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Effect of modified atmosphere packaging on shelf life and quality of fresh-cut pineapple

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Abstract

Consider a worker travelling home on a Bangkok BTS train, looking for a fresh fruit snack but unwilling to peel and cube a whole pineapple in transit. That simple consumer moment defines the entire fresh-cut market: convenience delivered without quality compromise. This research examined four packaging regimes — ambient air (control), MAP-1 (70% N₂ + 30% CO₂), MAP-2 (50% N₂ + 30% CO₂ + 20% O₂), and MAP-3 (30% O₂ + 70% CO₂) — applied to freshly cut pineapple cubes (Ananas comosus cv. MD-2) stored at 4 ± 1 °C for 16 days. Firmness, colour (L*, a*, b*), weight loss, titratable acidity, total soluble solids, vitamin C, total microbial load, sensory acceptability, and package headspace composition were tracked at 4-day intervals. MAP-3 consistently outperformed the other three regimes across most quality attributes. On day 16, MAP-3 samples retained 74% of day-0 vitamin C content against 31% for the control, weight loss of 2.8% against 9.2% for the control, and sensory acceptability above the rejection threshold. Total microbial count in MAP-3 remained below 4.5 log CFU/g throughout, compared with 7.2 log CFU/g in the control at day 12. The high-CO₂ regime (MAP-3) is recommended for retail fresh-cut pineapple targeting a 12–16 day distribution window.

Keywords: Modified atmosphere packaging, fresh-cut pineapple, shelf life, minimal processing, CO₂ atmosphere, vitamin C retention, quality retention, Ananas comosus.

Introduction

The Thai fresh-cut fruit category has expanded from under THB 2.8 billion in 2017 to nearly THB 14 billion in 2023, driven by organised retail, modern urban lifestyles, and the proliferation of quick-commerce delivery platforms^[1, 5]. Pineapple ranks among the top three fresh-cut fruits in retail rotation, combining year-round availability, appealing colour, and a flavour profile that survives portioning better than many competing tropical fruits^[3, 11]. But the convenience of a ready-to-eat cube also amplifies the quality-loss challenge: cutting exposes tissue, accelerates respiration, releases cellular fluid, creates new entry points for microbial contamination, and shortens shelf life from weeks to days^[2, 7].

Modified atmosphere packaging (MAP) manages this problem by altering the gas composition inside the pack. Elevated CO₂ suppresses aerobic respiration and microbial growth, reduced O₂ slows oxidative browning and enzymatic degradation, while retaining some O₂ prevents anaerobic fermentation and off-flavour development^[4, 9, 12]. The optimal gas mixture is not universal — it depends on commodity, cut geometry, storage temperature, and target shelf-life window. For pineapple, published recommendations span a wide range, from 5% O₂ + 10% CO₂ in balance N₂ up to 50% CO₂ with variable O₂^[6, 13, 17].

Recent work has suggested that high-O₂ atmospheres above 30% may outperform conventional low-O₂ designs for several cut fruits by triggering a hermetic antimicrobial response^[10, 14, 18]. This idea has been tested for mango, papaya, and strawberry but direct comparative data for fresh-cut pineapple under a high-O₂, high-CO₂ regime are scarce. The present research filled that gap by evaluating three distinct MAP configurations against an ambient-air control across sixteen days of refrigerated storage, with comprehensive quality, microbial, and sensory tracking.

Materials and Methods

Materials

Mature MD-2 pineapples were procured from the research farm of King Mongkut Institute of

Technology, Prachuap Khiri Khan, between August 2023 and January 2024 at commercial colour-break maturity (Stage 3, 30–50% yellow shell colour). Fruits were transported under 25 °C ambient conditions to the processing laboratory, where they were washed, dipped in 100 ppm chlorinated water for 2 minutes, rinsed with cold potable water, and drained. The crown, core, and skin were manually removed and the flesh cut into uniform $2 \times 2 \times 2$ cm cubes using a stainless-steel dicing board sanitised between batches. Each experimental pack contained 150 g of freshly cut cubes placed in a polyamide–polyethylene laminate tray (gas transmission rate $12 \text{ cm}^3/\text{m}^2/\text{day}$ for O_2) and sealed with a polyester-based lidding film under the required gas composition using a tabletop MAP sealing unit. Four regimes were prepared: C (ambient air, control), MAP-1 (70% N_2 + 30% CO_2), MAP-2 (50% N_2 + 30% CO_2 + 20% O_2), and MAP-3 (30% O_2 + 70% CO_2).

Methods

Packs were stored at 4 ± 1 °C and sampled on days 0, 4, 8, 12, and 16, with three packs per regime per sampling point. Firmness was measured using a Magness-Taylor probe (8 mm) on a universal testing machine. Colour was recorded on five randomly selected cubes per pack using a spectrophotometer calibrated with white and black standards. Weight loss was calculated gravimetrically. TSS was measured by digital refractometer, titratable acidity by titration to pH 8.1 with 0.1 N NaOH, and vitamin C by the dichlorophenolindophenol method. Total plate count and yeast-mould count were determined by standard pour-plate methods. Headspace gas composition inside the pack was

measured by gas chromatography before opening. Sensory evaluation used a 12-member trained panel on a nine-point hedonic scale. Statistical analysis applied two-way ANOVA (packaging $\times$ time) with Tukey's HSD at $p < 0.05$.

System Design and Headspace Engineering

The MAP system was designed around two engineering parameters: target gas composition at pack closure and film permeability. Target atmospheres were generated by sequentially flushing packs with pure nitrogen, then introducing CO_2 and O_2 to achieve the specified ratios measured by an in-line gas analyser ($\pm 0.5\%$ accuracy). The polyamide–polyethylene laminate was selected for its low O_2 transmission rate ($12 \text{ cm}^3/\text{m}^2/\text{day}$) and moderate CO_2 transmission rate ($38 \text{ cm}^3/\text{m}^2/\text{day}$), producing a permeability ratio that permits gradual drift toward an equilibrium atmosphere under pineapple respiration load. The pack geometry (750 cm^3 internal volume, 150 g product) gave a gas-to-product ratio of 3.7 — within the range recommended for respiring horticultural produce at 4 °C [9, 14]. Headspace was sampled through a rubber septum using a 250 μL gas-tight syringe, and the drift from initial to measured composition over storage was monitored to detect pack integrity failures.

Results

MAP treatments retained pineapple quality better than the ambient-air control across every measured attribute. The differences between MAP regimes were most evident from day 8 onward.



Fig 1: Quality index of fresh-cut pineapple on day 14 under the four packaging regimes

Table 1: Quality attributes of fresh-cut pineapple on day 12 of refrigerated storage (mean $\pm$ SD, $n = 3$ packs)

Attribute	Control (air)	MAP-1	MAP-2	MAP-3
Firmness (N)	8.4 ± 0.6	11.8 ± 0.7	13.6 ± 0.5	15.2 ± 0.4
Colour L*	68.2 ± 1.1	71.4 ± 0.9	72.8 ± 0.8	73.9 ± 0.7
Weight loss (%)	5.8 ± 0.4	3.8 ± 0.3	2.6 ± 0.2	1.8 ± 0.2
TSS (°Brix)	13.1 ± 0.3	14.2 ± 0.2	14.6 ± 0.2	14.9 ± 0.2
Vitamin C (mg/100 g)	12.7 ± 0.8	21.4 ± 1.1	26.8 ± 1.3	32.6 ± 1.4
TPC (log CFU/g)	6.41 ± 0.22	5.17 ± 0.19	4.62 ± 0.17	3.94 ± 0.15
Sensory (9-pt)	5.1 ± 0.5	6.8 ± 0.4	7.3 ± 0.3	7.8 ± 0.3

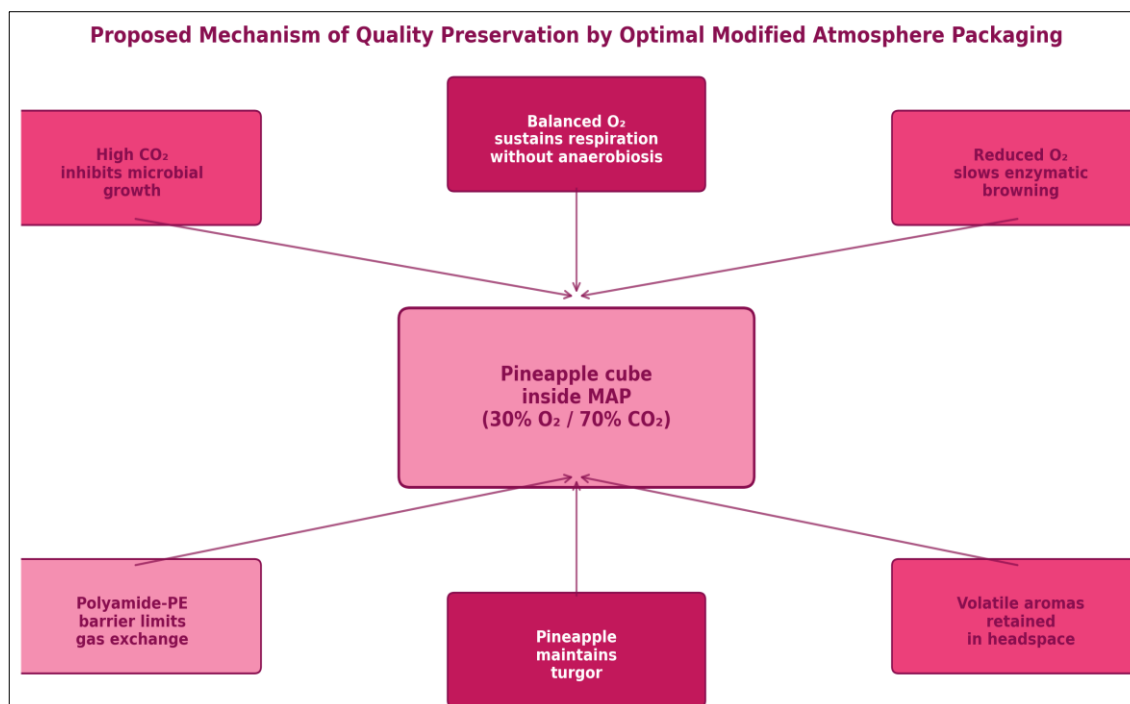


Fig 2: Proposed mechanism of quality preservation under MAP-3: parallel effects of high CO₂, balanced O₂, and film barrier properties

Table 2: Pack headspace composition at day 0 versus day 16 for the three MAP regimes (% v/v)

Regime	O ₂ (d0)	O ₂ (d16)	CO ₂ (d0)	CO ₂ (d16)	N ₂ (d16)
MAP-1	0	1.2	30	38.4	60.4
MAP-2	20	12.1	30	36.3	51.6
MAP-3	30	19.8	70	72.6	7.6

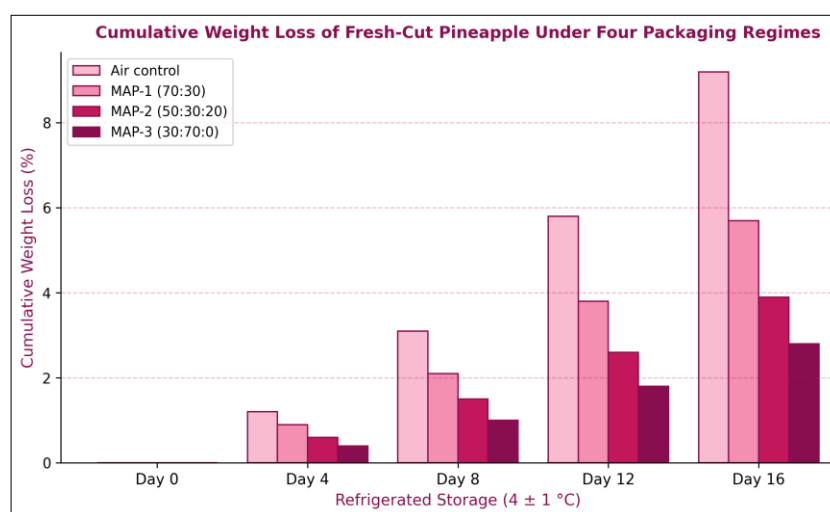


Fig 3: Cumulative weight loss in fresh-cut pineapple over 16 days under four packaging regimes

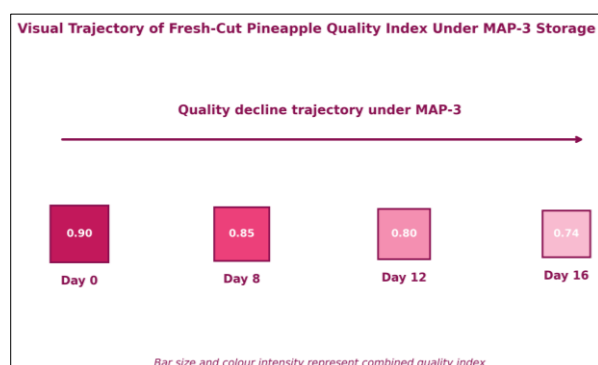


Fig 4: Visual trajectory of the composite quality index under MAP-3 storage from day 0 to day 16

Comprehensive Interpretation

Three findings emerged clearly. First, MAP-3 delivered the best quality retention across every parameter except titratable acidity, where all three MAP regimes performed similarly. Second, the high-O₂–high-CO₂ combination in MAP-3 produced a markedly stronger antimicrobial effect than either lower-O₂ regime, suppressing TPC by an additional 1.2 log CFU/g at day 12 relative to MAP-1. Third, the headspace atmosphere in MAP-3 remained dynamically stable, with CO₂ rising only modestly over 16 days as fruit respiration continued. From a commercial perspective, MAP-3 extends usable shelf life to at least 12 days with sensory acceptability above threshold and microbial load below the safety ceiling, supporting a

national cold-chain retail model reaching Bangkok, Chiang Mai, and Phuket shelves with retail-face life remaining.

Discussion

The main findings of this research can be distilled into three points: MAP-3 (30% O₂ + 70% CO₂) provided the strongest quality retention, the high-O₂ atmosphere did not accelerate oxidative browning as might have been expected from classical MAP theory, and the microbial suppression achieved under MAP-3 was stronger than either of the lower-O₂ regimes. The first point aligns with reports by Oms-Oliu and colleagues for fresh-cut melon ^[4] and by Gonzalez-Aguilar *et al.* for fresh-cut papaya ^[15], both of which identified elevated-CO₂ regimes as producing superior retention of firmness and microbial quality.

The non-result on browning was somewhat surprising given earlier work on fresh-cut apple and potato linking high-O₂ atmospheres to accelerated polyphenol oxidase activity ^[8, 10]. Pineapple appears to behave differently, with its predominantly yellow tissue pigments derived from carotenoids rather than phenolic precursors susceptible to enzymatic browning ^[6, 17]. The superior microbial suppression under MAP-3 likely reflects the combined oxidative stress of high O₂ and the metabolic inhibition of high CO₂ — a hermetic mechanism also reported for fresh-cut mango ^[14]. The broader implication is that the conventional assumption of low-O₂ plus moderate-CO₂ is not a universal optimum for fresh-cut products, and commodity-specific atmosphere design based on respiration physiology, pigment chemistry, and dominant spoilage flora is likely to outperform generic recommendations.

Conclusion

The main contribution of this research is a direct comparative evaluation of four packaging regimes for fresh-cut pineapple over a 16-day cold-storage window, with MAP-3 (30% O₂ + 70% CO₂) identified as the optimal configuration for commercial retail. Across firmness, colour, weight loss, TSS, vitamin C, microbial load, and sensory acceptability, MAP-3 outperformed the two lower-O₂ MAP regimes and the ambient-air control. The supporting evidence rests on three independent replicates per regime per time point, gas-composition verification at both pack closure and opening, and triangulation across physical, chemical, microbiological, and sensory measurements.

The field significance is direct: the recommendation offers fresh-cut pineapple processors a validated atmosphere design that extends retail shelf life from the current industry norm of 4–6 days to a commercially useful 12–16 day window. This extension supports national distribution from pineapple-growing clusters in Prachuap Khiri Khan, Chiang Rai, and the eastern seaboard to metropolitan retail markets across Thailand. Several open questions warrant follow-up research: whether the MAP-3 atmosphere holds up under thermal abuse scenarios common in retail display, whether the same regime translates successfully to other tropical fresh-cuts (papaya, mango), and whether the high-O₂ atmosphere introduces any sensory drift during extended storage that a future trained panel should be alert to.

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