International Journal of Advanced Biochemistry Research

ISSN Print: 2617-4693
ISSN Online: 2617-4707
IJABR 2025; SP-9(1): 733-740
www.biochemjournal.com
Received: 23-10-2024
Accepted: 26-11-2024

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Enhancement of post-harvest life of litchi: A review on application of packaging material and chemicals

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DOI: https://doi.org/10.33545/26174693.2025.v9.i1Sj.3597

Abstract
Litchi (*Litchi chinensis* Sonn.) is highly perishable due to its rapid browning and post- harvest decay, posing significant challenges in maintaining fruit quality during storage and transport. This review explores the latest advancements in packaging materials and chemical treatments aimed at extending the post-harvest life of litchi. Key packaging technologies, including modified atmosphere packaging (MAP) and bio-based materials, are evaluated for their effectiveness in preserving freshness. Chemical treatments, such as the use of sulfur dioxide (SO2), edible coatings, and antioxidants, are also discussed for their roles in reducing browning and microbial spoilage. Integrating these approaches could offer sustainable solutions to prolong litchi shelf life while maintaining its nutritional and sensory properties.

Keywords: Litchi, post-harvest life, packaging materials, modified atmosphere packaging, chemical treatments, browning, sulfur dioxide, edible coatings, shelf life etc.

Introduction
Litchi (*Litchi chinensis* Sonn.) is a highly perishable subtropical fruit known for its unique flavor, attractive red peel, and high nutritional value. Its appeal to consumers is largely attributed to its visual appearance and sensory qualities, which degrade rapidly after harvest due to physiological and biochemical changes. Post-harvest losses in litchi can be as high as 30-40%, making it essential to extend its shelf life and preserve its quality during storage and transportation. The primary causes of post-harvest deterioration in litchi include browning of the pericarp, desiccation, microbial decay, and loss of flavor, which significantly reduce its marketability (Menzel *et al.* 1989) [1].

The short shelf life of litchi is a major limitation in its commercial distribution, especially to distant markets. Upon exposure to ambient conditions, the delicate red color of the pericarp turns brown due to the enzymatic oxidation of phenolic compounds, while water loss accelerates desiccation and shriveling. Various techniques, including refrigeration, modified atmosphere packaging (MAP), and chemical treatments, have been explored to mitigate these issues. Packaging materials and chemical applications have emerged as two critical areas of intervention to maintain the quality and freshness of litchi post-harvest. Advancements in packaging technologies, such as active packaging, edible coatings, and the use of modified atmosphere packaging, have shown promise in reducing moisture loss, delaying browning, and minimizing microbial growth. Active packaging incorporates components that release or absorb substances to extend the shelf life of the product, while edible coatings, made from biodegradable materials, form a protective barrier around the fruit to reduce respiration rates and delay senescence. Modified atmosphere packaging (MAP) creates an optimal gaseous environment within the package, slowing down oxidative reactions and enzymatic activity, thus extending the fruit's shelf life (Pongener and Mahajan, 2016) [3].

Chemical treatments, including the application of anti-browning agents, fungicides, and other preservatives, have also been extensively studied to enhance the post-harvest life of litchi. Sulfur dioxide (SO_2) fumigation, ascorbic acid dips, and the use of other antioxidants have been employed to prevent pericarp browning and control microbial growth. However, concerns over the safety and consumer acceptance of chemical treatments have driven the need for alternatives that are safe, environmentally friendly, and acceptable to both consumers and regulators (Singh *et al.* 2012) [4].

This review aims to explore the recent advancements in packaging materials and chemical applications for enhancing the post-harvest life of litchi. By examining the efficacy of different approaches, this review provides insights into the potential of combining innovative packaging solutions with safe chemical treatments to minimize post-harvest losses and extend the marketability of litchi. Emphasis is placed on the sustainability and consumer safety aspects of these technologies, along with their practical applications in the supply chain (Underhill and Critchley, 1995) [5, 6].

Post-Harvest Challenges in Litchi Preservation

Litchi (*Litchi chinensis*) is highly perishable due to its delicate skin and sensitivity to temperature, making post-harvest preservation a significant challenge. The fruit's rapid deterioration is primarily driven by water loss, resulting in skin browning, weight reduction, and texture degradation. Additionally, the high susceptibility to microbial decay, especially fungal infections, further limits its shelf life. Temperature fluctuations during transport and storage exacerbate these issues, causing enzymatic reactions that affect the fruit's flavor and nutritional value (Huang and Xhu, 1983) [7].

One of the key challenges is maintaining the litchi's vibrant red skin color, which tends to turn brown shortly after harvest due to polyphenol oxidase (PPO) activity. This browning is accelerated by exposure to oxygen, humidity, and inappropriate storage conditions. Moreover, litchi's high-water content makes it prone to moisture loss, affecting both visual appeal and consumer acceptance (Joubert, 1986) [8].

Another challenge lies in developing packaging and chemical applications that can delay spoilage without compromising the fruit's sensory and nutritional qualities. Traditional packaging materials may not provide adequate protection against mechanical damage, while improper chemical treatments may lead to residual toxicity concerns (Li *et al.* 2001) [9].

Efforts to extend litchi's post-harvest life have focused on optimizing storage environments, using modified atmosphere packaging (MAP), and applying chemical treatments such as sulfur dioxide (SO_2), but balancing safety, effectiveness, and market requirements remains difficult. Sustainable and consumer-friendly solutions, such as bio-based packaging and natural preservatives, are gaining attention, but their scalability and cost-effectiveness still pose obstacles. Post-harvest preservation of litchi is challenged by environmental sensitivities and the limitations of current technologies, necessitating innovative approaches in packaging materials and chemical applications (Sivakumar and Korstern, 2004) [10].

Physiological and Biochemical Changes in Litchi during Storage

Litchi (*Litchi chinensis*) is a highly perishable fruit, with its post-harvest life limited by rapid physiological and biochemical changes that affect its quality. These changes primarily result in the deterioration of its attractive red peel, loss of flavor, and textural degradation, leading to significant economic losses during storage (Boyette *et al.* 1996) [11].

1. Respiration and Ethylene Production

Litchi is a non-climacteric fruit, meaning it does not exhibit a significant rise in respiration or ethylene production after harvest. However, even at low levels, respiration continues during storage, contributing to nutrient depletion and oxidative stress. Ethylene, albeit produced in small quantities, triggers ripening processes that accelerate senescence, leading to browning and decay (Robertson, 2006) [12].

2. Pericarp Browning

One of the most significant physiological changes during storage is the browning of the pericarp (peel). This occurs due to the oxidation of polyphenols by polyphenol oxidase (PPO) and peroxidase (POD) enzymes in the presence of oxygen. The degradation of anthocyanins, which give litchi its characteristic red color, also plays a key role in browning. Browning diminishes the fruit's visual appeal and marketability, a major concern in litchi post-harvest management (Vanderroost *et al.* 2014) [13].

3. Moisture Loss

Litchi is highly susceptible to moisture loss due to its thin skin and high water content, resulting in shriveling and desiccation during storage. This physiological change leads to a reduction in turgor pressure, impacting the fruit's texture and contributing to an undesirable wrinkled appearance (Freedman and Connors, 2011) [14].

4. Enzymatic Activity

Enzyme activity, particularly that of PPO, POD, and pectinases, accelerates during storage. Pectinase enzymes degrade pectin, a structural polysaccharide in the cell wall, leading to fruit softening. This enzymatic degradation reduces the overall firmness and texture quality of the litchi pulp (Nath and Purbey, 2015) [15].

5. Sugar and Acid Metabolism

Litchi undergoes changes in sugar and acid composition during storage, affecting its flavor profile. The fruit experiences a decline in ascorbic acid (vitamin C) content, which reduces its antioxidant potential. Additionally, fluctuations in sugar levels, particularly glucose and fructose, contribute to the loss of sweetness and overall sensory quality (Bryant, 2004) [16].

6. Microbial Growth

The physiological and biochemical changes in litchi create favorable conditions for microbial growth, especially molds and yeasts. Microbial spoilage accelerates the breakdown of tissues, further shortening the fruit's post-harvest life. Understanding these physiological and biochemical changes is critical for devising effective strategies to extend the post-harvest life of litchi. Packaging materials and chemical applications must be designed to mitigate these processes, enhancing the preservation of quality during storage (Chen and Hong, 1992) [17].

Pericarp Browning and Water Loss: Key Factors of Deterioration

Pericarp browning and water loss are critical factors that significantly affect the post- harvest life of litchi (Litchi chinensis), leading to rapid quality deterioration. Pericarp browning is primarily driven by oxidative reactions involving polyphenol oxidase (PPO) and peroxidase (POD) enzymes, which are accelerated by environmental factors like high temperature, low humidity, and mechanical damage. The vibrant red color of the litchi pericarp quickly fades to brown, reducing its market appeal. Simultaneously, water loss through transpiration exacerbates browning, shriveling the fruit, and causing a decline in freshness, texture, and overall weight (Kumar *et al.* 2016) [18].

These two factors are intricately linked, as water loss compromises the fruit's structural integrity, creating conditions favorable for browning. Furthermore, desiccation enhances the enzymatic activities responsible for pigmentation changes. Effective packaging and chemical treatments are essential for minimizing both browning and water loss, with modified atmosphere packaging (MAP), edible coatings, and anti-browning agents such as SO_2 being commonly employed. These interventions help maintain the fruit's moisture levels and delay oxidative processes, thereby extending the shelf life of litchi. Addressing pericarp browning and water loss remains crucial in enhancing the fruit's post-harvest longevity and quality retention, particularly for international markets (Alam *et al.* 2014) [19].

Role of Packaging in Extending Shelf Life of Litchi

Packaging plays a crucial role in extending the post-harvest life of litchi, a highly perishable fruit susceptible to rapid deterioration due to its delicate skin and sensitivity to environmental factors. Litchi fruit experiences rapid moisture loss, browning, and microbial growth, leading to significant post-harvest losses. Effective packaging helps mitigate these issues by creating a controlled microenvironment that reduces exposure to oxygen, light, and excessive humidity, thereby slowing down the physiological and biochemical changes (Purbey *et al.* 2018) [20].

Modified atmosphere packaging (MAP) and controlled atmosphere packaging (CAP) have been widely explored for litchi storage. These techniques adjust the concentrations of oxygen and carbon dioxide within the packaging, delaying enzymatic browning and reducing respiration rates. Additionally, the use of edible coatings, such as chitosan, enhances the fruit's natural barrier, preventing moisture loss and microbial spoilage (Li, 1999) [21].

Advancements in active packaging materials, which incorporate antimicrobial and antioxidant compounds, further contribute to extending litchi's shelf life. These materials not only maintain the fruit's sensory attributes, such as texture and flavor, but also inhibit the growth of spoilage organisms. Furthermore, innovative nanomaterials used in packaging offer promising potential in prolonging freshness by providing enhanced barrier properties (Pandey and Lal, 2015) [22].

Packaging innovations play a pivotal role in litchi preservation, significantly extending its marketable life while ensuring safety and quality. Future research should focus on optimizing packaging technologies to enhance efficiency, sustainability, and cost-effectiveness in commercial litchi production (Thompson, 2015) [23].

Innovative Packaging Materials: Active and Edible Coatings

Innovative packaging materials, such as active and edible coatings, offer promising solutions for enhancing the post-harvest life of litchi by maintaining its quality and extending shelf life. Active packaging involves incorporating functional agents like antioxidants, antimicrobial substances, and ethylene absorbers directly into the packaging materials. These agents can actively interact with the fruit's microenvironment, controlling moisture, oxygen levels, and microbial growth, thus preserving freshness and reducing spoilage. For litchi, active packaging has been particularly beneficial in mitigating post-harvest browning and microbial deterioration, common challenges in litchi preservation (Purbey, 2014) [24].

Edible coatings, typically composed of biopolymers like chitosan, starch, or alginate, form a protective barrier directly on the fruit's surface. These coatings reduce water loss, gas exchange, and oxidative reactions while being safe for consumption. Additionally, they can be enhanced with bioactive compounds such as essential oils or natural extracts, which further boost the fruit's resistance to spoilage. In litchi, edible coatings have shown potential in delaying pericarp browning, maintaining texture, and improving post-harvest quality (Zagory and Kader, 1988) [25].

By combining active and edible packaging technologies, the post-harvest management of litchi can be significantly improved, reducing post-harvest losses and promoting sustainable preservation practices (Brug and Brug, 1967) [26].

Modified Atmosphere Packaging (MAP) for Litchi Storage

Modified Atmosphere Packaging (MAP) is an advanced post-harvest technology that plays a crucial role in extending the shelf life of litchi, a fruit known for its rapid post-harvest deterioration due to its delicate skin and high susceptibility to browning and microbial decay. MAP involves altering the composition of gases, primarily reducing oxygen (O_2) and increasing carbon dioxide (CO_2) levels within the packaging environment. This creates conditions that slow down respiration rates, reduce ethylene production, and inhibit the growth of spoilage microorganisms, effectively delaying physiological and biochemical changes in litchi (Abeles *et al.* 1992) [27].

For litchi storage, MAP has proven beneficial in maintaining the fruit's vibrant red pericarp color, reducing moisture loss, and preserving flavor and texture. Various combinations of gas mixtures, such as low O_2 (1-5%) and high CO_2 (5-10%), are commonly used to optimize storage conditions. However, the effectiveness of MAP can vary depending on factors like litchi cultivar, temperature, and packaging material. To enhance MAP efficiency, integrating it with other preservation methods like refrigeration and chemical treatments (e.g., sulfur dioxide or ascorbic acid) can further extend the storage period while maintaining fruit quality. MAP offers significant potential in enhancing the post-harvest life of litchi, contributing to reduced wastage and improved marketability (Zheng and Tian, 2006) [28].

Chemical Treatments for Browning and Microbial Control

Litchi (*Litchi chinensis*) is a highly perishable fruit, susceptible to post-harvest browning and microbial spoilage, which significantly reduces its market value and shelf life. Browning, primarily caused by oxidation of phenolic compounds due to polyphenol oxidase (PPO) activity, is a major challenge that affects the fruit's visual appeal. To mitigate this, various chemical treatments have been employed to extend the post-harvest life of litchi by controlling both browning and microbial growth (Kumari *et al.* 2015) [29].

Sulfur dioxide (SO_2) fumigation is one of the most widely used chemical treatments to prevent browning. It inhibits PPO activity and preserves the red pericarp color of litchi, while also exhibiting strong antimicrobial properties, thus reducing fungal infections. However, its use is restricted due to potential health risks and the development of off-flavors. To overcome these issues, alternative chemicals such as ascorbic acid and citric acid are applied as dipping solutions. Ascorbic acid acts as an antioxidant, preventing oxidative browning, while citric acid lowers the pH, inhibiting PPO activity and microbial growth (Kumar *et al.* 2012) [30]

Another promising approach involves the use of chitosan coatings, which not only reduce browning by forming a barrier to oxygen but also possess natural antimicrobial properties. Chitosan has been shown to inhibit the growth of spoilage organisms, thereby enhancing the microbiological safety of stored litchis. Additionally, calcium chloride treatments are known to strengthen cell walls, reducing microbial penetration and delaying senescence.

Overall, integrating chemical treatments such as SO_2, ascorbic acid, and chitosan can effectively reduce browning and microbial spoilage in litchi, providing an economically viable means to extend its post-harvest life and ensure fruit quality during storage and transportation (Liguori *et al.* 2015) [31].

Safety and Regulatory Concerns in Chemical Applications

The post-harvest treatment of litchi (*Litchi chinensis*) often involves the application of various chemicals to extend shelf life and maintain quality. However, the use of these substances raises significant safety and regulatory concerns. The application of chemical preservatives, such as fungicides and ripening agents, must be carefully managed to ensure that they do not pose health risks to consumers or adversely affect the environment (Sivakumar and Korsten, 2006) [32].

Regulatory frameworks, such as those established by the Food and Drug Administration (FDA) and the European Food Safety Authority (EFSA), set maximum residue limits (MRLs) for agricultural chemicals. Compliance with these regulations is essential to protect consumer health and maintain market access for litchi products. The presence of pesticide residues beyond permissible levels can result in product recalls, loss of consumer trust, and significant economic losses for producers (De Reuck *et al.* 2009) [33].

Moreover, the potential for chemical interactions during packaging and storage further complicates safety assessments. For instance, certain packaging materials may react with chemical treatments, leading to the formation of harmful by-products. Thus, thorough evaluations of packaging materials are crucial to ensure compatibility with chemical applications and to prevent contamination (Vermeiren *et al.* 1999) [34].

Consumer awareness of food safety is increasing, and there is a growing demand for transparency regarding chemical use in agriculture. As a result, it is imperative for litchi producers to adopt safer alternatives, such as organic or biodegradable treatments, which align with sustainability goals while minimizing chemical residues (Scannell *et al.* 2000) [35].

Addressing safety and regulatory concerns in the chemical applications for enhancing the post-harvest life of litchi is vital. Adhering to established guidelines, ensuring compatibility of treatments with packaging materials, and exploring safer alternatives will contribute to consumer safety and the long-term viability of the litchi industry (Lee *et al*. 2008) [36].

Synergistic Approaches: Combining Packaging and Chemical Interventions

Enhancing the post-harvest life of litchi (*Litchi chinensis* Sonn.) requires innovative strategies that integrate both packaging materials and chemical interventions. The inherent sensitivity of litchi to mechanical injury, moisture loss, and microbial spoilage necessitates a multifaceted approach to maintain its quality and extend its shelf life (Todorovic *et al.* 2014) [37].

Recent research emphasizes the synergistic effects of using advanced packaging techniques alongside suitable chemical treatments. Modified atmosphere packaging (MAP) has proven effective in reducing respiration rates and delaying senescence by altering the gas composition around the fruit. When combined with edible coatings, which often include natural preservatives like chitosan or alginate, the synergistic effect can enhance barrier properties against moisture loss and provide an additional antimicrobial layer (Adetunji *et al.* 2014) [38].

Chemical interventions, such as the application of post-harvest fungicides and antioxidants, can further improve litchi preservation. For instance, treatments with ascorbic acid or citric acid can inhibit enzymatic browning and prolong fruit freshness. When integrated with appropriate packaging solutions, these chemical treatments can significantly mitigate decay and maintain sensory attributes, such as texture and flavor (Allegra *et al.* 2016) [39].

Moreover, the combination of active packaging, which incorporates bioactive compounds or antimicrobial agents within the packaging material itself, has shown promise. Such packaging not only protects litchi from external contaminants but also releases bioactive agents that can suppress microbial growth (Baldwin *et al.* 1999) [40].

Adopting synergistic approaches that combine innovative packaging technologies with effective chemical treatments holds great potential for enhancing the post-harvest life of litchi. This integrated strategy not only addresses the fruit's specific vulnerabilities but also aligns with current trends toward sustainable and environmentally friendly post-harvest practices. Future research should continue to explore optimal combinations of these interventions to establish best practices for litchi preservation in commercial settings (Bhowmick *et al.* 2015) [41].

Future Directions: Sustainable and Consumer-Friendly Technologies

As the global demand for litchi continues to rise, enhancing its post-harvest life through sustainable and consumer-friendly technologies is crucial. Future directions in this area should focus on developing packaging materials that not only extend shelf life but also minimize environmental impact. Innovations in biodegradable and compostable packaging made from natural polymers—such as starch, chitosan, and cellulose—offer promising alternatives to conventional plastic. These materials can effectively reduce carbon footprints while maintaining the quality of litchi during storage and transportation (Burton, 1985) [42].

Moreover, incorporating active packaging technologies that release natural preservatives or absorb excess moisture and ethylene can significantly enhance the freshness of litchi. Research into edible coatings, derived from natural sources like whey protein or alginate, can also create a barrier against microbial growth and moisture loss without compromising consumer acceptance (Gupta and Mehta, 1987) [43].

In parallel, the application of environmentally friendly chemicals, such as natural antioxidants and antifungal agents derived from plant extracts, should be explored. These alternatives can provide effective preservation while aligning with consumer preferences for clean- label products, thus enhancing marketability. Consumer education is another critical area for development. Raising awareness about sustainable practices and the benefits of innovative packaging and preservation technologies can drive consumer acceptance and demand for products with longer shelf life (Jiang *et al.* 2006) [44].

Integrating these sustainable approaches with advanced supply chain management systems, such as IoT and blockchain technologies, can enhance traceability and ensure optimal conditions throughout the distribution process. Overall, the future of litchi post-harvest management should prioritize eco-friendly solutions that cater to both sustainability goals and consumer preferences, ensuring a holistic approach to enhancing the fruit's market viability (Kumar, 2010) [45].

Conclusion

Enhancing the post-harvest life of litchi is crucial for maintaining its quality and extending its marketability. This review highlights the significant impact of various packaging materials and chemical applications in reducing post-harvest losses and preserving the fruit's sensory attributes. Biodegradable packaging options, such as modified atmosphere packaging (MAP) and natural fibers, have shown promise in mitigating respiration rates and delaying ripening, while also addressing environmental concerns. Additionally, the application of natural preservatives, including essential oils and edible coatings, has demonstrated efficacy in inhibiting microbial growth and reducing oxidation, further contributing to the longevity of litchi. Despite these advancements, challenges remain, particularly concerning the scalability of these methods and the need for standardization in commercial practices. Future research should focus on optimizing combinations of packaging materials and chemical treatments tailored to specific storage conditions and market requirements. By implementing innovative strategies and technologies, the litchi industry can significantly enhance post-harvest management, ultimately leading to improved fruit quality, reduced waste, and greater economic viability for producers. Thus, the integration of effective packaging and preservation techniques represents a vital step towards sustainable litchi production and consumption.

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