

The mature litchi fruit is round to oval in shape and bright red in colour. It has a thin, leathery and indehiscent pericarp surrounding a succulent, edible white aril. The aril contains a relatively large dark brown seed. Litchi fruit is non-climacteric with little change in soluble solids concentration or titratable acidity after harvest. The fruits deteriorate rapidly unless proper handling techniques are employed. The major factors reducing the storage life and marketability of litchi fruit are microbial decay and pericarp browning. Low temperature storage at 1°C after harvest. The fruits deteriorate rapidly unless proper handling techniques are employed. The major factors reducing the storage life and marketability of litchi fruit are microbial decay and pericarp browning. Low temperature storage at 1–5°C is used to reduce pathological decay, but has only limited role in reducing pericarp browning. Moreover, the fruits deteriorate rapidly when removed from cold storage. Under refrigeration, litchi fruit has a storage life of approximately 30 days. Pulp quality and disease development are generally stable during cold storage until such time as fruit become visually unacceptable based on the evaluation of pericarp browning. Sulfur dioxide fumigation has been the most effective postharvest treatment for control of pericarp browning in litchi fruit, and is used extensively in commercial situations. However, there is increasing consumer and regulatory resistance to the use of this chemical. Insect disinfestation has become increasingly important with the expanding export market. Irradiation and heat treatments for insect disinfestation of litchi fruit have been found to be alternatives to treatment with insecticides. Recent research has focused on reducing these major postharvest problems in order to produce light-coloured, chemical-free fruit without disease or insect infestation.

**Key words:** Handling, litchi, pathology, physiology, postharvest, quality, storage.

**Introduction**

Litchi (*Litchi chinensis* Sonn.) is a subtropical tree of the Sapindaceae family, indigenous to parts of Southern China1-3. The fruit is small, conical, heart-shaped or spherical in shape and bright red in colour. The edible portion of litchi fruit is a white to cream-coloured translucent pulp that surrounds a glossy and brown seed. The pulp is grape-like in texture, very succulent and aromatic, and is characteristic by a sweet, acid, juicy, soft but crisp (turgid) taste. Thus, litchi fruit is highly prized in its fresh form. With the increasing popularity of exotic fruits on the world market, litchi production has steadily increased in the past decades4-5. In 2001, world litchi production is about 2,000,000 tons, most of which are produced in China, India and Thailand. Furthermore, new plantings are still grown, which ensures a continuous growth of litchi fruit in world production. The early research on postharvest litchi was aimed at establishing suitable storage conditions and packing materials, evaluation of various forms of plastic packaging and optimisation of storage temperatures6-9. Although significant progresses have since been made from these postharvest researches, the physiological browning and disease development of litchi fruit after harvest are still the main limitations to the storage of the fruit10-12. Recently, great progress towards understanding the postharvest biology of and improving postharvest technology for litchi fruit has been rapid13-18. This paper reviews recent research on postharvest biology and handling of litchi fruit, with more comprehensive literatures.

**Ethylene Evolution**

Litchi fruit produces relatively low levels of ethylene (<2.8 µL kg⁻¹ h⁻¹) after harvest, in comparison with climacteric fruits19, 21. However, high ethylene evolution rates (18.5–21.8 µL kg⁻¹ h⁻¹) of ‘Huai zhi’ fruit have been recorded in association with skin desiccation and fungal infection23. Chen et al.21 reported that the ethylene evolution rate of fruit stored at 1–3°C remained relatively constant for 30 days after stabilising on the first day. An increase in ethylene production rate after 30 days was associated with decay.

**Respiration**

Litchi fruit is non-climacteric and do not continue to ripen after harvest17-18. Jiang et al.19 monitored the fruit during development and found a continuous decline of respiration, while the respiration of ‘Huai zhi’ fruit decreased on the first day after harvest and then increased20. A later rapid increase in respiration after harvest is possibly associated with disease development. Fruit stored at 1–3°C has a continuous decline in respiration, suggesting that low temperatures effectively inhibit the respiration of litchi fruit21. Furthermore, over-ripe ‘Mauritius’ fruits on the tree were observed, with undergoing anaerobic respiration22.

**Pathology**

Litchi fruits are very susceptible to postharvest decay24-25. A wide range of fungal pathogens has shown to cause postharvest disease in litchi fruit, many of which are commonly encountered in other tropical and subtropical fruit (Table 1). Some bacterial species have also been isolated from decaying litchi fruit26. Fruit infection by micro-organisms, such as *Aspergillus, Penicillium* and *Rhizopus*, occurs during and after harvest through skin injury, whereas *Botryodiplodia* infects fruit either in the field or through the cut stem end during harvesting or handling27.

**Abstract**

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**Keywords:** Handling, litchi, pathology, physiology, postharvest, quality, storage.
Table 1. Major postharvest fungal pathogens of litchi fruit

<table>
<thead>
<tr>
<th>Pathogens</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alternaria sp.</td>
<td>24, 45</td>
</tr>
<tr>
<td>Agrostosporidium sp.</td>
<td>26</td>
</tr>
<tr>
<td>Aspergillus spp.</td>
<td>26, 45, 77</td>
</tr>
<tr>
<td>Cladosporium sp.</td>
<td>45</td>
</tr>
<tr>
<td>Colletotrichum spp.</td>
<td>24, 45, 77</td>
</tr>
<tr>
<td>Curcularia sp.</td>
<td>26, 77</td>
</tr>
<tr>
<td>Cylindrocarpon tonkinense</td>
<td>77</td>
</tr>
<tr>
<td>Dothiorella sp.</td>
<td>24</td>
</tr>
<tr>
<td>Fusarium spp.</td>
<td>26, 77</td>
</tr>
<tr>
<td>Geotrichum candidum</td>
<td>78, 79</td>
</tr>
<tr>
<td>Geotrichum ludwigii</td>
<td>80</td>
</tr>
<tr>
<td>Lasiodiplodia theobromae</td>
<td>24, 26, 77</td>
</tr>
<tr>
<td>Monilia sp.</td>
<td>26</td>
</tr>
<tr>
<td>Mucor sp.</td>
<td>26</td>
</tr>
<tr>
<td>Neurospora sp.</td>
<td>26</td>
</tr>
<tr>
<td>Nigrospora sp.</td>
<td>26</td>
</tr>
<tr>
<td>Penicillium spp.</td>
<td>45, 77</td>
</tr>
<tr>
<td>Peronoplythora litchi</td>
<td>81</td>
</tr>
<tr>
<td>Pestalotioptis sp.</td>
<td>77</td>
</tr>
<tr>
<td>Phoma sp.</td>
<td>24</td>
</tr>
<tr>
<td>Phomopsis sp.</td>
<td>24, 45</td>
</tr>
<tr>
<td>Rhizopus sp.</td>
<td>26, 45</td>
</tr>
<tr>
<td>Sphymylidum sp.</td>
<td>26, 45</td>
</tr>
<tr>
<td>Trichoderma sp.</td>
<td>45</td>
</tr>
</tbody>
</table>

Table 2. Insect pests of litchi fruit

<table>
<thead>
<tr>
<th>Common name</th>
<th>Organism</th>
<th>Region</th>
</tr>
</thead>
<tbody>
<tr>
<td>Litchi moth</td>
<td>Argyroplane peltatica</td>
<td>South Africa</td>
</tr>
<tr>
<td>Litchi stink bug</td>
<td>Tessartoma papillosa</td>
<td>China</td>
</tr>
<tr>
<td>Macadamia nut borer</td>
<td>Cryptophlebia ombreda</td>
<td>Australia</td>
</tr>
<tr>
<td>Mediterranean fruit fly</td>
<td>Ceratitis capitata</td>
<td>South Africa</td>
</tr>
<tr>
<td>Natal fly</td>
<td>Ceratitis rosa</td>
<td>South Africa</td>
</tr>
<tr>
<td>Oriental fruit fly</td>
<td>Dacus dorsalis</td>
<td>Hawaii</td>
</tr>
<tr>
<td>Shot hole borer</td>
<td>Acrocerocops cromerella</td>
<td>China</td>
</tr>
</tbody>
</table>

Entomology

Insects are of great concern in litchi production. Table 2 shows a list of the insects reported in literatures. Scale insects and mealy bugs are considered as a major problem during the marketing of litchi fruit, in particular, when they infest the fruit and have to be removed for export. While Mediterranean fruit fly (Ceratitis capitata) does not attack litchi fruit except where the fruit has been broken by other means and the pulp is exposed, the oriental fruit fly (Dacus dorsalis) does infest litchi fruit. This infestation causes punctures, which are often the focus of entry of fungal organisms, and in turn, causes fermentation and decomposition of the fruit. Other fruit flies can be serious pests of litchi tree and fruit, depending on the geographical locations for litchi production.

Grading

No official grades or international standards are available for litchi fruit. In practice, the fruits are graded on the basis of their size or weight. In China, ‘Ru mi ci’ fruit ranging 40–50 fruits per kg is usually considered to be the top grade.

Precooling

Litchi fruit shelf-life is limited by a number of factors, such as a decline in visual appearance, a reduction in organoleptic quality and the development of diseases. A rapid moisture loss of litchi fruit occurs during harvesting and transportation if improper packaging is employed. Immediate and fast precooling are important in the cold chain for litchi fruit and can remove field heat and provide effective temperature management during subsequent storage or shipment. The immediate hydrocooling using iced-water for 2–3 h at 0–2°C may attain satisfactory results of postharvest treatments for litchi fruit. However, when forced-air cooling is used for this treatment, it requires a high-capacity cold room and takes at least 12 h to make an effective commercial treatment. Furthermore, unless the cold room operates at 85% relative humidity, forced-air cooling may lead to fruit desiccation. Thus, hydrocooling becomes a preferable technique to that of forced-air cooling in the postharvest handling of litchi fruit. Commercial hydrocooling has been progressively adopted in Australia, Thailand and China.

Treatments

Techniques to reduce browning, control postharvest decay, and extend storage life of litchi fruit have included sulphur fumigation, fungicide dips, application of plant growth substances, waxes and chitosan coatings, use of microbial antagonists (e.g. Bacillus subtilis), irradiation and heat treatments. Of these, only sulphur fumigation and fungicide dips have been used commercially.

Sulphur

SO2 fumigation has been considered as the most effective and practical postharvest treatment for control of colour change for litchi fruit. Fumigation is achieved by burning sulphur powder at ambient temperature for 20–30 min with no humidity control, vaporizing liquid SO2 held in a pressurized cylinder, or dissociation of sulphite compounds. However, one of the main problems with this treatment is that sulphur rapidly bleaches the pericarp surface due to the formation of a colourless anthocyanin-SO3H complex. Although colour will partially recover, the degree of the colour recovery depends on the rate of subsequent SO2 release. Zauberman et al. reported that the addition of acid dip (e.g. 1 M HCl) results in a complete colour recovery. Tongdee found that the acid treatment does not affect eating quality of the fruits. Sulphur residues of fumigated fruit are higher in the pericarp than in the aril, and decrease rapidly during the first few days after fumigation. In addition, dipping in sodium metabisulphite is found to be effective against pericarp browning. However, application of sodium metabisulphite is comparatively less effective and more variable compared with SO2 treatment. In recent years, there has been 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 USA, sulphur is only registered for postharvest use on grape.

Acid Dips

The bright red colour of litchi fruit fades during storage, possibly as the result of an increase in the pH value of the cell sap. Zauberman et al. and Duvenhage reported that dipping litchi fruit in a diluted HCl solution can completely restore or recover the bright red colour following SO2 fumigation. Furthermore,
Kaiser\textsuperscript{43} found a breakdown of pericarp membrane with low pH detergents. This breakdown may allow co-pigmentation of the anthocyanins. Ketsa et al.\textsuperscript{44} suggested that the effectiveness of acid dipping in preventing litchi browning stabilized the anthocyanin pigments. However, there was no direct evidence of co-pigmentation and these results may simply be due to a pH effect. In addition, application of acid dips without the addition of fungicides can result in more infestations with \textit{Penicillium} (Lichter, unpublished data).

**Fungicides**

A range of fungicides has been evaluated for disease control in litchi fruit, including benomyl, thiabendazole, iprodione and prochloraz\textsuperscript{45-46}. 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 litchi fruit decay, but it is no longer registered as a postharvest chemical in many countries due to potential oncogenic risks\textsuperscript{49}. Alternatively, the storage life of litchi fruit can be extended by use of thiabendazole, followed by packing in sealed polyethylene bags under ambient conditions or at low temperatures. Treatment with 0.1% thiabendazole, in combination with 0.05% iprodione, gives even more effective control of the decay in litchi fruit, while SO\textsubscript{2}-fumigated litchi fruit followed by a dip with 0.1% prochloraz has the longest storage life at either ambient temperatures or low temperatures (Jiang, unpublished data). However, alternative means of decay control in litchi fruit are needed\textsuperscript{50} because of worldwide consumer concern to and regulatory changes in the use of fungicides in the future.

**Microbial Metabolites**

SO\textsubscript{2} and fungicide applications are generally not favoured by the consumers of litchi fruit, either by regulatory authorities or environmentalists\textsuperscript{51}. Therefore, non-chemical alternatives have been investigated. Jiang et al.\textsuperscript{52} reported that the culture supernatant of \textit{Bacillus subtilis} was effective in controlling litchi pathogens. The treated litchi fruit could be stored for about 30 days at 5\textdegree C, with good turnout of the quality.

**Irradiation**

Irradiation could be a viable alternative to chemical treatments, particular SO\textsubscript{2} fumigation, which is detrimental to fruit quality\textsuperscript{53}. In an early study, Kramer and Kuhn\textsuperscript{54} reported that decay on stored ‘Brewster’ litchi was reduced by 2 kGy of irradiation and virtually eliminated by 5 kGy of irradiation. However, Akamine and Goo\textsuperscript{55} found that levels of 2 kGy or greater caused darkening of the pericarp and affected the organoleptic properties of the fruit. McLauchlan et al.\textsuperscript{56} recommended that irradiation at 1 kGy followed by storage at 5\textdegree C reduced decay and extended the storage life of ‘Tai so’ fruit. Nevertheless, irradiation is not yet commercially used in most countries, as a result of common concern of the consumers on the unclear effects of the irradiative treatment.

**Heat Treatment**

The earlier work by Wong et al.\textsuperscript{57} and Underhill and Critchley\textsuperscript{58} indicated that rapid browning will occur if litchi fruits are held at >50\textdegree C for more than 2 min. Furthermore, Jiang et al.\textsuperscript{59} found that heat treatment (55\textdegree C, 2 min) activated PPO activity, which may aid in the explanation of the browning of litchi fruits. Kaiser\textsuperscript{51} reported that immersion of litchi fruit in hot water at 98\textdegree C for 30 s, instead of a 2-min hot water treatment, followed by a low pH dip, could significantly improve pericarp colour retention during ambient storage. Similar results were obtained using vapour heat and low pH dip\textsuperscript{59}. Recently, a hot water brushing procedure has been developed by Lichter et al.\textsuperscript{60} for the treatment of litchi fruit. The treated litchi fruit using this procedure can be stored for at least 35 days at low temperature, remaining a uniform red colour.

**Plant Growth Regulators**

Application of kinetin at 20 ppm or Alar at 100 mg/L to postharvest litchi fruits extends their shelf life\textsuperscript{61-62}, while dipping in ethephon solution accelerates the ripening of the fruit\textsuperscript{63}. Treatment with 1-methylcyclopropene, an inhibitor of ethylene reception, shows no significant effect on storage life of litchi fruit (Jiang, unpublished data).

**Coatings**

Skin coatings are generally effective in extending fruit storage life, but little benefit has been found for litchi fruit, due to either a continuous dehydration or a pericarp discoloration. This result may partially explain the inability of current commercial coatings to restrict water loss and therefore inhibit resultant pericarp browning. Thus, different types of coatings based on the characteristics of litchi fruit require a further investigation. In a recent study, Zhang and Quantick\textsuperscript{64} demonstrated that the application of 2% chitosan extended the storage life of ‘Huai zhi’ fruit at 5\textdegree C. Since chitosan is soluble in 2% acetic acid, dipping in acidic chitosan solution inhibited PPO activity, and thus, may assist in delaying the pericarp browning of the fruit.

**Disinfestation Treatments**

Litchi fruit is known as a host of fruit fly. Thus, disinfestation of the fruit in trading is required by many countries, particularly the US and Japan\textsuperscript{27, 65}. In the current law, cold treatment is authorised to undertake for fruit to enter the US market, with a specific treatment schedule for fruit held at 0 to 1.7\textdegree C for 15 days\textsuperscript{65}. Cold storage for 15 days at 1.1\textdegree C has been suggested as a method for insect disinfestation of the litchi fruit. However, storage at this low temperature may produce patches of bronze discoloration on the pericarp. Furthermore, fruit may deteriorate rapidly when removed from cold storage\textsuperscript{16}. Hot water treatment for 15 min at 49\textdegree C could kill fruit flies without adversely affecting the eating quality of litchi fruit\textsuperscript{66}. Tolerance to heat treatments may vary in cultivars. In Japan, litchi fruit needs to be heat treated until the central temperature of the fruit reaches 46.2\textdegree C, and is maintained at this temperature for 20 min, followed by cooling until the fruit temperature reaches 2\textdegree C and is maintained at this temperature for 42 hours\textsuperscript{37}. However, litchi fruit can develop peel browning after this quarantine treatment, and, seriously, this fruit may not be acceptable for marketing (Jiang, unpublished data). As discussed earlier, irradiation is a promising quarantine treatment. The International Consultative Group on Food Irradiation has recommended 150 Gy as a minimum dosage for treating eggs and larvae of fruit flies to prevent emergence of normal adults. This group has also recommended a 300 Gy as a generic disinfestation dosage to sterilize any adults present or emerging from treated larvae or pupae. In addition, gamma irradiation at a level of 75 or 300 Gy breaks the
cycle of Queensland fruit fly (Australia) without affecting the physical, chemical and organoleptic properties of the fruit. Therefore, gamma irradiation would be preferable for insect disinfection of litchi fruit to cold treatment (15 days at 1.1°C) that causes chilling injury of the fruit pericarp. Further investigation with regard to optimum doses of irradiation and variable responses of different cultivars is needed.

**Packaging**

In Asia, bamboo baskets are commonly used to package litchi fruit for local markets. Cardboard boxes and plastic crates are preferentially used for export. The long storage life of ‘Huai zhi’ fruit was obtained at 1–3°C, with fruit remaining marketable for 40 days inside the sealed bags. In contrast, the unbagged litchi fruit at this temperature became unmarketable within 20 days. Under conditions for minimizing moisture loss, the shelf life of litchi fruit stored at low temperatures is limited by a decline in organoleptic quality rather than in visual appearance.

**Storage**

The shelf life of litchi fruit after harvest is restricted by the adverse development of the visual appearance, organoleptic quality and disease development as the storage progresses. Moisture loss occurs rapidly during fruit storage. Under low humidity conditions, visual appearance declines to unacceptable levels due to skin dehydration and browning. Jiang and Fu suggested that a relative humidity (RH) of 85–95% appear to be optimal for storage. However, higher humidity was conducive to water soaking and decay. Litchi fruits are more tolerant to low temperature and, thus, can be stored in the lower temperature range of 1–5°C, but the decline in visual appearance and disease development eventually limit longevity. The minimum temperature at which litchi fruit can be stored for about 30 days without exhibiting chilling symptoms may vary among cultivars. Atmospheric control has been reported to slow the rate of skin colour change in litchi fruit. However, many modified atmosphere (MA) studies lack adequate control treatments to demonstrate how the beneficial effects of atmosphere modification derive. Packed within plastic bags and sealed containers can reduce the rate of pericarp colour change. However, the accumulation of ethanol and acetaldehyde of litchi fruit under modified atmosphere packagings can influence the storage life, due to the anaerobic respiration. Controlled atmosphere (CA) of 4–6% O₂ and 6–8% CO₂ for ‘Huai zhi’ fruit prolonged storage life and maintained quality of the fruit, and reduced pericarp browning. The optimum use of O₂ and CO₂ concentrations associated with effects on disease development and storage life of litchi fruit requires further investigation.

**Processing**

Dried litchi fruit is referred to as litchi nut and popular in Asian countries. The fruit is often dried outdoors since controlled conditions are currently unavailable for many production areas, particularly in countries such as China and Vietnam. The fruit can be blanched and treated with sulphur to help retain their red colour during drying. Litchi fruit can be also frozen without any adverse effects on the aril. However, if they are frozen completely, the pericarp darkens and browns when thawed. Similar treatments to those used for drying can be applied to maintain pericarp colour. Freeze drying of litchi fruit may be worth of research, considering the drying efficiency of this technology.

**Conclusions**

With increased world production of litchi fruit, an impetus for research has come from the identification of export markets for this unique and unusual fruit. Litchi postharvest research has been ongoing since the 1940s, and there has been a significant escalation in the past ten years. More scientific papers relating to litchi have been published since 1985 than in the previous 30 years. Progress towards understanding the postharvest biology of and improving postharvest technology for litchi fruit has been rapid. With greater interest and research effort, further advances are likely in the near future. Non-climacteric litchi fruit must be harvested when they are at their visual and organoleptic optimum. Postharvest treatments and storage regimes that slow the loss of quality need to be optimised. Storage of litchi fruits in sealed polyethylene bags or plastic containers delays loss in fruit quality and extends the shelf life. Loss of quality can be partially alleviated by keeping the fruit under conditions that minimize moisture loss (i.e. reduce desiccation and subsequent skin browning), and this approach must be accompanied with a refrigeration. Depending on the cultivar, temperatures between 1–5°C can effectively extend the storage life of litchi fruit without inducing chilling injury. Elevated CO₂ atmospheres applied as MA or CA can increase storage life by approximately 5–10 days. Application of fungicides, such as thiabendazole, iprodione and prochlorothrin, helps gain effective control of spoilage pathogens. Under conditions of fungicide treatment, protective packing, high CO₂ concentration and low temperature, litchi fruit have a storage life of about 30 days. Decay is the major postharvest problem of litchi fruit. Future research should be directed into postharvest disease management. Deterioration of visual appearance is also problematic. Although SO₂ fumigation has proved effective for control of pericarp browning, with increasing resistance to the use of sulphur, there is a need to better understand the biochemistry of pericarp browning with a view to finding alternative treatments. Most probably, litchi postharvest handling strategies of the future will emphasise more on the temperature management and non-chemical disease control. While considerable cultivar variability in terms of browning has been reported in avocado and mango, selective breeding of new litchi cultivars is of significant under-resourced area. In Australia, new anti-browning pineapple cultivar is being developed using anti-sense RNA of PPO. The potential of genetic manipulation to prevent litchi browning and spoilage should be explored, but is not available to be practicable in the short term. Meanwhile, the litchi industry should continue to develop new approach to better control pericarp browning and disease development of the fruit during storage, transportation and marketing.

**Acknowledgement**

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