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Postharvest Physiological Studies on the Quality and Shelf Life of Tropical Fruits: A Literature Review

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ABSTRACT

Tropical fruits possess high economic value but are highly susceptible to quality deterioration after harvest due to ongoing physiological processes. This study aims to review postharvest physiological factors that affect the quality and shelf life of tropical fruits by synthesizing findings from recent literature. Key physiological processes such as respiration, transpiration, ripening, and enzymatic activity are critical in maintaining fruit quality. The findings indicate that effective management of temperature, humidity, controlled atmosphere, and the application of ethylene inhibitors can significantly delay senescence and extend the shelf life of tropical fruits. The novelty of this review lies in its synthesis of recent literature (2020–2024), emphasizing the integration of biological approaches (e.g., plant hormone treatments) and innovative technologies (e.g., edible coatings and smart packaging) to regulate postharvest physiological processes. This review also proposes a synergistic approach combining physiological understanding with technological interventions to optimize the tropical fruit supply chain in developing countries.

Keywords:, ***Postharvest Physiology, Tropical Fruits, Shelf Life, Fruit Quality, Literature Review***

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INTRODUCTION

Tropical fruits are among the leading horticultural commodities with high economic value, particularly in tropical countries such as Indonesia, Thailand, the Philippines, and Brazil. These commodities not only serve as essential sources of nutrition for local populations but also play a vital role in international trade, especially in the export of fresh produce. However, tropical fruits are highly perishable due to the continuation of physiological processes after harvest. According to Wills et al. (2020), the high water content and rapid metabolic activity characteristic of tropical fruits result in a short shelf life if not properly managed postharvest.

Postharvest physiology refers to the series of biological processes that persist after harvesting, including respiration, transpiration, enzymatic activity, and ethylene production. These processes significantly affect the physical, chemical, and sensory qualities of fruits during storage and distribution. Kader (2023) notes that the high respiration rate in climacteric fruits such as bananas and mangoes accelerates ripening and leads to rapid quality deterioration. Additionally, excessive transpiration results in water loss, leading to weight reduction and surface wrinkling, which diminishes consumer appeal.

Various external factors, such as temperature, relative humidity (RH), and storage atmosphere composition, critically influence postharvest physiological rates in tropical fruits. Consequently, effective postharvest handling is essential to extending shelf life and maintaining product quality. According to Singh and Sharma (2021), controlling storage environments using Modified Atmosphere Packaging (MAP) technology can slow down respiration and enzymatic activity, thereby preserving fruit freshness. Technologies such as cold storage, edible coatings, and ethylene inhibitors like 1-MCP have also shown positive outcomes in delaying quality degradation.

Nonetheless, developing countries face major challenges, including limited cold chain infrastructure and insufficient awareness among farmers and distributors regarding postharvest physiology. These issues contribute to high postharvest losses, which can reach 30–50% of total production (FAO, 2022). The complexity is exacerbated by rising global demand for tropical fruits, while inconsistent export quality remains a concern due to inadequate handling practices.

Previous literature has primarily focused on storage and packaging techniques, with

limited in-depth discussion on the relationship between postharvest physiological processes and science-based or technological interventions. Therefore, a scientific approach that integrates physiological understanding with modern technological applications is needed to develop adaptive and efficient postharvest strategies. As Zhao et al. (2022) point out, knowledge of enzymatic mechanisms such as polygalacturonase, pectinase, and amylase activity can serve as a foundation for designing technologies that slow fruit softening.

Furthermore, advancements in smart packaging and Internet of Things (IoT)-based sensors provide new opportunities for real-time quality monitoring during distribution. These systems enable early detection of physiological changes, such as increased CO_2 levels or ethylene production, allowing timely corrective actions. Kumar and Arora (2024) report that the use of visual indicators in fresh produce packaging enhances distribution efficiency while maintaining product quality through to the end consumer. This innovation underscores the importance of integrating postharvest physiology with digital technology.

In addition, biological treatments such as the application of plant growth regulators, ethylene inhibitors, and the use of antagonistic microorganisms are gaining interest for controlling postharvest physiology. Research by Herlina and Sutrisno (2023) demonstrates that the application of 1-MCP on papaya can reduce respiration rates by up to 40% during storage, thereby significantly extending shelf life and preserving fruit quality. This approach is considered more environmentally friendly and cost-effective than conventional chemical treatments.

Based on the discussion above, this literature review aims to identify and analyze key postharvest physiological factors that influence the quality and shelf life of tropical fruits. The study also seeks to synthesize various handling strategies developed based on physiological principles, and to highlight novel insights regarding the integration of technology and biology in addressing postharvest challenges in tropical regions. The findings are expected to contribute to the development of more adaptive and sustainable postharvest management systems.

METHODS

This study employed a systematic literature review (SLR) method to identify, evaluate, and synthesize various relevant research findings related to the postharvest physiology of tropical fruits and its impact on quality and shelf life. This approach was chosen to provide a

comprehensive overview of the biological mechanisms occurring after harvest and how postharvest interventions can mitigate the rate of deterioration. The primary focus of the review includes respiration, transpiration, ethylene production, and enzymatic activity that contribute to quality loss in tropical fruits. Within this context, the articles analyzed cover a range of scientific perspectives, both in terms of cellular biology and postharvest technologies, such as cold storage, edible coatings, and the application of ethylene-inhibiting compounds.

The literature search was conducted systematically across several reputable and open-access scientific databases, including the Directory of Open Access Journals (DOAJ), Google Scholar, ScienceDirect, and SpringerLink. Keywords used in the search included: "postharvest physiology," "tropical fruits," "shelf life," "fruit ripening," and "ethylene inhibition." Selected articles met specific inclusion criteria: (1) peer-reviewed scientific publications, (2) studies discussing tropical fruits and postharvest physiological aspects, (3) published between 2020 and 2024, and (4) openly accessible to ensure transparency. Articles that were duplicative, irrelevant, or failed to explicitly address postharvest physiological aspects were excluded from the analysis. Article eligibility was determined by reviewing the abstract, keywords, and main content of each manuscript.

Following selection, the articles were analyzed using a qualitative descriptive approach, categorizing findings based on fruit type, physiological parameters studied, and the postharvest strategies implemented. The analysis was carried out thematically, identifying recurring issues within the literature, such as respiration rate, softening enzyme activity, and the effects of modified atmosphere conditions on fruit freshness. In its final synthesis, this review highlights the link between understanding postharvest physiology and the application of innovative handling technologies. All references were compiled using the APA format, and only literature from open-access journals indexed in DOAJ or published by reputable academic platforms were included, ensuring transparency and reproducibility for future researchers.

RESULTS AND DISCUSSION

1. The Role of Respiration and Transpiration in Quality Deterioration

The respiration rate is one of the key physiological factors determining the postharvest quality of tropical fruits. Respiration is a metabolic process that provides energy for cellular activity, but it also accelerates fruit ripening and senescence. Tropical fruits such as mangoes, bananas, and papayas tend to exhibit high respiration rates after harvest, leading to rapid

breakdown of carbohydrates into unstable simple compounds, thereby causing a swift decline in both physical and chemical quality (Putri & Santoso, 2023). In climacteric fruits, the respiratory peak often triggers uncontrolled ripening processes, resulting in noticeable changes in color, texture, and flavor. Therefore, regulating respiration is essential to extending shelf life and preserving fruit quality.

Transpiration, the evaporation of water from the fruit surface, also plays a significant role in postharvest quality. Continuous water loss from fruit tissues leads to weight loss, skin wrinkling, and a decrease in visual freshness factors that directly influence consumer preference (Amalia et al., 2024). Temperature and relative humidity (RH) conditions greatly affect the rate of transpiration. Fruits stored in low-humidity environments undergo faster water loss, causing them to wilt more quickly. A mere 3–5% loss in water content is sufficient to cause significant visual and textural changes in tropical fruits (Siregar & Hidayah, 2022). Therefore, controlling transpiration through protective packaging or microclimate regulation during storage is critically important.

Efforts to inhibit respiration and transpiration have been explored in various recent studies. One widely adopted strategy is prompt postharvest cooling, which has been proven effective in lowering metabolic rates and reducing water loss (Rahmawati & Yusuf, 2023). In addition, the use of natural polysaccharide-based coating films has shown promising potential in minimizing water loss and slowing respiration. Recent findings reveal that fruit coating using materials such as chitosan or modified starch can reduce transpiration rates by up to 50% and double the shelf life compared to untreated controls (Handayani et al., 2024). These findings underscore the importance of a thorough understanding of postharvest physiology particularly respiration and transpiration in developing sustainable tropical fruit handling technologies.

2. Enzymatic Activity and Ripening

Postharvest enzymatic activity plays a pivotal role in the ripening and softening processes of tropical fruits, especially climacteric fruits such as bananas, mangoes, and papayas. After harvest, fruits continue to undergo physiological and biochemical changes driven by enzymes such as pectinase, polygalacturonase, and cellulase, which are responsible for the degradation of cell wall components, resulting in fruit softening. Zhao et al. (2023) emphasized that pectinase plays a dominant role in pectin degradation, particularly in the

middle lamella, thereby accelerating the softening process and reducing shelf life. Although such textural changes are desirable at certain stages of consumption, they pose significant challenges for distribution and storage due to increased susceptibility to mechanical and microbial damage.

In addition to softening, amylase activity contributes to starch breakdown into simple sugars, enhancing sweetness during ripening. This is particularly evident in bananas, where starch is converted into glucose and fructose. Ramadhani et al. (2023) reported that amylase activity increases significantly post-climacteric peak, supporting flavor transformation as a maturity indicator. Ethylene, a ripening hormone, plays a central role in inducing these enzymatic activities. Elevated ethylene concentrations can accelerate ripening and lead to rapid quality deterioration if not carefully regulated during storage or transport.

To mitigate these effects, various strategies have been developed to suppress enzymatic activity and prolong fruit shelf life. One of the most effective methods is the application of ethylene inhibitors such as 1-methylcyclopropene (1-MCP), which blocks ethylene receptor binding and delays the expression of ripening-related genes (Putri & Herlina, 2024). Additionally, cold storage and atmospheric modification have been proven to slow enzymatic reactions and reduce ethylene release. Postharvest strategies that consider enzymatic physiology are essential to maintaining organoleptic quality, extending shelf life, and minimizing postharvest losses and economic impact..

3. Postharvest Physiological Control Technologies

Controlling postharvest physiological processes is crucial for maintaining the quality and extending the shelf life of tropical fruits. One innovative approach involves the application of edible coatings derived from natural materials such as chitosan, Aloe vera, or modified starch. These materials form a semi-permeable barrier on the fruit surface, which reduces respiration rate, minimizes water loss, and inhibits microbial activity responsible for spoilage (Rahman et al., 2023). A recent study by Nugraheni and Yuliana (2024) demonstrated that 1% chitosan coating on mangoes could maintain firmness and vitamin C content for up to 10 days of storage. Moreover, combining chitosan with plant extracts such as cinnamon enhances the antimicrobial and antioxidant properties of the coating, providing dual protection against quality degradation.

Temperature and relative humidity (RH) control during storage are also key factors in

effective postharvest management. Elevated temperatures accelerate metabolic and ripening processes, while low humidity promotes transpiration and shriveling. Therefore, cold storage systems with tightly controlled temperature and RH conditions are highly effective in suppressing the physiological activity of tropical fruits. Putri and Hartati (2024) found that storing dragon fruit at 10°C and 90% RH doubled its shelf life compared to ambient storage. The integration of refrigeration with smart packaging systems equipped with temperature and gas indicators has also been developed for real-time monitoring of fruit quality during distribution.

Modified Atmosphere Packaging (MAP) is another modern strategy increasingly adopted at industrial scales. MAP alters the gaseous environment surrounding the fruit—typically reducing oxygen levels and increasing carbon dioxide—to slow respiration and enzymatic activity. This has proven effective in maintaining the sensory and nutritional quality of fruits such as mangoes, papayas, and dragon fruits. Research by Wijayanti et al. (2023) showed that storing mangoes under MAP conditions (3% O_2 and 5% CO_2) preserved fruit texture and inhibited browning for up to 14 days. The success of MAP is further enhanced by nanomaterial-based gas sensors capable of accurately detecting ethylene concentration changes, enabling adaptive decision-making for distribution and marketing.

4. Novelty of the Study

This literature review offers a novel perspective on tropical fruit postharvest management by integrating physiological insights with cutting-edge technological innovations. One emerging focus is the application of ethylene inhibitors such as 1-methylcyclopropene (1-MCP), which has proven effective in delaying ripening and extending the shelf life of climacteric fruits, including bananas and papayas. This compound functions by binding to ethylene receptors in fruit tissues, thereby interrupting ethylene-triggered biochemical pathways (Xie et al., 2023). The effectiveness of 1-MCP in preserving fruit freshness has been validated under various storage conditions, showing significant reductions in softening rate and water loss. Its use as a biological agent represents a promising breakthrough in tropical fruit postharvest technology.

Beyond biological approaches, this review also highlights the growing importance of smart packaging innovations in fruit distribution systems. These technologies enable real-time visual detection of physiological changes in fruits through indicator labels that change color in

response to elevated CO_2 or ethylene levels markers of declining fruit quality. Wang et al. (2024) demonstrated the successful use of nanomaterial-based visual indicators in packaging for dragon fruit and mango, allowing producers and consumers to monitor freshness in real-time. This not only enhances supply chain efficiency but also reduces waste caused by the distribution of overripe fruits. The implementation of smart packaging in postharvest management is a highly relevant innovation in the era of agricultural digitalization.

The integration of postharvest physiological understanding with modern technologies such as 1-MCP and smart packaging represents a holistic approach to tropical fruit quality management. This combined strategy synergizes biological, physical, and technological elements to slow down postharvest deterioration. The study asserts that adopting such integrated approaches enhances physiological control effectiveness and opens new opportunities for developing adaptive, data-driven logistics and marketing systems. Thus, the novelty of this review lies in its integrative and forward-looking perspective on managing tropical fruit quality and shelf life.

CONCLUSION AND IMPLICATIONS

Postharvest physiology plays a crucial role in determining the quality, freshness, and shelf life of horticultural products, particularly tropical fruits. High rates of respiration and transpiration after harvest can accelerate quality degradation in terms of texture, moisture content, and nutritional value. Enzymatic activities such as those of pectinase and polygalacturonase further hasten fruit softening, especially in climacteric fruits triggered by ethylene production. Therefore, controlling these physiological factors is essential to delay deterioration and maintain product quality. Management strategies involving temperature and humidity adjustments, as well as biological interventions, are key to effective postharvest handling.

In the context of innovation, integrating preservation technologies such as edible coatings, modified atmosphere packaging (MAP), and biological approaches involving plant hormones like 1-MCP has proven effective in extending shelf life. The use of smart packaging with freshness indicators also facilitates real-time quality monitoring for consumers. These findings underscore that the synergy between physiological understanding and modern technological applications opens new opportunities for more efficient and sustainable postharvest

management of tropical fruits, contributing significantly to food security and the reduction of food loss in the horticultural sector.

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