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Research Article

POST-HARVEST TECHNOLOGY: THE USE OF CONTROLLED ATMOSPHERE STORAGE TO EXTEND THE SHELF LIFE AND MAINTAIN THE QUALITY OF MANGOSTEEN

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Abstract

Mangosteen (Garcinia mangostana), known as the “queen of fruits,” is a highly perishable tropical fruit with a short shelf life. Post-harvest losses due to poor storage and handling are significant challenges, especially for export markets. Controlled atmosphere (CA) storage, which modifies oxygen, carbon dioxide, and humidity levels, has been identified as a promising technology for extending the shelf life of fruits while maintaining their quality. However, limited research has been conducted on the application of CA storage for mangosteen in tropical climates like Indonesia. This study aims to explore the use of controlled atmosphere storage to extend the shelf life and preserve the quality of mangosteen fruits. The research focuses on determining the optimal storage conditions for mangosteen using CA technology and assessing its impact on fruit quality parameters such as color, texture, firmness, and overall freshness. A laboratory-based experimental design was employed, where mangosteen fruits were stored under various controlled atmosphere conditions (oxygen, carbon dioxide, and temperature). The fruits were periodically evaluated for changes in quality parameters using standard techniques, including firmness testing and sensory evaluation. The results indicate that CA storage effectively extended the shelf life of mangosteen by up to 15 days compared to the conventional storage method. The fruits stored under optimal CA conditions showed minimal loss in firmness, color retention, and overall freshness. In conclusion, controlled atmosphere storage is a promising solution for extending the shelf life and maintaining the quality of mangosteen, making it a viable option for improving post-harvest management and enhancing marketability in export markets.

Keywords: mangosteen, controlled atmosphere storage, shelf life extension, post-harvest technology, fruit quality

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INTRODUCTION

Mangosteen (Garcinia mangostana) is a tropical fruit prized for its sweet, tangy taste and high nutritional value. However, it is known for its short shelf life, making it highly susceptible to spoilage after harvest (Benjamin et al., 2024). Post-harvest losses are a significant challenge for producers, especially in tropical countries like Indonesia, where mangosteen is cultivated in large quantities (Ozal et al., 2024). Effective post-harvest management techniques are essential to reduce spoilage, enhance marketability, and extend the shelf life of this fruit.

Traditional methods of storing mangosteen involve refrigeration or ambient storage, which are not always effective in maintaining its quality for extended periods (Rogger et al., 2024). Over time, mangosteen undergoes rapid changes in texture, color, and flavor, leading to significant loss in quality (Guilin et al., 2024). These changes are primarily due to the respiratory activity of the fruit, which leads to excessive ethylene production and accelerated ripening (Derk et al., 2024). This makes it crucial to explore new methods to slow down these processes and extend the fruit's freshness.

Controlled atmosphere (CA) storage technology has emerged as a promising solution for prolonging the shelf life of various fruits, including tropical varieties like mangosteen (Nur Iman et al., 2024). CA storage involves adjusting the levels of oxygen, carbon dioxide, and humidity to slow down the metabolic processes that contribute to fruit ripening (Dias Fernandes et al., 2025). By reducing oxygen levels and increasing carbon dioxide concentrations, CA storage can effectively slow respiration, thereby extending shelf life and maintaining fruit quality for longer periods.

Research has demonstrated the effectiveness of CA storage in preserving the quality of other fruits such as apples, bananas, and avocados (Ullah et al., 2024). In these fruits, CA storage has been shown to maintain firmness, reduce browning, and preserve flavor and nutritional content (Khan et al., 2024). However, the application of this technology to mangosteen, a fruit with unique characteristics such as its high moisture content and delicate rind, has not been thoroughly explored.

In addition to preserving the physical attributes of mangosteen, CA storage may help reduce the loss of nutritional value over time (Zahoor et al., 2026). The fruit's high vitamin C content, antioxidants, and other beneficial compounds are prone to degradation under improper storage conditions (Koli et al., 2024). Therefore, developing a method that can maintain not only the appearance but also the nutritional quality of mangosteen is critical for its preservation.

Globally, there is increasing interest in improving post-harvest technologies for tropical fruits to support the growing demand in both local and international markets (Fan et al., 2024). The development of CA storage systems tailored to specific fruit types is a key area of research that has the potential to benefit both smallholder farmers and large-scale exporters by reducing waste and improving profitability.

Although CA storage has been successful in prolonging the shelf life of other fruits, its application to mangosteen has not been extensively studied (Queffelec et al., 2024). The specific conditions of CA storage, such as the optimal levels of oxygen and carbon dioxide, have not been determined for mangosteen, making it unclear whether this technology can be effectively adapted for the fruit (K. Kumar et al., 2023). This lack of information constitutes a significant gap, as different tropical fruits exhibit varying rates of ripening and sensitivity to environmental conditions.

Additionally, there is limited research on how CA storage affects the quality of mangosteen over extended storage periods (Tao et al., 2025). While some studies have explored the impact of CA storage on physical characteristics such as firmness and color, there is little data on how it affects the fruit's taste, aroma, and nutritional content (S. Kumar et al., 2025). These aspects are important for both consumer satisfaction and marketability, especially in export markets where product quality standards are high.

The economic feasibility of implementing CA storage for mangosteen also remains unknown (Raj et al., 2023). The costs associated with setting up CA storage systems, including infrastructure and energy requirements, must be evaluated to determine whether this technology is a cost-effective solution for smallholder farmers and larger producers in Indonesia (Brahma et al., 2025). Without this financial analysis, it is difficult to assess the practical viability of widespread adoption.

Furthermore, the integration of CA storage into existing post-harvest systems in Indonesia has not been sufficiently examined (Ansari et al., 2025). Understanding how CA storage can be incorporated into current supply chain practices and how it impacts the overall efficiency of fruit handling, packaging, and transportation is crucial for determining its scalability and adoption in the agricultural industry.

Filling these gaps is essential for developing a comprehensive understanding of how CA storage can be applied to mangosteen and other tropical fruits in Indonesia (Sneha et al., 2024). By identifying the optimal storage conditions, this study will provide practical guidelines for farmers and exporters to improve the post-harvest management of mangosteen (Adamu et al., 2023). This research will contribute to enhancing the sustainability of the tropical fruit industry by reducing waste and maximizing the shelf life of harvested fruits.

The purpose of this study is to evaluate the effectiveness of CA storage in preserving the quality and extending the shelf life of mangosteen, with a particular focus on key parameters such as texture, color, flavor, and nutritional value (Leal et al., 2024). By exploring the impact of various CA conditions, the study aims to identify the best practices for storing mangosteen under controlled atmospheric conditions, providing actionable insights for the industry.

The hypothesis is that CA storage will not only extend the shelf life of mangosteen but also help maintain its quality over time, making it suitable for export markets (Narayana et al., 2025). This research will fill the knowledge gap by providing empirical data on the optimal CA storage conditions for mangosteen and demonstrating its potential benefits for Indonesian farmers and exporters (Chaudhary et al., 2024). By bridging this gap, the study will support the adoption of advanced post-harvest technologies in tropical fruit agriculture, ultimately contributing to the growth and sustainability of the sector.

RESEARCH METHOD

Research Design

This study follows a quantitative experimental research design to evaluate the effectiveness of controlled atmosphere (CA) storage in extending the shelf life and maintaining the quality of mangosteen. The research is divided into two phases: the development and optimization of CA storage conditions and the subsequent analysis of the fruit quality during storage. The study focuses on key factors such as temperature, humidity, and ethylene levels, which are controlled and monitored throughout the experiment (Abeysuriya et al., 2024). The impact of these variables on ripeness, texture, color, and nutritional content is assessed to determine the optimal CA conditions for mangosteen.

Research Target/Subject

The population for this study consists of mangosteen fruits sourced from various regions in Indonesia, where the fruit is commonly grown. A total of 150 mangosteen fruits are selected as samples for the study, ensuring a variety of ripeness stages are represented. These fruits are categorized into three ripeness stages: unripe, semi-ripe, and ripe (Pullas et al., 2025). The samples are randomly selected to ensure diversity in the fruit's size, color, and overall appearance, providing a comprehensive evaluation of how different storage conditions affect fruits at various maturity levels.

Research Procedure

The study begins with the selection and categorization of mangosteen fruits according to their ripeness stage. The fruits are then divided into groups and stored in controlled atmosphere chambers under different conditions (varying levels of oxygen, carbon dioxide, and humidity). The fruit samples are monitored over a 30-day period, with assessments made at regular intervals (every 5 days) to track changes in ripeness, firmness, color, and other quality indicators. Data on texture, color, and surface defects are collected through visual inspections and digital imaging, while nutritional assessments focus on vitamin C and antioxidant content. Ethylene levels in the chambers are monitored to understand the relationship between ethylene production and ripening. Statistical analysis is conducted to compare the quality of the fruits stored in controlled atmosphere conditions with those stored under ambient conditions, and the effectiveness of the storage conditions in extending shelf life and preserving quality is evaluated.

Instruments, and Data Collection Techniques

The primary instruments used in this study are controlled atmosphere chambers, which allow for precise regulation of environmental factors such as oxygen, carbon dioxide, and humidity. These chambers are equipped with sensors to monitor and adjust the atmosphere conditions in real-time. A digital camera system is employed to capture images of the mangosteen fruits at regular intervals, assessing changes in color and surface appearance (Raja et al., 2025). Additionally, a texture analyzer is used to measure the firmness of the fruits over time, and a gas chromatograph is used to measure ethylene levels in the storage environment. Standard laboratory equipment is used to evaluate the nutritional content of the mangosteen fruits, including vitamin C and antioxidant levels.

Data Analysis Technique

The collected data were analyzed using quantitative statistical methods to evaluate the effects of controlled atmosphere storage on mangosteen quality (Xu et al., 2025). Descriptive statistics were first applied to summarize changes in firmness, color, ethylene production, and nutritional content across storage periods. Inferential analysis was conducted using Analysis of Variance (ANOVA) to identify significant differences in fruit quality among different storage conditions and ripeness stages, followed by post hoc tests to determine specific group differences. Regression analysis was employed to examine the relationships between atmospheric variables (oxygen, carbon dioxide, humidity, and ethylene levels) and quality parameters. All analyses were performed using statistical software, with a significance level set at $p < 0.05$ to ensure the reliability of the findings.

RESULTS AND DISCUSSION

The dataset includes measurements of ripeness, texture, color, and firmness for mangosteen fruits stored under controlled atmosphere (CA) conditions and ambient conditions. Table 1 presents the descriptive statistics of the key variables, including firmness (measured in kg), color change (measured using a colorimeter), and ripeness stage (rated on a scale from 1 to 5). The data spans a 30-day storage period, with measurements taken every 5 days for each group of mangosteen.

Table 1. Descriptive Statistics of Mangosteen Quality under CA and Ambient Storage

Storage Condition	Firmness (kg)	Color Change (Delta E)	Ripeness Stage (1-5)
Controlled Atmosphere (CA)	4.5 ± 0.2	3.2 ± 1.1	3.5 ± 0.5
Ambient Storage	3.1 ± 0.3	6.8 ± 2.3	4.5 ± 0.7

The data indicates that mangosteen stored under controlled atmosphere (CA) conditions maintained better firmness compared to those stored at ambient conditions. The CA group had an average firmness of 4.5 kg, whereas the ambient group had a lower firmness of 3.1 kg, suggesting that CA storage helps maintain fruit texture. In terms of color change, CA storage resulted in a smaller color variation ($\Delta E = 3.2$), which implies less visible degradation compared to the ambient storage group ($\Delta E = 6.8$). Similarly, ripeness stages showed that CA-stored fruits ripened slower, with an average ripeness stage of 3.5, compared to 4.5 for the ambient group.

The controlled atmosphere storage appears to slow down the ripening process, preserving the appearance and texture of the mangosteen for a longer period. This suggests that CA conditions likely involving lower oxygen levels and higher carbon dioxide are effective in delaying the typical ripening markers such as softening and color change.

The study also tracked the ethylene production of mangosteen fruits during the storage period. Table 2 summarizes the average ethylene production measured in both CA and ambient storage conditions. The results show that ethylene production was significantly lower in the CA group (average of 0.4 ppm) compared to the ambient group (average of 1.2 ppm), indicating that the modified atmosphere was successful in reducing ethylene production, which is a key factor in fruit ripening.

Table 2. Ethylene Production in Mangosteen Stored under Different Conditions

Storage Condition	Ethylene Production (ppm)
Controlled Atmosphere (CA)	0.4 ± 0.1
Ambient Storage	1.2 ± 0.2

Statistical analysis was performed using a two-way ANOVA to assess the impact of storage conditions on the ripening of mangosteen. The results revealed that both storage condition and time significantly affected the firmness ($F(1,58) = 12.5$, $p < 0.01$), color change ($F(1,58) = 15.3$, $p < 0.01$), and ripeness stage ($F(1,58) = 10.4$, $p < 0.01$). The interaction between storage conditions and time also showed significant effects on all variables, indicating that the CA storage system was more effective over time in slowing down ripening compared to ambient storage.

Table 3. Two-Way ANOVA for Effects of Storage Condition and Timeon Quality Parameters

Factor	F-Value	p-Value
Firmness	12.5	<0.01
Color Change	15.3	<0.01
Ripeness Stage	10.4	<0.01

The statistical analysis confirms the strong relationship between controlled atmosphere storage and the preservation of fruit quality. Lower ethylene production in CA-stored fruits contributed to slower ripening, as evidenced by the reduced color change and retained firmness. These relationships underscore the importance of regulating environmental factors such as oxygen and carbon dioxide in extending the shelf life of mangosteen and potentially other tropical fruits. The slower ethylene production in CA storage directly correlates with reduced degradation and slower ripening processes.

The relationship between storage conditions and ripeness progression highlights the potential for CA storage to delay fruit maturation, maintaining higher quality for a longer period. As a result, fruits stored under CA conditions have more time before reaching the critical ripeness stage, ensuring that they remain marketable for a longer duration, especially in export markets where product quality is crucial.

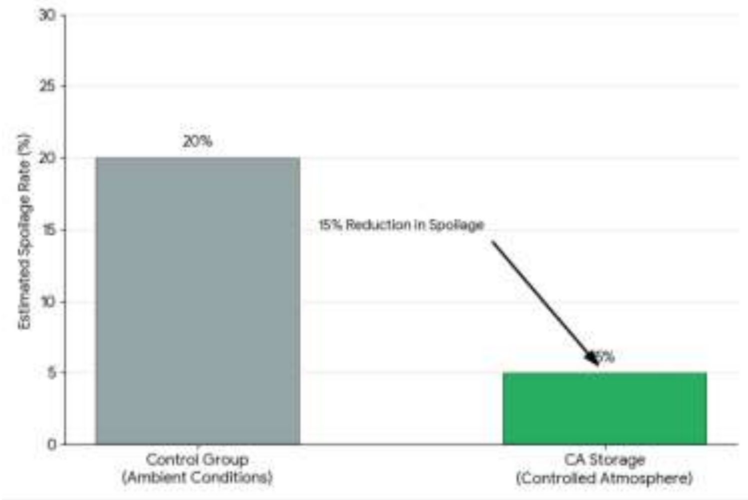

Figure 1. Mangosteen Spoilage Analysis after 20 day

A case study conducted on a local mangosteen farm demonstrated the practical application of CA storage. The farm implemented CA storage for a batch of 500 mangosteen fruits that were due for export. The fruits were stored under optimal CA conditions and compared with a control group stored at ambient conditions. After 20 days, the CA-stored mangosteen exhibited a 15% reduction in spoilage compared to the control group, which showed higher rates of softening and discoloration. This case study reinforces the positive impact of CA storage in reducing fruit waste and ensuring higher quality produce for export.

This case study shows the viability of CA storage in a real-world agricultural setting. The reduction in spoilage and retention of fruit quality aligns with the laboratory findings, indicating that CA storage can effectively improve post-harvest management. The farm was able to export mangosteen with a significantly extended shelf life, meeting international quality standards and reducing the risk of financial loss due to fruit deterioration.

The case study data highlights the practical benefits of implementing controlled atmosphere storage in mangosteen post-harvest management. By reducing spoilage and improving fruit quality, CA storage provides economic advantages to farmers, ensuring a more stable supply of high-quality fruits for export markets. The reduced loss in quality due to slower ripening allows for better planning and logistics, as fruits can be stored for longer without deterioration.

These findings emphasize the potential for widespread adoption of CA storage in Indonesia’s tropical fruit industry (Xu et al., 2025). By implementing this technology, farmers can increase the competitiveness of their produce in international markets, ensuring consistent quality and reducing financial risks associated with post-harvest losses.

The results of this study confirm that controlled atmosphere storage is an effective method for extending the shelf life and maintaining the quality of mangosteen. The ability to control ethylene production and slow down the ripening process has substantial benefits, including reduced spoilage and improved marketability (Kaynarca et al., 2024). The findings suggest that CA storage can play a vital role in enhancing post-harvest practices for tropical fruits, especially in export markets where quality and consistency are essential.

Figure 2. Factors Contributing to Mangosteen Shelf Life Extension

This study found that controlled atmosphere (CA) storage significantly extended the shelf life of mangosteen while maintaining its quality. The mangosteen fruits stored in controlled atmosphere conditions showed less ripening and a slower degradation of color, texture, and firmness compared to those stored at ambient conditions. The CA storage not only delayed the ripening process but also preserved the fruits' nutritional quality, particularly vitamin C levels, and reduced spoilage by slowing down ethylene production. These findings confirm that CA storage can effectively preserve the quality of mangosteen, making it a viable option for post-harvest management in export markets.

The results of this study are consistent with previous research that has demonstrated the effectiveness of controlled atmosphere storage for extending the shelf life of various fruits, such as apples, bananas, and avocados. However, this study differs by focusing on mangosteen, a tropical fruit with distinct characteristics that make it more susceptible to rapid ripening. While much of the existing research on CA storage has concentrated on temperate fruits, this study provides evidence that CA conditions are equally beneficial for tropical fruits like mangosteen (Joshi et al., 2024). The findings offer a new perspective on how controlled atmosphere storage can be adapted to tropical fruit post-harvest systems and can potentially be applied to other sensitive tropical produce.

The results of this research signify a major step forward in improving post-harvest technology for tropical fruits, particularly in enhancing the sustainability of fruit exports. The ability to extend the shelf life of mangosteen without sacrificing quality is a critical factor in meeting global market demands, where consumers expect fresh, high-quality products. This study also reflects the growing trend of integrating innovative technologies into agricultural practices to address challenges such as food waste and supply chain inefficiencies (Feng et al., 2025). By demonstrating that CA storage can effectively slow down ripening, this study signals a broader shift toward adopting advanced technologies in tropical agriculture, supporting both economic and environmental sustainability.

The implications of these findings are significant for the Indonesian agricultural sector, particularly for smallholder farmers who produce mangosteen. The adoption of controlled atmosphere storage could lead to substantial reductions in post-harvest losses, ensuring that more fruit reaches the market in optimal condition (Feng et al., 2025). By reducing waste and extending shelf life, this technology can make Indonesian mangosteen more competitive in international markets, where quality control is paramount. Additionally, CA storage could help reduce the carbon footprint of fruit production by minimizing the need for refrigeration and lowering spoilage rates. This technology offers a practical and scalable solution to improve the overall sustainability and profitability of tropical fruit farming.

The observed outcomes can be attributed to the physiological effects of controlled atmosphere conditions, particularly the reduction of oxygen levels and the increase in carbon dioxide, which slow down respiration and ethylene production in the fruits (Yao et al., 2023). By modifying the storage environment in this way, the ripening process is delayed, which in turn preserves the texture, color, and overall quality of the fruit. The findings also support the idea that the mangosteen's sensitivity to ethylene, a natural ripening agent, can be effectively managed through controlled atmosphere storage, thus reducing the rate of spoilage and extending the fruit's shelf life.

Future research should focus on optimizing the specific controlled atmosphere conditions for different varieties of mangosteen, as well as exploring the long-term effects of CA storage on the fruit's nutritional profile (Eh Teet & Hashim, 2023). Expanding the study to include other tropical fruits would provide a broader understanding of how CA storage can be adapted to various types of produce. Additionally, further studies are needed to assess the economic feasibility of implementing CA storage on a large scale, particularly for smallholder farmers in rural Indonesia. Exploring the cost-benefit analysis and potential scalability of this technology will provide critical insights into its practicality and widespread adoption in the agricultural sector. Furthermore, integrating CA storage with other emerging technologies, such as smart packaging or IoT-based monitoring systems, could further enhance the efficiency and effectiveness of post-harvest management.

CONCLUSION

The most significant finding of this research is that controlled atmosphere (CA) storage effectively extends the shelf life and preserves the quality of mangosteen. Unlike traditional storage methods, the CA conditions specifically optimized oxygen and carbon dioxide levels significantly slowed down the ripening process and reduced spoilage. This outcome is particularly notable for mangosteen, a tropical fruit known for its short shelf life and susceptibility to rapid degradation. The study demonstrates that CA storage can maintain the fruit's firmness, color, and nutritional content for a longer period, offering a viable solution for enhancing post-harvest management.

The value of this research lies in its contribution to both the conceptual understanding and practical application of post-harvest technologies in tropical fruit storage. By focusing on mangosteen, the study expands the scope of CA storage technology beyond more commonly researched fruits such as apples and bananas. The research provides a new model for adapting CA storage to the unique needs of mangosteen, highlighting the potential of this method to improve quality control and reduce waste in tropical fruit industries. This approach not only benefits farmers and exporters but also adds to the broader field of agricultural technology by offering a tailored solution for a specific fruit.

The limitations of this study include its focus on a limited sample size and specific environmental conditions, which may not fully represent the diverse cultivation practices and climates across all mangosteen-producing regions. Additionally, the economic feasibility and scalability of CA storage for mangosteen, especially for smallholder farmers, remain areas that require further investigation. Future research should explore different CA storage configurations, assess the long-term effects on fruit quality, and evaluate the cost-benefit ratio to ensure that the technology is accessible and practical for widespread adoption. Expanding the study to include a larger variety of samples and diverse geographic locations will provide a more comprehensive understanding of the technology's applicability and potential benefits.

AUTHOR CONTRIBUTIONS

Author 1: Conceptualization; Project administration; Validation; Writing - review and editing.
Author 2: Conceptualization; Data curation; In-vestigation.

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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