucescent beneath. The new flushes are a distinctive red brown when immature and light to dark green as they mature.

The leaf characteristics include leaf size, shape and colour, e.g. 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.

Flower The inflorescences are many branched panicles, each with one or more leaves and up to 3000 flowers, and form 5–80 fruits at harvest. The flowers are small, yellowish white, functionally male or female and apetalous. Functionally, male flowers have 6–10 stamens. There are usually two stages of male flowering overlapping with the female cycle: a true male flower first and then a functionally male flower that opens towards the end of the flowering period. The second male flower has a rudimentary bicarpellate pistil. This is absent in the first stage. Functionally, female flowers have 6–10 staminodes and a functional, bicarpellate pistil (Fig. 5.2). The last stage of male flowering generally supplies most of the pollen used to fertilize the female flowers. The ovary is bilobed, compressed and silky; usually only one lobe develops into a fruit. The stigma is bilobed. According to their hermaphrodite nature, flowers are classified into three classes, viz. type I, type II and type III. Type I and type III flowers are male, while type II flowers function as a fruit-bearing female. Most of the flowers are of type III and only 20 % of the flowers are of fruit producing type II females.

Fruit Fruits are highly variable, depending on the cultivar (Fig. 5.3). They can be round, ovoid or heart shaped and from 2.0 to 3.5 cm in diameter. The skin can be smooth or rough with distinct protuberances, thick or thin and pink red, bright red or purple red. The flesh or aril is an outgrowth of the outer cells of the seed coat (outer integument), and in good cultivars may comprise 80% of fruit weight. The aril is generally translucent white, juicy or firm and sweet and aromatic in better cultivars. Many cultivars can be distinguished by their flavour and aroma. The fruit contains a single dark brown seed 6–12 mm wide and 10–23 mm long. Some cultivars have a high proportion of aborted seeds and thus a high flesh recovery. They are popular in the marketplace, especially in Asia. There are a few cultivars that produce nearly seedless fruit, although the fruit usually weighs less than 10 g. The fruit shape of some cultivars is very distinctive. 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. The fruit 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 hairlike 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. Salathiel produces nearly always fruit with small seeds, while Bengal, Souey Tung, Haak Yip and Wai Chee produce hardly any. Other varieties such as Tai So and Kwai May Pink vary. Description to major lychee cultivars grown in different countries is shown in Table 5.2.

Table 5.2 Description of the lychee cultivars/breeding lines

Variety	Origin/cultivation	Characteristics	Reference(s)
Aili	Hainan Province, China	Selected from local *Litchi chinensis*; dwarf selection; average fruit weight 24.8 g; cultivated in Hainan Province (China)	Miao et al. (1998)
Ajhauli	Ajhauli village, Bihar, India	Early maturing; selected from Ajhauli village; a 16-year-old tree yields 80–100 kg fruit; average fruit weight 15–18 g; big seeds; fruits highly susceptible to cracking; proper irrigation can minimize cracking	Singh and Babita (2001)
Amboina	–	Bright red medium-sized fruits; borne in clusters of 6–20; slow-growing tree of warm climate	Singh et al. (2012)
Bah Lup	Dian Bai and Gao Zhan, Guangdong, China	Productive Chinese cultivar; important export variety; dome-shaped tree; narrow, long, glossy, dark green and pointed leaves; heart-shaped fruits; average weight 20–29 g; brilliant red to light purple soft skin; obtuse protuberances	
Bai-Teng-Ying	–	Early-maturing cultivar; dwarf tree; good-quality fruits; tolerant to various environmental stress; floral differentiation occurs between October and February	Ooyang et al. (1994)

(continued)

Table 5.2 (continued)

Variety	Origin/cultivation	Characteristics	Reference(s)
Bengal	India	Seedling of an Indian cultivar 'Purbi'; selected in Florida; vigorous trees but with thin branches; resistant to wind damage; leaves are large, green, with prominent curl or twist along their length; attractive fruits with pleasant taste and large seed; fruits borne in cluster of 50 or more; outer skin is thick, rough and attractive red in colour; fruit shape is lopsided heart shaped to egg shaped; pulp is sweet, soft and juicy; usually aril is undeveloped and does not cover the seed at pointed end; flesh recovery is lower than 50%; not a good marketing type variety	Morton (1987)
Bombai	India	Important cultivar from West Bengal; vigorous trees yield 80–90 kg fruits; fruits are obliquely heart shaped with brilliant deep red in colour with greyish-white, juicy, soft and sweet pulp; average fruit weight is 15–20 g	Anonymous (2001) and Bose (2001)
Brewster	Florida	Brewster (Chen family purple) variety obtained from Fujian; propagated in Florida; small and upright trees with strong and wide crotch angles; dense foliage; distinct corky outgrowths and lenticels are present on branches; leaves are green, large and pointed; heart-shaped fruits with a pink-red, thick and rough skin; fruits borne in small loose clusters; full-seeded fruit has rounded tip; chicken-tongue fruit has pointed tip; mature fruit pulp is juicy and sweet; flesh recovery is 65–70%	Anonymous (2001), Morton (1987), and Chauhan (2001)
Calcutta	India	Successful variety for hot and dry areas; less vigorous trees with height of 4 m; yields 80–100 kg fruits/tree; fruits are deep carmine to red in colour with lopsided to oblong in shape; average fruit weight is 22 g; flesh is creamish white, juicy, soft and sweet; bold seed; fruit is less prone to cracking and sunburn	Bose (2001)
Chacapat/ Chakrapad	Thailand	Grown in Thailand; imported to Australia; trees are erect, vigorous, dense foliage with long branches; leaves are green, small, narrow and pointed; from the midrib leaves curl upwards and downwards towards tip; fruits are slightly heart shaped to rounded; skin is deep red and soft with juicy pulp; average fruit weight is 28–32 g; large seeds; flesh recovery is 60–70%	Anonymous (2001)

(continued)

Table 5.2 (continued)

Variety	Origin/cultivation	Characteristics	Reference(s)
CHES-2	Ranchi, India	Late-maturing variety developed from Bombaia cultivar; canopy bearing habit helps in decreasing sunburn and fruit cracking; fruits are deep red and borne in clusters of 15–20; average fruit weight is 21.3 g	Rai et al. (2001) and Singh and Babita (2001)
China	India	Late-maturing variety; tolerant to hot winds, soil moisture fluctuations and fruit cracking; trees are high yielding but short; oblong to conical-shaped fruit with dark-pink colour skin, fruit weighing about 20–25 g, aril sweet juicy aroma with excellent quality, heavy yielder, resistant to fruit cracking and sunburning; fruits are large sized of weight 22.0 g; pulp is soft, juicy and sweet; seeds are dark chocolate, glaucous and oblong to concave in shape	Singh and Babita (2001) and Rai et al. (2001)
China-3	India	Best variety in Bangladesh; late maturing; average height of tree is 5–6 m; leaves are small; globose fruits with a mixture of red-orange and green patches; average fruit weight is 25 g; flesh is soft, juicy and creamy white in colour; small seed; pulp/seed ratio is 15:1	Siddiqui (2002)
Chu Ma lsu or Chu Ma Isz (China grass fibre)	–	Trees with lush green foliage; leaves are overlapping, large with long petioles; fruits with rough skin; pulp is fragrant but of inferior flavour	Morton (1987)
Dahong Nuomizi	Guangdong, China	Matures in late June to early July; average fruit weight is 20–15 g; bright red fruit with small seed; sweet and juicy pulp; poor transportability and unstable yield	Li (1996)
Dahongpao	Eastern Sichuan province, China	Matures in mid-late July; large fruit clusters of weight 500–1000 g; good eating quality	Wong (1999)
Dazao (Tai So, Hong Huai, Mauritius) 'Tai So'	China, Thailand, South Africa, Florida, Israel, Australia	Trees have insufficient number of female flowers; vigorous trees with open crown; leaves are glossy, large and dark green; leaves have an upward curl from midrib; fruits are large and egg shaped with rounded tip; fruit skin is dull red at maturity; pulp is sweet when fully ripe but bland when overripe flesh recovery is 60–70%	Degani et al. (2003) and Singh et al. (2012)

(continued)

Table 5.2 (continued)

Variety	Origin/cultivation	Characteristics	Reference(s)
Dehra Dun (Dehra Rose, Dehra Dhun)	India, Pakistan	Important cultivar in India and Pakistan; late-maturing cultivar; attractive bright rose-colour fruits are medium to large in size and small seeded; greyish-white, soft and juicy pulp; total sugar content is 10.4%; acidity is 0.72%; seeds are small (2.4 cm long, 1.4 cm diameter) shrunken, oblong, dark chocolate in colour and shrunken; fruits are most prone to sunburn and cracking	Anonymous (2001), Morton (1987), Rai et al. (2001), Chauhan (2001), Singh and Babita (2001), and Bose (2001)
Deshi	India	Early-maturing cultivar, medium-size trees of height 5.5 m and spread of 6.5 m; high fruit yield; oblong to conical in shape bright rose-pink-colour fruits; fruit pulp is greyish white, juicy and soft; oblong in shape, dark chocolate smooth seeds; fruits are less susceptible to sunburn and fruit cracking	Chauhan (2001)
Dong Si Ji Li	China	Rare lychee variety which is used in hybridization programmes; uneven, elongated and oval-shaped fruits with soft aril; flowering for the whole year; this cultivar is used as a parent in breeding programmes because of high TSS and vitamin C (53.7 mg/100 g)	Rai et al. (2001)
E Dan Li	China	This cultivar ripens during late June; sparkling and spotless aril makes it more suitable for canning; fruits are reddish yellow in colour, oval or cordate in shape; 15.3–18.00 brix; 22.1–27.6 mg/100 g of vitamin C	Rai et al. (2001)
Early Bedana	India (Uttar Pradesh, Uttrakhand, Punjab, Bangladesh)	Early-maturing cultivar with average tree height is 5.0 m and spread of 6.2 m; yields about 50–60 kg/tree; medium-sized heart-shaped or oval fruits with deep red and rough skin; good fruit quality; pulp is soft, juicy, creamy white and sweet with 19.50 brix TSS; sugar content is 13.91; seeds are small, shrunken, dirty chocolate and glabrous; average seed weight is 1.47 g	Singh and Babita (2001) and Rai et al. (2001)
Early Large Red	–	Early-maturing cultivar; obliquely heart-shaped, red-colour fruits with firm, rough and leathery skin; pulp is greyish white and sweet	Morton (1987)
Edanli	Hainan Province of China	Local cultivar of China; large-sized and good-quality fruits; average fruit weight is 52 g; colour of fruit is greenish red	Li et al. (2003)

(continued)

Table 5.2 (continued)

Variety	Origin/cultivation	Characteristics	Reference(s)
Elachi (Elaichi, Ellaichi)	India (West Bengal)	Important cultivar for commercialization; vigorous tree with height of 5–6 m and spread 6–7 m; fruit yield is 50–60 kg/tree; cone-shaped fruits with average size 12–15 g; pulp is creamy white, soft and juicy; 18.00 brix TSS; sugar content is 1.5%; acidity is 0,45%; seeds are small and shining with average weight of 1.5–2.0 g; fruits are less prone to cracking and sunburn	Bose (2001), Rai et al. (2001), and Singh and Babita (2001)
Emperor	Florida and California	Tree is slow grower; not a commercial variety; variety of largest fruits of size about golf ball; fruit is hard with acid flavour; fruit skin with distinct bumps	Degani et al. (2003) and Singh et al. (2012)
Extra Early Green	–	Fruit is heart shaped, rarely rounded and 3.2 cm long; skin is rough, yellowish red and leathery; pulp is firm, creamy white, slightly acidic and of good quality; seeds are flat, oblong or cylindrical	Morton (1987)
Feizixiao (Fay Zee Siu) 'Fay Zee Siu'	South Africa, China	Vigorous tree; one of the best export cultivar of China; average fruit weight is 24–32 g; amber-colour fruit with size of about goose egg; pulp is fragrant, sweet, delicious and very fragrant; early-maturing variety with good storage quality	Froneman (1999) and Anonymous (2001)
Fei Tsu Hsiao or Fi Tsz Siu (imperial concubine's laugh or smile)	–	This cultivar has large, amber-coloured, thin-skinned fruits, with very sweet and fragrant flesh. The seeds vary from large to very small. It ripens early in the season	Morton (1987)
Feizixiao	–	Early-maturing cultivar; stable and high yield; vigorously grown trees; large fruits of average weight 60 g; pulp is juicy, sweet and of good quality; best grows at altitude between 600m and 1300 m	Wu and Zhang (1997) and Zhuang (1999)
Fengli	Hainan Province of China	Selected from local *Litchi chinensis* seedlings; average yield is 11.6 kg/tree	Miao et al. (1998)
Groff	–	Selected from seedling of Haak Yip cultivar; late-maturing cultivar; upright tree of medium vigour; medium-sized rose-red-colour fruit with yellowish-green tinges at the apex of tubercle; firm and white pulp with sweet and subacid flavour; seeds are abortive and chicken tongue	Morton (1987)

(continued)

Table 5.2 (continued)

Variety	Origin/cultivation	Characteristics	Reference(s)
Guiwei	Eastern Sichuan province of China	Late-maturing cultivar; trees are productive and precocious; large fruits of average weight 24 g; fruit skin is dark red; pulp is juicy and pure white; TSS is 18.20 brix; vitamin C content is 58.96 mg/100 ml	Wong (1999), Zhu and Yuan (1999), and Yuan and Zhu (2001)
Gulabi	North India	Late-maturing cultivar; profusely branched and medium vigour (7 m spread and 6 m height) tree; yield about 90–100 kg/tree; medium-sized fruits of average weight 20.0 g; variable fruit shape; fruit colour is pinkish to red colour; pulp is greyish white, firm and sweet; TSS is 18.20 brix; seeds are heavy, big, chocolate-coloured and shiny	Rai et al. (2001), Morton (1987), Chauhan (2001), and Singh and Babita (2001)
Haak Yip (Haak Yip, Hei Yeh, Black Leaf)	China, Taiwan, Thailand	Medium vigour trees, dense foliage, long and thin branches; leaves are dark green, long, glossy and narrowly pointed; medium-sized fruits borne in compact clusters; skin of fruit is thin, soft and more prone to insect attack; pulp is sweet, crisp and of excellent quality; good marketing type cultivar	Anonymous (2001), Chauhan (2001), and Morton (1987)
Hongxin	China	Promising cultivar selected from Dahongpao cultivar; fruits are large sized of average weight 24.2 g; TSS is 17.4–18.10 brix	Li et al. (1999)
Hsi Chio Tsu or Sai Kok Tsz (rhinoceros horn)	–	Early-maturing cultivar; fruit is rough, large, narrow at apex and broad from base; fruit skin is tough and fibrous; pulp is fragrant and sweet	Morton (1987)
Hsiang Li or Heung Lai (fragrant lychee)	–	Erect trees, leaves pointing upwards; fruit is rough, small and prickly; seed are small; pulp is of superior taste and high-quality aroma	Morton (1987)
Huai Chih or Wai Chi (the Wai River lychee)	–	Late-maturing cultivar; blunt leaves of medium size; round fruits with smooth skin	Morton (1987)
Huazhi (Wai Chee)	China, Thailand, Australia	Dome-shaped trees with thick branches, compact foliage with many growing points; trees are more prone to wind damage; oval-shaped leaves curved upwards from the midrib; fruits borne in small clusters; average fruit size is 16–18 g; fruit skin is of medium texture; pulp is juicy, soft and sweet; fully developed seeds; large seeds decrease the eating quality	Degani et al. (2003) and Singh et al. (2012)

(continued)

Table 5.2 (continued)

Variety	Origin/cultivation	Characteristics	Reference(s)
Jiangmiaolan	Eastern Sichuan province of China	Dark red-coloured fruits which mature in late July	Wong (1999)
Kaimana or Poamoto	Hawaii, Australia	Selected from Haak Ip cultivar; medium-sized trees with long and strong branches; leaves are long, elongated and mid-green in colour; fruits are heart shaped, large and purple red in colour; pulp is sweet, crispy and of excellent quality; medium-sized seeds	Anonymous (2001)
Kasba	India (Bihar)	Selected from Kasba village for its large-sized fruit; mid-late-maturing cultivar; large compact tree with long and broad leaves; yield is 85–100 kg/tree; average fruit weight is 23–27 g; pulp is juicy soft and greyish white in colour; TSS 16.80 brix; acidity is 1.14%; fruits are less prone to sunburn and cracking; seed is shiny, smooth and dark in colour	Singh and Babita (2001) and Chauhan (2001)
Kaselia (Khatti, Pickling)	–	Late-maturing cultivar; medium-sized tree; pink-coloured fruits; large seeds hence low pulp content; no commercial value	Singh and Babita (2001)
Khom	China, Thailand, Australia	Popular tropical cultivar; high yielding; not a good marketing type because of small size and poor flavour fruits; trees are erect, vigorous, compact foliage with long and strong branches; leaves are pointed, narrow, dark green in colour and of medium size; fruits borne in small loose clusters; fibrous pulp; small-sized fruits with chicken-tongue seeds; flesh recovery is 60–80%	Anonymous (2001)
Kwa Luk or Kua Lu (Hanging green)	–	Famous lychee cultivar; large red fruits with green tip having superior fragrance and flavour	Morton (1987)
Kwai May Pink	China, Australia	Large, erect trees having thin and long branches; leaves are long, narrow, shiny and oval shaped; round-shaped, rough skin medium-sized fruits; pulp is sweet, juicy, crispy and aromatic; seeds are of variable size; average fruit weight is 18–22 g	Anonymous (2001)
Kwai May Red	China	Trees have long and thin branches; leaves are oval shaped, small and shiny green in colour; good-quality fruits; pulp recovery is 70–80%; fruits have good aroma	Anonymous (2001)

(continued)

Table 5.2 (continued)

Variety	Origin/cultivation	Characteristics	Reference(s)
Kwai Mi or Kue Wei (Cinnamon flavour)	Hawaii	Trees with upwardly curved branches; leaves curl inwards from midrib; heart-shaped small fruits with red skin; pulp is very fragrant and sweet; seeds are small in size; only 10% of the fruits have chicken-tongue seeds	Degani et al. (2003) and Singh et al. (2012)
Late Bedana (Late Seedless)	North India	Late-maturing cultivar; vigorously grown trees with an average height of 5.5 m and spread of 7.0 m; annual yield is 80–100 kg/tree; compact panicle; fruits are carmine in colour and conical in shape; fruit skin is rough and firm; flesh is creamy white; juicy and very soft; TSS is 19.50 brix; total sugar is 13.00%; seeds are glabrous, small, shrunken, chocolate colour and of fusiform shape; good-quality fruit	Rai et al. (2001), Morton (1987), Chauhan (2001) and Singh and Babita (2001)
Late Long Red or Muzaffarpur	India (Bihar, Punjab, Uttarakhand)	Heavy bearer and late-maturing cultivar; good-quality fruits; fruits are less than 4 cm in length; fruit shape is conical to oblong; fruit colour is dark red with greenish lines; fruit skin is firm, leathery and rough; pulp is greyish white, sweet and soft; fully developed cylindrical seeds	Morton (1987)
Liquili	Guangxi Province of China	Late-maturing cultivar; trees yield fruit after 3 years of planting; average fruit weight is 15.68–21.3 g; fruit contains 15.02–18.45% soluble solids, 37–38 mg ascorbic acid/100 g of fruit pulp and 13.5–14.9% sugar; yield is more and stable; resistant to various adverse environmental conditions	Xie (1995)
Longia	North Bihar (India)	Late-maturing cultivar; small-sized tree; small leaves of light colour; compact panicles; medium-sized fruit with excellent fragrance	Singh and Babita (2001)
Madras	South Africa (Nelspruit)	Heavy bearer cultivar; bright red-colour fruits with rough skin; pulp is sweet and juicy	Morton (1987)
Maguili	–	Late-maturing variety; trees are precocious; large-sized fruit with average weight of 39.6 gm; pulp is pure white in colour; TSS is 17–21 brix; ascorbic acid is 50.2 mg/l; good-quality fruit	Ooyang et al. (2002)

(continued)

Table 5.2 (continued)

Variety	Origin/cultivation	Characteristics	Reference(s)
Mandraji	–	Vigorously grown trees with an average height of 6.0 m; fruits borne in clusters; average weight of fruit is 22–26 g; fruit skin is bright red in colour and rough; TSS is 19.50 brix; seeds are smooth, shiny and light chocolate in colour	Chauhan (2001)
Mianbaoli	Hainan Province of China	Selected from local lychee seedling; fruits having soluble solid content of 17.5%	Miao et al. (1998)
Mombaia (Mumbai)	India (West Bengal)	Early-maturing variety; vigorously grown trees with an average height of 6–7 m; large-sized heart-shaped fruits with an average weight of 15–20 g; fruit colour is attractive carmine; each fully developed fruit has a small underdeveloped fruit attached to stalk; pulp is greyish white, soft and juicy; TSS is 20.50 brix; total sugar is 11.68%; seeds are elongated, large, smooth, shiny and chocolate colour; seed having 2.3 cm length, 1.6 cm diameter and weight 3.83 g	Rai et al. (2001) and Chauhan (2001)
Muzaffarpur	India (Bihar)	One of the best litchi cultivar; trees are of medium vigour with an average height of 5.5 m and spread of 6.0 m; average yield is 80–100 kg/tree; fruits are less susceptible to cracking; large fruit with an average weight of 18.2 g; fruit shape is oblong conical to oval; pulp is juicy, white and soft; TSS of pulp is 17.70 brix; acidity is 0.48%; seeds are large with an average weight of 4.5 g and dark chocolate in colour	Chauhan (2001) and Bose (2001)
Muzaffarpuri	India, Bangladesh	Medium vigour tree with an average height of 5 m; pink-coloured oval-shaped fruits; average fruit weight is 20 g; pulp is soft and sweet; TSS of pulp is 17–18 brix; big seeds; seed/pulp ratio is 4.75:1	Degani et al. (2003) and Singh et al. (2012)
Nafarpal	India (West Bengal)	Important cultivar of West Bengal; not a commercial cultivar; fruits resemble with Chinese cultivar	Pereira et al. (2005)
Nanmuye	Sichuan province of China	Highly productive trees; yellowish-red fruits matures in mid-August; fruits borne in large clusters of an average weight 400–1 1100 g; soluble solid content is 15.4 brix	Wong (1999)

(continued)

Table 5.2 (continued)

Variety	Origin/cultivation	Characteristics	Reference(s)
No Mai Chee	China (Taiwan)	Highly prized and late cultivar; large trees with dense canopy; leaves are small soft with thin edges; large fruits with chicken tongues; pulp recovery is 75–85%; pulp is smooth, clean and firm with excellent aroma	Anonymous (2001)
No Mai Tsze or No Mic Tsz (glutinous rice)	China	Leading variety of China; late-maturing cultivar; fruits are red, dry, large and clean; best cultivar for drying; seeds are shrivelled and small	Morton (1987)
Nuomizi		Late-maturing cultivar; grows best at an altitude between 800–1400 m	Zhuang (1999)
O-Hia ('Baidum')	China	Third most cultivar after Tai So and Wai Chee; trees with dense foliage and long and thin branches; leaves are large, dark green and narrow; fruits mature in mid-season; medium-sized heart-shaped fruits; pulp is sweet and juicy; flesh recovery is 65–75%	Anonymous (2001)
Olan	Philippines	Selected from seeds brought from Thailand; fruit is oval shaped and of average weight 26 g; TSS is 17.5 brix	Sotto (2001)
Pai La Li Chih or Pak Lap Lai Chi (White wax lychee)	–	Late-maturing variety; large fruits with pink, rough outer skin; pulp is not sweet	Morton (1987)
Panjore Common	India (Punjab)	Trees bear heavily with longest fruit season; fruit is heart shaped, large and pink coloured; fruit skin is thin and rough	Morton (1987)
Pat Po Heung (eight precious fragrances)	Hawaii	Slow-growing tree of spreading habit; not a commonly planted cultivar; skin of fruit is thin and purple red in colour; pulp is soft, sweet and juicy; juice leaks from the broken fruit skin	Morton (1987)
Peerless	Florida	Selected from seedling of Brewster; good productivity of average productivity 174 kg/tree; abortive seed ranged from 62 to 80%	Morton (1987)
Purbi	Australia, India	Vigorously grown tree with an average height of 6.5 m and spread of 7.5 m; also called Bengal in West Bengal; large fruit of an average weight 23–27 g; fruit borne in clusters of 50 or more fruits; yield is 90–100 kg/tree; heart-shaped fruits with uneven shoulders; pulp is juicy, soft with 19.00 brix TSS; seeds are shiny, smooth and dark chocolate in colour; fruits are less prone to cracking	Chauhan (2001)

(continued)

Table 5.2 (continued)

Variety	Origin/cultivation	Characteristics	Reference(s)
Pyazi	–	Early-maturing variety; fruits are 3.4 cm long, heart shaped to oblong conical; fruit skin is leathery and adhering; greyish-white pulp, sweet and with flavour of boiled onion; fully developed and cylindrical seeds; poor-quality fruits	Morton (1987)
Qinzhou red	–	Derived from spontaneous mutation of Black Leaf cultivar; early maturing and high yielding; big fruits of excellent quality	Peng et al. (2001)
Qinzhouhongli	–	Promising cultivar; large bright red fruits with an average fruit weight of 44.7 g; pulp is white, sweet and crispy; good eating quality	
Rose Scented	India (North Bihar, Jharkhand, Uttarakhand and Uttar Pradesh)	Fruits with distinct aroma hence called Rose Scented; vigorously grown trees with an average yield of 80–90 kg/tree; fruits are medium to large in size; mature fruits are susceptible to cracking; pulp is soft, juicy and sweet; seeds are small, shining, smooth, round and dark chocolate in colour; fruits are moderately susceptible to cracking	Rai et al. (2001) and Chauhan (2001)
Sah Keng	Taiwan, Australia	Medium-sized dome-shaped trees with fragile branches; heavy yielding cultivar; leaves are mid-green and 6–8 cm long; large, purple-red heart-shaped fruits; pulp is sweet and soft; seeds are small; flesh recovery is 75%	Degani et al. (2003) and Singh et al. (2012)
Saharanpur	India	Heavy bearing and early-maturing cultivar; matures in the first week of June; large, pink-coloured heart-shaped fruits; fruit and plant characters show similarity with Panjore and Large Red cultivar; TSS content is 19.80 brix; average fruit weight is 17.6 g	Bose (2001) and Lal and Nirwan (1980)
Salathiel	Australia	Small compact trees with undeveloped leaves and long branches; leaves are broad, small and curved inwards from the tip; tip of the leaf is round; egg-shaped small fruits which borne in clusters; tip of the fruit is obtuse; pulp is juicy, thick and sweet; sometimes, fruit is completely seedless; important variety in domestic markets; also exported to Asia	Degani et al. (2003) and Singh et al. (2012)

(continued)

Table 5.2 (continued)

Variety	Origin/cultivation	Characteristics	Reference(s)
San Yueh Hung or Sam Ut Hung (third month red)	–	Popular early-maturing cultivar; grown along Dykeys; brittle branches of trees; large-sized fruits with rough, thick and tough skin; pulp is sweet and juicy; seeds are long but aborted	Morton (1987)
Seedless Late	–	Vigorous trees with an average height of 7.5 m; average yield is 80–100 kg/tree; fruit attains maturity at the third week of June; cone- to oval-shaped fruits; average fruit weight is 29.0 g; pulp is creamy white, juicy and soft; TSS is 18.00 brix; sugar content is 13.8%; acidity is 0.44%; seeds are shrivelled, chocolate coloured, small and glabrous; average seed weight is 0.85 g	Bose (2001)
Shan Chi or Shan Chih (mountain lychee)	–	Grows wild in the hills; trees with pointed, short-petioled leaves and erect branches; fruits are bright red, rough skin, elongated in shape and acidic in flavour	Morton (1987)
Shatouli	–	Late-maturing cultivar; fruit attains maturity in early August; small fruits with an average weight of 21.6 g; fruit skin is crispy and red; pulp is sweet and white in colour; good eating quality; soluble solid content is 18.5%	
Sheung shu wai or Shang hou huai (President of a Board's embrace)	–	Late-maturing cultivar with small leaves tree; large-rounded fruit with many dark spots; flesh is scented and sweet; size of seed is variable	Morton (1987)
Shuidong	–	Early-maturing cultivar; grows best at an altitude of 1000 m	Zhuang (1999)
Shuyou	China	Promising cultivar selected from cultivar Dahongpao; productive and produce large fruits of average size 24.2 g; TSS is 17.4–18.10 brix	Li et al. (1999)
Sinco	Philippines	Important cultivar; selected from local seedling of China; fruits are dull red and ovate to round in shape	Sotto (2001)
Songmei 9	Hainan Province of China	High yielding and stable production cultivar	Miao et al. (1997)

(continued)

Table 5.2 (continued)

Variety	Origin/cultivation	Characteristics	Reference(s)
Souey Tung	China, Australia, Fujian	Tree is short with long, thin, open and spreading branches; leaves are flat, large, glossy green and pointed; medium-sized heart-shaped fruits of an average weight 20–22 g; fruit skin is dull, thin dark red to purple; tip of the fruit is obtuse; pulp is juicy, soft and of high quality; seeds vary in size; flesh recovery is 65–75%; 5–10% seeds are abortive	Anonymous (2001)
Sum Yee Hong	Guangdong province of China	Early-maturing cultivar; medium-sized tree with spreading habit and long, fragile, thin branches; leaves are narrow, long, dark green and thick; large fruits with an average weight of 26–42 g; skin of the fruit peels off easily; pulp is juicy, soft and sweet acid; seeds are large	Anonymous (2001)
Swarna Roopa	India	Selected by clonal selection of seedless cultivar; medium-tall tree with dense foliage; panicle is compact; leaves are similar to Bedana cultivar; mid-season-maturing cultivar; medium-sized attractive red-coloured fruits with an average fruit weight is 8–20 g; seeds are small; TSS of pulp is 19.00 brix; total sugar is 12.5%; skin/pulp/seed ratio is 8.7:76.62:16.36; fruit is resistant to cracking; commercial cultivar	Rai et al. (2001) and Singh and Babita (2001)
Sweet Cliff	–	Small pink fruit; good eating quality; not planted anymore because of many other superior varieties	Degani et al. (2003) and Singh et al. (2012)
Sweetheart	–	Finest lychee; consistent bearer cultivar; large heart-shaped fruits with chicken-tongue seeds; variety of choice because of its superior quality	Singh et al. (2012)
T and Po or T Ong Pok (pond embankment)	–	Tree with small leaves; small fruit with red and rough skin; pulp is juicy and acidic; early-maturing cultivar	Morton (1987)
T Im Ngan or T Ien Yeh (Sweet cliff)	Kwangtung (China)	Common lychee variety; not a commercial cultivar	Morton (1987)
Ta Tsao or Tai Tso (large crop)	Canton	Widely grown cultivar; egg-shaped fruits; fruit skin is bright red, rough with dense dots; pulp is crispy, sweet, firm and yellow near the seed; juice leaked out from the broken skin	Morton (1987)

(continued)

Table 5.2 (continued)

Variety	Origin/cultivation	Characteristics	Reference(s)
Tatuo	–	Large fruits of average size 25.6 g with pink red and TSS is 19.30 brix	Yuan and Zhu (2001)
Trikolia	East Champaran	Similar to Shahi cultivar; good fruit retention capacity; average fruit weight is 18–20 g	
UPLB Red	Philippines, Thailand	Trees bear fruit after 3–4 years of planting; fruits harvested from April to May; red-coloured fruits which are dark red when fully matured; average fruit weight is 14 g	Sotto (2001)
Yuan Gyang Hong (Yuan Yang Mi)	Dahongpao (China)	Promising lychee cultivar with high soluble solid content (19.50 brix); small fruits of an average weight of 23.4 g	Li et al. (1999)
Zeng Cheng Gua Li	China	Excellent cultivar of China; fruits are oval to rounded with an average weight of 14.4–29.5 g; pulp is sweet, crispy and fragrant; TSS is 17–21.50 brix; vitamin C content is 13.4–31.2 mg/100 g; fruits attain maturity during the last week of June to the first week of July	Rai et al. (2001)
Ziniangxi	Hainan Province of China	Selected from local lychee seedlings; large fruits of high quality; average fruit weight is 52 g; fruit colour is purple red	Li et al. (2003) and Miao et al. (1998)

5.5 Nutritional Composition

Lychee fruit is classified as drupe and has a large seed, white translucent 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 and with sweet citrus flavour. Lychee is mainly consumed fresh, but different products like canned lychee, squash, cordial, syrup, jam, jelly and juice are also manufactured and marketed. It can be dried or dehydrated (lychee nuts) or used in ice creams and sorbets (Hui, 2008; Salunke and Desai 1984). Dried lychee is very popular among the Chinese. In China, various other products such as pickles and wine are also made from lychee. The food value of lychee mainly lies in its sugar content which varies from variety to variety. Depending upon the variety and climate, the fruit contains 60% juice, 8% rag, 19% seed and 13% skin. Apart from proteins, fats, carbohydrates, minerals, fibrous matter, calcium, phosphorus, iron and carotene, the fruit is also rich in vitamin B1, riboflavin and vitamin C (Table 5.3). Lychee is also an excellent source of anti-oxidants which protects the body from harmful free radicals. Lychee flesh is loaded with nutritional and functional compounds. According to the data released by USDA, 100 g of lychee flesh contains 16.5 g sugars, 276 kilojoule energy, 0.83 g protein, 0.44 g fat, 0.44 g ash, 1.3 g edible

Table 5.3 Nutritive value per 100 g of lychee fruit (*Litchi chinensis*)

Principle	Nutrient value	Percentage of RDA*
Energy	66 kcal	3.3%
Carbohydrates	16.53 g	12.7%
Protein	0.83 g	1.5%
Total fat	0.44 g	2%
Dietary fibre	1.3 g	3.5%
Vitamins		
Folates	14 µg	3.5%
Niacin	0.603 mg	3.5%
Choline	7.1 mg	1%
Pyridoxine	0.100 mg	9%
Riboflavin	0.065 mg	5%
Thiamin	0.011 mg	1%
Vitamin C	71.5 mg	119%
Vitamin E	0.07 mg	0.5%
Vitamin K	0.4 µg	0.3%
Electrolytes		
Sodium	1 mg	0%
Potassium	171 mg	3.5%
Minerals		
Calcium	5 mg	0.5%
Copper	0.148 mg	16%
Iron	0.31 mg	4%
Magnesium	10 mg	2.5%
Manganese	0.055 mg	2.5%
Phosphorus	31 mg	4.5%
Selenium	0.6 µg	1%
Zinc	0.07 mg	0.5%

Source: USDA National Nutrient Database
RDA * Recommended dietary allowance

fibre, 5 mg Ca, 0.31 mg Fe, 10 mg Mg, 31 mg P, 171 mg K, 1 mg Na, 0.07 mg Zn, 71.5 mg vitamin C, 0.011 mg thiamin, 0.065 mg riboflavin, 0.603 mg niacin, 0.1 mg vitamin B6, 14 mg folate, 0.07 mg vitamin E, 0.007 mg tryptophan, 0.041 mg lysine and 0.009 mg methionine. Taking 100 g lychee flesh satisfies 2–4% of the daily requirement for P, K, Mg, Fe, Zn and Mn and 22% for Cu (Wall 2006). Apart from nutritional value, lychee flesh improves digestion and blood circulation, moistens skin and alleviates symptom of anaemia (Chi et al. 2005). However, active compounds and mechanisms of these functions are unknown. Anti-oxidant activity of lychee flesh is well documented. In addition to vitamin C and E, lychee flesh contains anti-oxidant polysaccharides (Wu et al. 2004) and flavonoids including procyanidin A2 and leucocyanidin (Rooyen and Redelinghuys 1983). Polysaccharides in lychee flesh are effective to eradicate O_2 and reported to significantly suppress lipid peroxidation in rat liver (Wu et al. 2004). However, based on Chinese traditional

medicine, lychee flesh is a typical 'heating' food. Excessive taking causes 'heating symptoms' including sore and swell in the throat, boils in the mouth, tongue and face and tonsillitis. 'Heating effect' of lychee, which is only shown in some individuals, is not understood in terms of mechanism and effective compounds.

5.6 Phytochemistry and Functional Activities

Nowadays, HPLC (high-performance liquid chromatography) and HPTLC (high-performance thin-layer chromatography) have become regular analytical techniques due to their efficiency in quantitation of analytes at micro- or even nanogram levels and cost-effectiveness. Leaf, root, seed, fruit and pericarp extracts of various lychee varieties have been subjected to HPLC and HPTLC followed by pharmacological analyses. The recent reports reveal a total of 50 bioactive compounds from different parts of the lychee plants (Table 5.4). These compounds have been categorized under flavonoids, glycosides, phenolic aldehyde, monoterpenes, anthocyanins amino acid, phenolic compounds and fatty acids (Fig. 5.6).

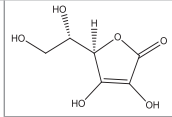
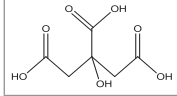
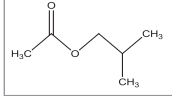
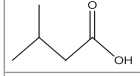
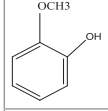
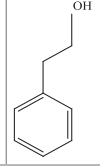
5.6.1 Functional Activities and Compounds in Lychee Skin

Anti-oxidant

Traditionally, lychee skin is useful to prevent the 'heating effect' from taking litchi flesh, but the mechanism is still unknown. However, the anti-oxidant activity of litchi skin is well defined (Guo et al. 2003a, b; Surinut et al. 2005). Lychee skin contains free-radical scavenging compounds like ascorbic acid, glutathione, carotenoids, polysaccharides (Huang and Wu 2006; Yang et al. 2006) as well as rich phenolic substances including flavonoids (flavonols and anthocyanins) and phenolic acids (Li and Jiang 2007). Zhang et al. (2000) found epicatechin, procyanidin B2, epigallocatechin and procyanidin B4 are among the major flavonoids in fruit skin of 'Huaizhi'. Analysis conducted by Sarini-Manchado et al. (2000) showed that polymerized tannins (procyanidins) were the most abundant (0.4% fresh weight) in 'Guiwei' skin, followed by epicatechin (0.17%), procyanidin A2 (0.07%), anthocyanins (0.04%) and flavanols (0.04%). Two flavonoids in lychee skin especially anthocyanins and procyanidins contribute to the major part of its anti-oxidant activity (Luximon-Ramma et al. 2003). Zhao et al. (2006) found procyanidin B2 was stronger in scavenging hydroxyl free radical and superoxgen anion than procyanidin B4 and epicatechin, while epicatechin is more active in eradicating DPPH than the other two flavonoids.

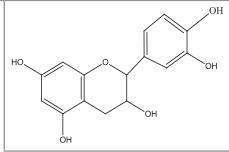
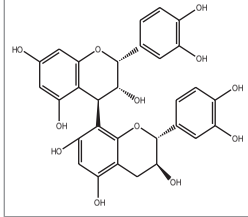
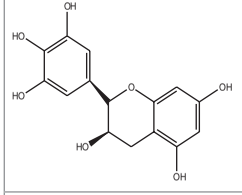
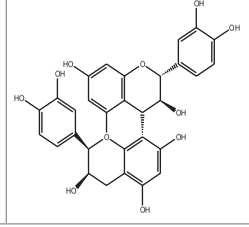
Lychee fruit development is accompanied by changes in chemical compositions including phenolic substances (Huang and Wu 2006). Hence, anti-oxidant activity in the skin at different maturity differs. Zheng et al. (2003) found skin of immature fruit had a much stronger anti-oxidant activity than that of mature fruit. Cultivars also differ in quantity and quality of phenolics including flavonoids, so do their anti-oxidant activities.

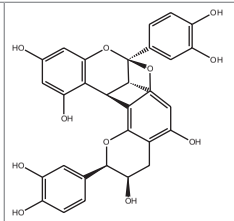
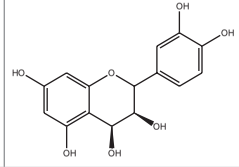
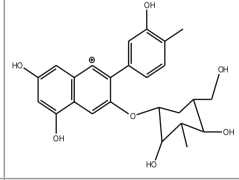
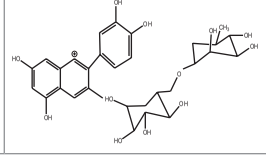
Table 5.4 List of bioactive compounds reported in *Litchi chinensis*

S.no.	Name of compound	Class	Structure	Property	Reference(s)
1	Ascorbic acid	Organic compound		Growth and repair of tissues in all parts of the body	Ong and Acree (1999), Huang and Wu (2006), Yang et al. (2006) and Wu et al. (2009)
2	Citric acid			Anti-bacterial; anti-fungal; anti-oxidant	
3	Isobutyl acetate			Antibacterial	
4	Isovaleric acid			Antibacterial	
5	Guaiacol			Antimicrobial activity	
6	2-phenyl ethanol			Anti-tyrosinase; antimicrobial	

(continued)

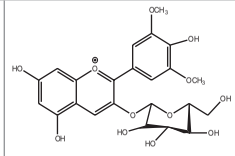
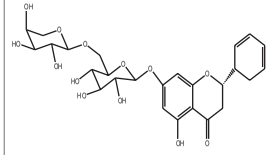
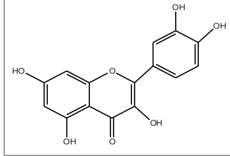
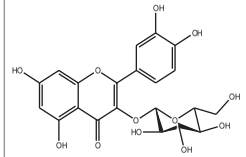
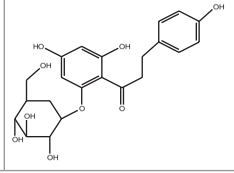
Table 5.4 (continued)

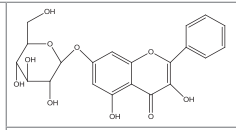
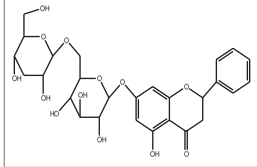
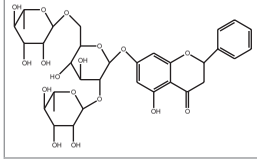
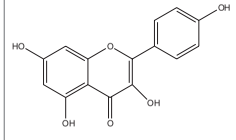
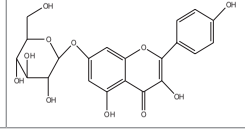
S.no.	Name of compound	Class	Structure	Property	Reference(s)
7	Epicatechin	Flavonoids		Anti-oxidant; free-radical scavenging activity; reduce blood sugar level; anti-diabetic; anti-cancer	Van Rooyen and Redelinghuys (1983), Ding (1999), Ong and Acree (1999), Sarini-Manchado et al. (2000), Luximon-Ramma et al. (2003), Luo et al. (2006), Liang et al. (2006), Gong et al. (2008), Shen et al. (2013), Wu et al. (2009), Reichel et al. (2014), and Su et al. (2016)
8	Procyanidin B2			Anti-oxidant activity; prevents malignancies	
9	Epigallocatechin			Chemoprevention and anti-cancer activities	
10	Procyanidin B4			Possess anti-oxidant activity; inhibition of proliferation and induction of apoptosis in cancer cells through up- and downregulation of multiple genes	

11	Procyanidin A2			Prevents hyperglycemia and type 2 diabetes	
12	Leucocyanidin			Protects the stomach lining	
13	Cyanidin-3-O-glu			Free-radical scavenging activity	
14	Cyanidin-3-O-rut			Free-radical scavenging and anti-platelet aggregating activity	

(continued)

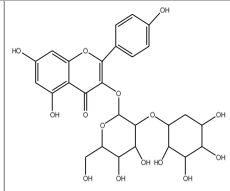
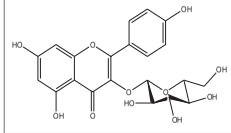
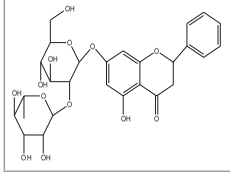
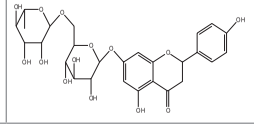
Table 5.4 (continued)

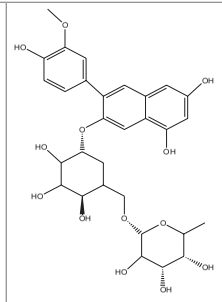
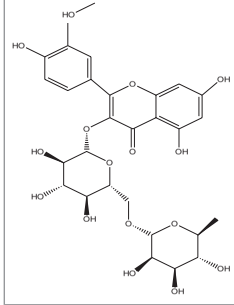
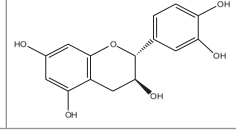
S.no.	Name of compound	Class	Structure	Property	Reference(s)
15	Malvidin-3-acetyl-O-gluoenin			Anti-oxidant properties	
16	(2S)-pinocembrin-7-O-(6′′-O-α-L-arabinosyl-β-D-glucopyranoside)			Anti-diabetic property	
17	Quercetin			Supports normal respiratory health; supports cardiovascular health; promotes balanced blood pressure; offers protection against stress; offers nutritional support for overall health	
18	Quercetin 3-O-glucoside				
19	Phlorizin			Anti-oxidant; anti-diabetic	

20	Pinocembrin-7-O-glucoside			Anti-oxidant activity; used to treat cerebral ischaemia, neurodegenerative diseases, cardiovascular diseases and atherosclerosis	
21	Pinocembrin-7-O-[(6′′-O-β-D-glucopyranoside)-β-D-glucopyranoside]				
22	Pinocembrin-7-O-[(2′′,6′′-di-O-α-L-rhamnopyranosyl)]-β-D-glucopyranoside]				
23	Kaempferol			Anti-oxidant; anti-cancer	
24	Kaempferol-7-O-β-D-glucopyranoside				

(continued)

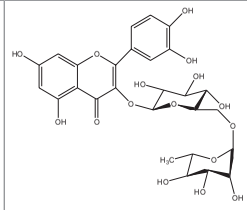
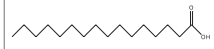
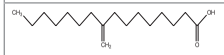
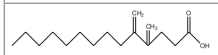
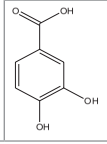
Table 5.4 (continued)

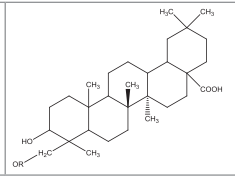
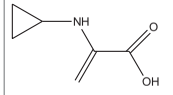
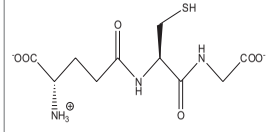
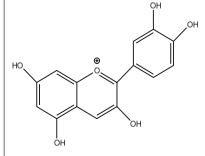
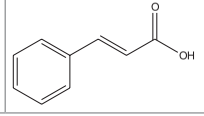
S.no.	Name of compound	Class	Structure	Property	Reference(s)
25	Kaempferol 3-O-rutinoside				
26	Kaempferol 3-O-glucoside				
27	Onychin			Anti-oxidant; anti-cancer	
28	Nairutin			Anti-oxidant	

29	Peonidin 3-O-rutinoside			Anti-oxidant	
30	Narcissin (Isorhamnetin-3-O-rutinoside)			Anti-oxidant	
31	Catechin			Anti-oxidant	

(continued)

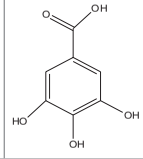
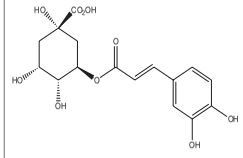
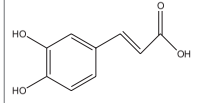
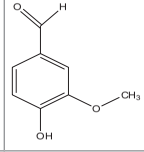
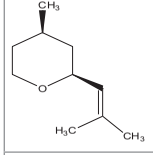
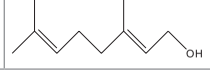
Table 5.4 (continued)

S.no.	Name of compound	Class	Structure	Property	Reference(s)
32	Rutin			Anti-oxidant; helps the body to utilize vitamin C and produce collagen; heals conditions such as haemorrhoids and high blood pressure and reduces cholesterol levels	
33	Palmitic acid	Fatty acids		Blood lipid-reducing activity	Ding (1999) and Ning et al. (1996)
34	Linoleic acid			Anti-oxidant; anticarcinogenic	
35	Dihydrosterculic acid			Anti-cancer; anti-tumour	
36	8-methylenehexadecanoic acid			Antibacterial	
37	Cis-5,6-methylenetetradecanoic acid			Antibacterial	
38	Cis-3,4-methylenedodecanoic acid			Antibacterial	
39	Protocatechuic acid			A major metabolite of anti-oxidant polyphenols; possess anti-cancer property	

40	Saponin	Glycoside		Cholesterol reduction; anti-oxidant; reduce cancer risk; immunity booster; reduce bone loss; anti-oxidant	Yang et al. (2004), Guo et al. (2003a, b), Yang and Liang (2004), and Jiang et al. (2008)
41	α-Methylenecyclopropylglycine	Amino acid		Possesses hypoglycaemic activity	Huang (1994)
42	Glutathione			It is capable of preventing damage to important cellular components caused by reactive oxygen species such as free radicals, peroxides, lipid peroxides and heavy metals	
43	Cyanidin glycoside	Anthocyanin		Anti-oxidant; anti-ageing	Sarni-Manchado et al. (2000)
44	Trans-cinnamic acid	Phenolic acid		Anti-oxidant; antimicrobial	

(continued)

Table 5.4 (continued)

S.no.	Name of compound	Class	Structure	Property	Reference(s)
45	Gallic acid	Phenolic acid		Anti-tumour; anti-oxidant; anti-inflammatory	
46	Chlorogenic acid	Phenolic compounds		Anti-oxidant; blood pressure-lowering effect; laxative effect	
47	Caffeic acid (3,4-dihydroxycinnamic acid)	Phenolic compounds		Anti-oxidant; antihypertension; antithrombosis; anti-fibrosis; anti-virus and anti-tumour	
48	Vanillin	Phenolic aldehyde		Anti-oxidant; antibacterial	
49	Cis-rose oxide	Monoterpene		Anti-inflammatory	
50	Geraniol			Anti-oxidant; anti-cancer properties	

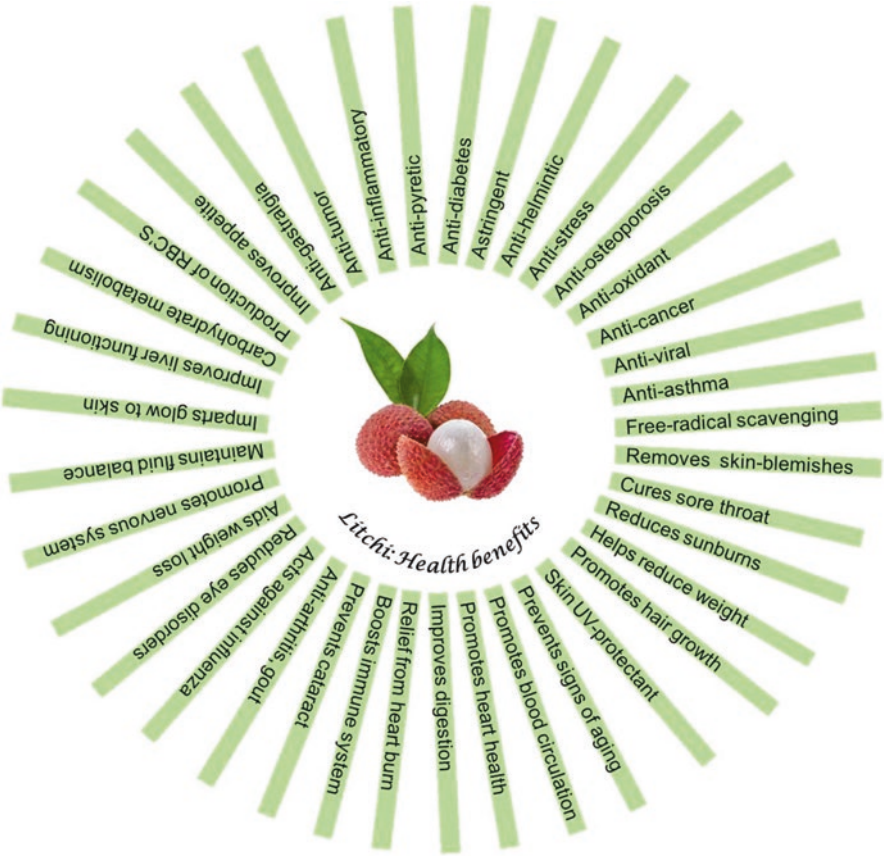


Fig. 5.6 Pharmacological activities of *lychee*

Anti-cancer Activity

Lychee skin is rich in insoluble fibre (40% dry weight), which prevents rectum cancer, diabetes and haemorrhoids (Li et al. 2006). Wang et al. (2006a) reported that water soluble alcohol extract from lychee skin significantly inhibited growth of human hepatoma cells in vitro and that feeding mice carrying liver cancer with lychee skin extract suppressed cancer development. In both cases, the anti-cancer effect was dosage and time dependent. Dosages at 0.14, 0.3 and 0.6 g/kg/day led to a cancer inhibiting rate of 17.3, 30.8 and 44.0%, respectively. Wang et al. (2006b) further found lychee skin extract also effective to suppress breast cancer. They found lychee skin extract caused changes in gene expression pattern, induced programmed cell death and suppressed multiplication in cancers cells (Wang et al. 2006a, b). However, active ingredients in lychee skin were not indicated in their studies. A study made by Zhao et al. (2007) indicated that flavonoids (epicatechin and procyanidin B2) were effective to suppress human breast cancer cells and human lung fibroblast (HLF), although their toxicity to cancer cells was lower than that of paclitaxel.

5.6.2 Functional Activities and Compounds in Lychee Seed

Chemical Composition of Lychee Seed

Lychee kernel contains starch (40.7%), crude fibre (24.5%), proteins (4.93%) and minerals including Mg (0.28%), Ca (0.21%) and P (0.11%). Fatty acids include 12% palmitic acid, 27% linoleic acid, 11% linoleic acid and 42% cyclopropanoic fatty acids (CPFA), among which dihydrosterculic acid accounts for 37%, cis-7,8-methylenehexadecanoic acid 4%, cis-5,6-methylenetetradecanoic acid 0.4% and cis-3,4-methylenedodecanoic acid 0.1% (Ding, 1999). Lychee seed contains also phenolic acids and flavonoids such as methyl 5-O-p-coumaroylquinate, protocatechuic acid, cyanidin-3-O-glu, cyanidin-3-O-rut and malvidin-3-acetyl-O-gluoenin (Ding 1999). Twenty-one amino acids were detected by Huang and Chen (2007), among which four were unknown. There were reports indicating lychee seed contains a special amino acid, α-methylenecyclopropylglycine (Ding 1999). Volatile compounds including ketones, aldehydes, esters, alcohols, enes and terpenoids with unknown functions were also detected in lychee seed (Ding 1999; Le and Fu 2001; Chen et al. 2005; Guo and Pan 2006). Tu et al. (2006) found sterol derivatives, while Yang et al. (2004) measured crude saponin in lychee seeds.

5.6.2.1 Functional Activities and Pharmacological Studies

Dried lychee seed is characterized by traditional Chinese medicine as slightly bitter, warming, qi flow promoting, cold driving, painkilling and liver and kidney tonifying (Tian 2005). There is abundant information on the health-promoting and medical functions of lychee seed, including anti-oxidant, anti-cancer, anti-virus, controlling diabetes and reducing blood lips.

Anti-oxidant Activity

As mentioned above, lychee seed contains flavonoids, which contribute to the anti-oxidant activity of the seed. Water and ethanol extracts from lychee seed were found to reduce the damage caused by free radicals and promoted SOD activity in alloxan monohydrate (ALX)-treated mice (Pan et al. 1999).

Anti-cancer Effect

Xiao et al. (2007) and Wang et al. (2007) reported in the same year that water extract of lychee seed or lychee seed pellets were effective to suppress tumour and hepatoma. Water extract of lychee seed at dosage of 62.5 kg/kg.d obtained 30% suppression on hepatoma tumour in mice (Wang et al. 2007). Xiao et al. (2007) found that extract from lychee seed inhibited the formation of telomere in hepatoma cells and thus their cell division.

Reducing Blood Sugars and Lipids

There have been reports about the effects of lychee seed in reducing blood sugars and lipids and in promoting the function of the liver (Wu et al. 1991; Zheng et al. 1998; Pan et al. 1999; Guo et al. 2003a, b). Results obtained by Wu et al. (1991), Zheng et al. (1998) and Pan et al. (1999) showed that the water extracts of lychee

seeds reduced blood sugar in rat suffering from diabetes induced by ALX and that the effect was similar to that of the anti-diabetic drug, biguanides. And it was found that lychee seed extract was safer and the effect lasted longer (over 1 week) than biguanides (Zheng et al. 1998). Pan et al. (1999) suggested that lychee seed extract reduced blood sugar because it inhibited glucose uptake by blood capillary but promoted glucose uptake in ambient tissues. Guo et al. (2003a, b) also found that lychee seed extract alleviated sugar metabolism disorder and improved sensitivity to insulin in rat suffering from insulin-resistant type 2 diabetes (T2DM) induced by streptomycin and therefore reduced blood sugar. There is little information about active antidiabetes and lipid-reducing substances in lychee seed. Ning et al. (1996) attributed the abundant unsaturated fatty acids to blood lipid-reducing effect of lychee seed. Some authors suggested that α-methylenecyclopropylglycine in lychee seed was effective to reduce the blood sugar and glycogen in liver in mice treated with ALX (Huang 1994), while others believed antidiabetes activity was related to saponins (Guo et al. 2003a, b; Yang and Liang 2004).

Anti-virus Effects

There have been not a few reports about the anti-virus effects of lychee seed extracts, which were effective to hepatitis B virus (Zheng and Zheng 1992; Li 1997; Pan et al. 2000; Xu et al. 2004; Xiao et al. 2005; Jiang et al. 2008), respiratory syncytial virus (RSV) (Liang et al. 2006), influenza virus (Luo et al. 2006) and SARS coronavirus (Gong et al. 2008). Zheng and Zheng (1992) found that lychee seed was the second most effective to control hepatitis B among 1000 tested herbal medicines. Pan et al. (2000) found direct inhibition on in vitro expression of HBsAg and HBV-DNA. Yang et al. (2001) showed that both water and alcohol (50%) extracts from lychee seeds were effective to inhibit HBsAg and HbeAg, but water extract was more effective on HbeAg, while alcohol extract was more effective on HBsAg. Xu et al. (2004) examined six extraction fractions of lychee seed, all showing strong effects in inhibiting the expression of HBsAg and HbeAg in Hep G 2.2.15 cell line, with an inhibiting rate reaching 90.9 and 84.3% on HBsAg and HbeAg, respectively. Most authors attribute anti-virus effect of lychee seed extracts to its flavonoids (Luo et al. 2006; Liang et al. 2006; Gong et al. 2008), while Jiang et al. (2008) suggested that saponins in lychee seed were the effective component.

Other Functions

Lychee seed is especially effective to cure haemorrhoids (Deng 2006).

5.7 Postharvest Strategies

The lychee 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 perishable nature of lychee (*Litchi chinensis* Sonn.) poses a serious problem in its transportation and marketing also. Lychee is delicate, so minimal handling is preferred. Ideally, fruit should be shipped

on the day of harvest. The fruit must also be marketed and consumed quickly. 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 antifungal treatment in the orchard prior to harvest. The harvested fruit would be initially placed in a coolroom to remove the field heat and then sorted on a roller conveyor in the packhouse. 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 3–5% O_2 and 3–5% CO_2 was mentioned earlier, but other mixtures, and gases such as nitrous oxide (Qadir 2001), may also be used.

The shelf life of lychee at ambient temperature (26 ± 2 °C) is less than 72 h. Postharvest losses of lychee are estimated to be 20–30% of the harvested fruit and could reach as high as 50% (Jiang et al. 2001). As fruits start deteriorating quickly upon plucking, they are graded, packed in boxes with green leaves as cushioning materials and immediately routed to wholesale and retail markets (Shi et al. 2001). Besides postharvest decay, pericarp browning is another problem limiting market value of lychee. Much work has been done on the roles of pigments, plant growth regulators and other factors responsible for pericarp browning (Zhang and Quantick 1997). Optimizing suitable temperature and chemicals to inhibit or delay pericarp browning during postharvest is necessary (Paull and Chen 1987, Jiang and Fu 1999). It has been reported that pericarp browning of harvested lychee is due to a rapid degradation of anthocyanidin by polyphenol oxidase (PPO) and peroxidase (POD) (Akamine 1960; Chen and Wang 1989; Lee and Wicker 1991). Dehydration also contributes to pericarp browning (Scott et al. 1982; Underhill and Simons 1993) and leads to 40% decrease in water content after 48 h storage at 25 °C, 60% relative humidity (Underhill and Critchley 1994). Postharvest decay also occurs due to bacteria, yeast and fungi.

Various techniques to reduce browning, control postharvest decay and extend storage life of lychee fruit include sulphur fumigation, fungicide dips, application of plant growth substances, waxes and chitosan coating, use of microbial antagonists (e.g. *Bacillus subtilis*), irradiation and heat treatments (Table 5.5). Of these, only sulphur fumigation and fungicide dips have been used commercially (Jiang et al. 2003). Alternative procedures to sulphur dioxide (SO_2) fumigation of lychee fruits have been proposed. These include team treatment (Kaiser et al. 1995) or hot benomyl dipping (Scott et al. 1982), but so far, no method has been widely accepted or established commercially (Lichtera et al. 2000). SO_2-fumigated fruits absorb 30–65% of applied SO_2. In recent years, there has been an increasing concern about sulphur residues in fruit, particularly when some consumers are sensitive to sulphites. A maximum residue limit of 10 ppm sulphur is set in Europe, Australia and Japan, while in the USA, sulphur is only registered for postharvest use on grape (Paull et al. 1995). Similarly, a range of fungicides has been evaluated for disease control in lychee fruit, including benomyl, thiabendazole, iprodione and prochloraz (Huang and Scott 1985; Scott et al. 1982; Wong et al. 1991). Among these fungicides, benomyl is known to have a strong and broad spectrum of fungicidal activities and has been shown to be effective for control of lychee fruit decay, but it is no

Table 5.5 Overview of strategy used for postharvest management of lychee fruit

Treatments	Result	References
Sodium metabisulphite	Slowing browning and decay	Liang et al. (2012)
Hydro-cooling for 30 min	Prolonged storage life and suppressed fruit decay	Liang et al. (2013)
Nitric oxide (SNP 2 mM)	Extended shelf life up to 8 days	Barman et al. (2014)
Chitosan 1%	Shelf life extension up to 5 days	Lin et al. (2011)
Cold storage, anaerobic and pure oxygen environment	Short-term anaerobic treatment has been found effective than pure oxygen	Liu et al. (2011, 2014)
Gamma radiations (400Gy)	Maintaining quality attributes	(Gautam et al. 2013)
Inhibitory chemicals (butanol or hexanal) treatment	Oxidative stress management	Sun et al. (2011) and Sharma et al. (2010)
Ascorbic acid treatment and chitosan coating	5 mg/l ClO_2 solution significantly inhibited lychee anthracnose spore germination. In addition, treatments with 80 and 120 mg/l of ClO_2 significantly reduced postharvest decay and peel browning of the fruit	Sun et al. (2010)
Combinatorial treatment of sodium metabisulphite, acid dips and perforated LDPE storage	Enhanced shelf life of 9 days at ambient temperature	Neog and Saikia (2010)
Modified atmosphere at low temperature	Maximum retention of pericarp colour	Semeerbabu et al. (2007)
Apple polyphenols	Controlling enzymatic browning	Zhang et al. (2015)
Hot water brushing with micro-polyethylene film	Accumulated acetaldehyde and ethanol inhibited fungal growth	Pesis et al. (2002)
1-Methylcyclopropane	PPO, POD and browning decreased	Reuck et al. (2009)

longer registered as a postharvest chemical in many countries due to potential oncogenic risks (National Research Council 1987). Irradiation of fruit is considered to reduce browning and postharvest losses. Storage temperature of 2–5 °C is considered to extend the shelf life. Uses of perforated polythene bags (0.2% ventilation) and storage at 3 °C have also been reported to increase shelf life.

Ascorbic acid treatment of lychee fruit has been reported to increase the antioxidation capacity, and chitosan coating inhibits dehydration and microbial attack. Recently, a novel strategy of the combinatorial use of both the aforesaid treatments has been proposed. It includes treatment of the harvested fruits with 1.0% ascorbic acid (w/v) and 40 nmol/l chitosan solution (Sun et al. 2010).

5.8 Lychee Diseases

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 Lycheei*) 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.

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 (Table 5.6).

5.9 Lychee Biotechnology

Since lychee is a cross-pollinated plant, it is highly heterozygous, and the progeny is not true to the parental type. Conventional vegetative propagation methods currently being used, air layering or marcottage, are slow and inefficient (Chapman 1984). Hence, in vitro techniques have potential use in lychee propagation for the large-scale cloning of elite plants. However, lychee has so far proven to be a difficult material for propagation using in vitro culture. Attempts to regenerate plants from explants derived from mature trees have failed to give satisfactory results (Kantharajah et al. 1989). The biotechnological research on lychee, including tissue culture, anther culture, protoplast culture and lychee biopharming, are still in infancy but progressing (Table 5.7). Lychees are now widely grown in tropical and subtropical regions of the world. However, irregular and poor yields are commonly reported, and there is considerable scope for improving fruit quality and marketability through biotechnology (Menzel 1983; Galan Saúco and Menini 1989).

Table 5.6 Diseases of *Lychee chinensis* caused by various classes of organisms

Disease	Causative organism	Symptoms	Images	Control measures	Reference(s)
Algal	*Cephaleuros virescens*	Velvety, cushionary, reddish-brown or orange-coloured patches appear on leaves surface		–	Papademetriou and Dent (2002)
Fungal	*Botryosphaeria* spp.	Sunken, shrinking, irregular and dying tissues and expose the inner-side wood		Wound paint should be applied on the cut surface	
	Colletotrichum gloeosporoides	Anthracnose fruit rot: brownish spots appear on the fruit surface; mycelial mat of white colour also appears on mature fruit skin		5 mg/l ClO_2 solution could significantly inhibit lychee anthracnose spore germination. In addition, treatments with 80 and 120 mg/l of ClO_2 significantly reduce postharvest decay and peel browning of the fruit	
	Colletotrichum gloeosporoides (leaf necrosis)	Lesions appear on the leaf surface		–	
	Diplodia spp. (lychee dieback)	Wood becomes shrivelled and changes to black or brown in colour		Pruning of trees	
	Gloeosporium spp. (leaf blight)	Light brown-colour spots are visible on leaf surface		–	

(continued)

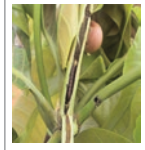
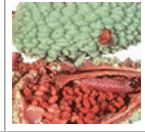
Table 5.6 (continued)

Disease	Causative organism	Symptoms	Images	Control measures	Reference(s)
	Phoma spp. (corky bark lesions)	Rough and brown-coloured lesions appear on the branches		–	
	Phomopsis spp. (dieback, canker and leaf spot)	Branch tip starts dying, red-colour spots appear on leaves		–	
	Phyllosticta spp. (Phyllosticta leaf rot)	Large, round, brownish-black-coloured spots appeared along the margins and tips of leaves which lead to wilting of leaves		–	
	Pythium spp. (root rot)	Root tips are rotten, the number of secondary roots is lesser, pale yellow leaves		Destroy the infected trees	
	Rhizoctonia solani (root rot)	Rotten roots turn dark brown in colour		Destroy the infected trees	
	Spheropsis spp. (Spheropsis dieback)	Cankers appeared on the branches and form witches broom		Remove the brooms from the tree	

	Peronophythora lychee	Fruit rotting		Crude extract of *Bacillus subtilis* used as antifungal against *Peronophythora lychee*	Jiang et al. (2001)
		Affect fruits, leaves and panicles, immature fruit turns brown		Spraying of copper oxychloride in winters and copper sulphate in spring	Menzel (2002)
	Colletotrichum gloeosporoides	Affect leaves, branches, flowers and fruits, small light grey lesions appear on leaf surface		Spray of copper oxychloride and copper hydroxide	
	Peronophythora lychee (downy blight)	Brown and withering spots appear on panicles, fruits and shoots		Application of fungicide mandipropamid protects the plant from downy blight	Tang et al. (2011)
	Colletotrichum spp.	Browning of pericarp and fruit decay		Application of chlorine dioxide (ClO_2) inhibits the spore germination	Wu et al. (2011)

(continued)

Table 5.6 (continued)

Disease	Causative organism	Symptoms	Images	Control measures	Reference(s)
Insect pests (fruit borers)	*Conopomorpha sinensis*	Lays yellow-coloured scale like eggs on fruits, leaves and shoots. Larva penetrates into fruit which leads to fruit fall		Insecticides (permethrin, cypermethrin, deltamethrin, carbofuran or fenthion)	
	Conopomorpha Lycheeella	Lays eggs on shoots, larva penetrates into leaf blades, midrib and veins and leads to wilting of shoots		Insecticidal spray	
	Argyroploce illepida	Lays eggs on fruit surface, larva penetrates into fruit which results in fruit fall		Spray of triflumuron (insecticide) 40 days before harvest	
Insect pests (Fruit-piercing moths)	*Eudocima fullonia*, *E. salaminia*, *E. jordani*	Sucks fruit juice through hole, contamination of fruit with yeast and bacteria damage the fruit		Trap system is used to capture the moths	
Insect pests (leaf feeding caterpillar)	*Oxyodes scrobiculata* F., *Oxyodes tricolor*	Severe defoliation occurs		Spray of carbaryl (insecticide) on young larvae	
Insect pests (leaf-rollers)	*Olethreutes perdulata* Meyr., *Platypeplus aprobola*, *Adoxophyes cyrtosema* Meyr., *Homona coffearia*, *Isotenes miserana*	Rolling of leaf and then leaf fall		Rolled leaves are removed manually or spraying of insecticides (phosphamidon, fenitrothion or endosulfan) for heavy infestation	

Insect pests (bark borers)	*Aristobia testudo*, *Anoplophora*, *Maculate*	Kill branches and shoot tips		Beetles can be picked manually, or dichlorvos (insecticide) is injected into the tunnels made by beetles	
Scarab beetles	*Xylotrupes gideon*	Damage the fruit		Can be picked manually, chemical control is not satisfactory	
Soft scales	*Pulvinaria psidii*, *Coccus hesperidum*, *Parasaissetia nigra*, *Saissetia coffeae*	Affects the leaves, flowers, twigs and young fruits, discolouring of fruits		Application of methidathion (insecticide)	
Bugs	*Tessaritoma papillosa*, *Tessaritoma javanica* Thunberg, *Tessaritoma quadrata* Distant	Causes severe fruit fall		Application of two sprays of endosulfan after every 2 weeks	
Gall flies	*Dasineura* spp.	Formation of galls on the leaf surface which later turn brown and fall off		Burn or remove the infected leaves, methyl parathion (2.5%) applied under trees or spraying of isofenphos (0.001%)	
Fruit flies	*Bactrocera tryoni* (Froggatt)	Damage the fruit pericarp by laying eggs		Spray of protein hydrolysate in combination with trichlorfon or mercaptothion is used	

(continued)

Table 5.6 (continued)

Disease	Causative organism	Symptoms	Images	Control measures	Reference(s)
Mites	*Aceria litchii* (Keifer)	Bristles on entire leaf which leads to curling of leaf, fruit deforming		Infected leaves should be removed and burnt, spraying of dimethoate, dicofol, chlorpyrifos, omethoate and isocarbophos	
		Leaf galls are formed, which later fall down from tree after drying up		Burn the infected leaves, spraying of Kelthane or Neoron or Torque or wettable sulphur (2.0 ml/l) of water in April or May	Papadimitriou and Dent (2002)
Weevil/fruit borer	*Apoderous sp.*, *Conopomorpha cramerella*	Tan spots appear on the leaves surface which causes severe harm to new leaves, young trees of age less than 5 years are totally damaged		Use of biocontrol agents such as *Trichogramma* spp. and neem (*Azadiracta indica*)-based insecticidal sprays	Kumar et al. (2006)

Table 5.7 Tissue culture reports on *Lychee chinensis*

Explant	Media composition (mg/l or µM or %)	Response	Reference(s)
Embryo	MS media + sucrose (0.2 g/l) + royal jelly (400 mg/l)	Callus formation	Kantharajah et al. (1992)
Embryonic shoots	MS media + BAP (100.0 mg/l)	Shoot formation	
Shoots	MS media + NAA (0.5 mg/l) + sucrose (0.2 g/l) + agar (0.8%)	Root formation	
Young embryo	MS media + 2,4-D (8.0 mg/l) + NAA (0.2 mg/l) + sucrose (0.5 g/l)	Embryogenic callus formation	Zhou et al. (1996)
Embryogenic callus	MS media +2,4-D (1.0 mg/l)	Embryogenic callus was maintained	
Embryogenic callus	½ MS media + NAA (0.2 mg/l) + IBA (1.0 mg/l) + sucrose (0.3 g/l)	Germination	
Shoot buds	MS media + BA (0.2 mg/l) + IAA (0.1 mg/l) + GA3 (0.5 mg/l)	Shoot differentiation	Chandra and Padaria (1999)
Cotyledonary node	MS media + BAP (20.0 mg/l)	Multiple shoot induction	Das et al. (1999)
Shoots	MS media + IBA (25.0 mg/l)	Root induction	
Zygotic embryos	MS media +1 2,4- D (2.0 mg/l) + sucrose (50.0 g/l) + agar (8.0 g/l)	Embryogenic callus formation	Yu et al. (2000)
Protoplast	MS media + KIN (1.0 mg/l) + NAA (0.1 mg/l) + glutamine (500.0 mg/l) + sucrose (0.8 g/l) + agar (15.0 g/l)	Somatic embryo formation	
Somatic embryo	MS media + glutamine (500 mg/l) + coconut water (50.0 ml) + sucrose (0.5 g/l) + agar (0.9 g/l)	Maturation of somatic embryo	
Somatic embryo	MS media + GA (5.0 mg/l) + coconut water (50.0 ml) + sucrose (0.3 g/l) + agar (0.7 g/l)	Germination of somatic embryo	
Leaf	MS media + 2, 4-D (2.0 mg/l) + NAA (2.0 mg/l) + IAA (2.0 mg/l) + BAP (1.0 mg/l) + KIN (1.0 mg/l) + sucrose (0.3 g/l) + phytagel (0.25%) + ascorbic acid (225.0 mg/l) + citric acid (225.0 mg/l)	Callus induction	Puchooa (2004a)
Callus	MS media + BAP (2.0 mg/l) + IAA (3.0 mg/l) + sucrose (0.3 g/l) + phytagel (0.25%) + ascorbic acid (225.0 mg/l) + citric acid (225.0 mg/l)	Shoot induction	
Shoots	MS media + IBA (2.0 mg/l) + NAA (3.0 mg/l)	Root formation	

(continued)

Table 5.7 (continued)

Explant	Media composition (mg/l or µM or %)	Response	Reference(s)
Cotyledonary nodes	MS media + BAP (20.0 mg/l)	Shoot induction	Khan and Ahmad (2005)
Shoots	MS media + IBA (25.0 ml/l)	Root formation	
Embryo	MS media + BAP (0.5 mg/l) + KIN (0.5 mg/l) + LH (500.0 mg/l) + sucrose (60.0 g/l) + agar (10.0 g/l)	Somatic embryogenesis	Chao-jun et al. (2007)
Leaflet	B5 media + glutamine (400.0 mg/l) + 2,4-D (4.52 µM) + KIN (9.30 µM) + casein hydrolysate (200.0 mg/l) + sucrose (30.0 g/l) + gellan gum (3.0 g/l)	Embryogenic callus formation	Raharjo and Litz (2007a)
Embryogenic callus	MS media + sucrose (45.0 mg/l) + coconut water (20%) + gellan gum (3.0 g/l)	Somatic embryo development	
Somatic embryo	MS media + sucrose (30.0 mg/l) + gellan gum (3.0 g/l)	Germination	
Leaflet	B5 media + glutamine (400.0 mg/l) + 2,4-D (4.52 µM) + KIN (9.30 µM) + casein hydrolysate (200.0 mg/l) + sucrose (30.0 g/l) + gellan gum (3.0 g/l)	Embryogenic callus formation	Raharjo and Litz (2007b)
Embryogenic callus	MS media + sucrose (45.0 mg/l) + coconut water (20%) + gellan gum (3.0 g/l)	Somatic embryo development	
Somatic embryo	½ MS media + GA3 (14.4 µM) + activated charcoal (0.2 g/l)	Germination	
Leaflet	MS media +2,4-D (2.0 mg/l) + NAA (0.5 mg/l) + KIN (2.0 mg/l) + activated charcoal (200.0 mg/l) + sucrose (3.0 g/l) + agar (7.0 g/l)	Callus	Ma et al. (2009)
Callus	MS media + IAA (3.0 mg/l) + BAP (2.0 mg/l)	Friable callus formation	
Friable callus	MS media +2,4-D (2.0 mg/l) + NAA (0.5 mg/l) + KIN (2.0 mg/l) + activated charcoal (200.0 mg/l)	Suspension culture	

(continued)

Table 5.7 (continued)

Explant	Media composition (mg/l or µM or %)	Response	Reference(s)
Nodal explant	Modified liquid woody plant medium + BAP (11.0 µM) + KIN (2.30 µM) + GA3 (0.60 µM) + bavistin (30 µg/l) + polyvinyl polypyrrolidone (0.2%)	Callus formation	Kumar et al. (2006)
Callus	Modified liquid woody plant medium + BAP (11.0 µM) + KIN (2.30 µM) + GA3 (0.60 µM) + coconut water (15%)	Shoot formation	
Shoots	MS media + BAP (6.6 µM) + GA3 (0.15 µM) + SN (30 µM) + CH (300.0 mg/l)	Shoot multiplication and elongation	
Elongated shoots	MS media + IBA (20.6 µM) + lychee seed powder (1.0 g/l)	Root formation	
Zygotic embryos	MS media (modified)	Transgenic plantlet	Das and Rahman (2012)
Shoot tip	MS media + ascorbic acid (250.0 mg/l) + citric acid (250.0 mg/l) + sucrose (0.3 g/l)	Callus formation	Pankaj et al. (2014)

5.10 Conclusions

Lychee is a wonder-fruit with a blend of taste and medicinal value. Lychee postharvest research has been ongoing since the 1940s, and there has been a significant growth in the past 10 years. Most of the scientific papers relating to lychee have been published since 1985. Due to its increasing demand, the area under cultivation has increased manifold. But, there are several factors which have cumulatively hampered its production. These include irregular flowering and fruit-set, frost and wind damage, narrow cultivar base, poor growing techniques, high incidence of insect pests, short production season, variable yields, poor-quality fruit, short harvest season, lack of planting material and growing technology, high cost of planting material, lack of irrigation, lack of technical information for new growers, susceptibility of fruits to browning and rotting, short shelf life of fruits, inappropriate pruning, harvesting and postharvest management, high cost of fertilizers, inefficient marketing system and inadequate industry research and extension. The following suggestions can ensure a marked improvement in lychee production, storage and supply strategies.

- Lychee has a very narrow genetic base, which needs to be widened through selection of genotypes from the existing population. Target-oriented programmes must be launched so that germplasm is conserved and used. In this context of a

network programme, 'operation lychee production' (OLP) should be initiated, and exchange of information and cultivars among countries should be encouraged. Starting of this network programme would boost lychee production and ensure livelihood security of the people.

- It should also be possible to apply in vitro mutation induction and selection procedures to address certain fungal diseases that affect specific lychee cultivars.
- Genetic transformation could possibly be utilized to develop the preferred 'chicken-tongue' seeds, using the pistillate gene from *Arabidopsis thaliana*, which directs seedlessness.
- Protoplast technology could be harnessed to produce somatic hybrids between haploids and diploids, so as to develop seedless triploids.
- Suitable cultivars are needed for various climatic conditions. It is also essential to develop promising lines/hybrids, which have larger fruit size, small/chicken-tongued seeds and tolerance to pericarp splitting.
- Suitable agro-techniques particularly for production and consumption management, postharvest technology and effective marketing need due attention.
- A systematic approach for the description of cultivars is needed. Thus, a lychee descriptor needs to be developed for herbaria and agriculture.
- There is need to develop propagation technology for faster multiplication of quality plants.
- The development of nutrition management to maintain tree health and encourage successful flowering and fruiting quality in sustainable manner requires attention.
- For efficient fertilizer use, monitoring through leaf analysis should be encouraged.
- Integrated management of nutrient and water with efficient monitoring mechanisms would improve both production quantity and quality.
- Through effective recycling of residues coupled with organic manure, it is possible to improve soil health. Thus, there is an immense potential for organic production of lychee through integrated pest management (IPM) to improve productivity and reduce the cost of production.
- The infrastructure for postharvest management requires input for timely marketing and to reduce the storage losses.

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