Effect of Ozone Fumigation Period on the Postharvest Quality of 'Pattavia cv.' Pineapple.

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Abstract

Postharvest decay and senescence are major limitations to the storage and export of pineapple (*Ananas comosus*), resulting in significant quality loss and economic impact. This study evaluated the effectiveness of ozone fumigation at different exposure durations in suppressing decay and delaying senescence in pineapples. Fruits were fumigated with ozone gas at 325-350 ppm at the flow rate of 6 mL/min for 0 (control), 20, 40, and 60 min and stored at 13°C and 95 % RH for 25 days. Quality assessments, including disease incidence and severity, weight loss, peel color, and internal browning score, were recorded. The results showed that ozone fumigation markedly reduced color change, internal browning, and decay compared with the control. After 20 days of storage, fruits fumigated for 60 min exhibited a 60 % reduction in disease severity relative to the control, while both the 40 and 60 min treatments maintained lower b* values, indicating delayed yellowing or ripening. However, ozone fumigation has no significant effect on weight loss across treatments. These findings demonstrate that ozone fumigation with an exposure time of 40-60 min is an effective treatment to extend storage life and preserve the visual quality of pineapple fruit.

Keywords: Senescence, Postharvest decay, Storage life

Introduction

Pineapple (*Ananas comosus* L. [Merr.]) is a perennial herbaceous plant native to the tropical regions of the Americas. It is an edible and highly nutritious fruit belonging to the family Bromeliaceae (Sapak et al., 2021). The major constituents of pineapple are carbohydrates and water, which provide essential dietary components such as fiber, sugars, and organic acids. In addition, pineapple is a rich source of vitamins, including ascorbic acid, niacin, and thiamine, as well as minerals such as magnesium, manganese, and copper (Ancos et al., 2017). Pineapple and its processed products are considered valuable export commodities (Apipatpapha et al., 2022).

However, pineapple fruits are highly susceptible to postharvest decay, which often originates from infections that occur during harvest. Pathogens typically enter through wounds on the fruit surface, damaged peduncles, or other injuries sustained during handling, and these infections subsequently develop during storage. Several pathogens have been reported as causal agents of postharvest pineapple decay, including *Thielaviopsis paradoxa*, the primary causal agent of black rot, as well as *Curvularia eragrostidis*, *Trichoderma asperellum*, *Neoscytalidium dimidiatum*, *Aspergillus assiutensis*, and *Aspergillus aculeatus* (Kuruppu et al., 2025).

Another major challenge is peel yellowing, which is a signal of ripening that leads to fruit senescence. The loss of green color and progression to full yellow not only shortens the visual shelf life but also increases susceptibility to pathogen infection and disease development. As decay and senescence progress, they compromise visual quality, reduce consumer acceptance, shorten shelf life, and may also diminish nutritional value (Rohrbach and Phillips, 1990).

Alongside senescence, chilling injury (CI), manifested as internal browning (IB), poses another critical postharvest storage disorder that significantly exacerbates postharvest losses, particularly during prolonged storage (Li et al., 2024). Even under the recommended commercial storage temperature (13 °C), pineapples frequently develop CI symptoms in the form of IB (Jiragittidoon et al., 2023), which significantly reduces their market value (Stewart et al., 2001). IB results from chilling-induced metabolic dysfunction, primarily caused by membrane damage that disrupts organelle integrity. This disruption facilitates contact between plastid polyphenol oxidase (PPO) and phenolic compounds normally sequestered in the vacuole. The subsequent enzymatic oxidation generates o-quinone intermediates that polymerize into brown pigments, ultimately producing the tissue discoloration characteristic of IB (Mengzhuo et al., 2022; Raimbault et al., 2011).

Various postharvest technologies, including chemical, physical, and biological treatments, have been employed to maintain pineapple quality during storage. Although fungicides are effective against decay, their residues pose health risks (Sui et al., 2025). Alternative approaches have shown potential to reduce the decay and senescence, such as coating (chitosan-aloe vera, ethanolic shellac-modified coconut oil) that suppresses decay and IB (Basumatary et al., 2021; Jiragittidoon et al., 2023) , ethylene absorbents that mitigate senescence-related disorders (Sabater-Vilar et al., 2018), and biological control agents that alleviate IB during storage (Shen et al., 2023).

Ozone (O_3) is a highly reactive, short-lived gas that decomposes into oxygen, leaving no harmful residues on treated produce. Ozone is recognized as safe by the U.S. Food and Drug Administration (Glowacz et al., 2015). It is increasingly regarded as a potential alternative to chlorine-based disinfectants. In both gaseous and liquid forms, ozone exhibits strong oxidizing properties and a broad-spectrum antimicrobial activity while helping preserve the quality of agricultural produce during storage (Botondi et al., 2021; Sarron et al., 2021). Ozone application has been demonstrated to effectively control postharvest diseases and maintain fruit quality. In table grapes, fumigation with 2.0 mg L^{-1} ozone inhibited the growth of *Talaromyces rugulosus* (blue mold) while maintaining weight, sugars, acidity, and vitamin C level (Li et al., 2025). Similarly, ozone treatment (325–350 ppm) reduced jackfruit rot by 53.4%, enhanced defense enzymes, and preserved firmness, color, soluble solids, and antioxidant content while suppressing ethylene production and respiration rates (Kartika et al., 2025).

Nevertheless, despite these promising findings, studies on gaseous ozone treatment in whole pineapple fruits remain limited. Sasmita et al. (2022) investigated ozonated water for washing honey pineapple, focusing on bacterial count and vitamin C content, but not on fungal infection or physiological disorders. Similarly, Alothman et al. (2010) examined the effects of gaseous ozone on fresh-cut pineapple, emphasizing antioxidant properties rather than the storage performance of whole fruits. These studies highlight a clear gap regarding the impact of ozone fumigation on fungal disease incidence, internal browning, and senescence in whole pineapples during extended cold storage. Therefore, this study hypothesizes that controlled exposure of ‘Pattavia’ pineapple to gaseous ozone at 325–350 ppm can delay senescence, suppress fungal decay, and reduce physiological deterioration, whereas excessive exposure may induce oxidative stress or peel discoloration. The present study aims to evaluate the effect of ozone fumigation at different exposure durations on maintaining postharvest quality and extending the shelf life of pineapple, emphasizing its potential as a safe, effective, and sustainable postharvest technology.

Materials and methods

Fruit preparation and ozone treatment

‘Pattavia cv.’ Pineapple fruits at commercial maturity (1.2-1.5 kg) were sourced from the Talaad Thai wholesale market, Pathum Thani Province, Thailand. All fruits originated from a single orchard and were carefully selected for uniformity in size and color, as well as for the absence of defects, pests, or diseases. The fruits were transported to the Postharvest Technology Division Laboratory, King Mongkut’s University of Technology Thonburi (KMUTT), washed, crowns trimmed by three-quarters, stems cut to 5 cm, and air-dried. Ozone fumigation was then applied at 325–350 ppm at the flow rate of 6 mL/min for 0 (control), 20, 40, and 60 min. Ozone was produced using an ozone generator (model CCA-5G-W), and its concentration was monitored with an ozone detector (WASP-XM-E-O_3, maximum 5,000 ppm; China). Treated fruits were placed in plastic baskets, covered with perforated plastic bags for 25 days at 13°C and 95% RH. Peel color, disease incidence, severity, and weight loss were measured at 5-day intervals, while browning score was evaluated at the end of storage.

Measurement of fruit color and internal browning score

The color of the fruit peel was assessed at three points (top, middle, and bottom of longitudinal regions) using a colorimeter (Minolta 400; Japan). Values of lightness (L*), red-green (a*), and yellow-blue (b*) were recorded. The Internal browning score was evaluated as described by Jiragittidoon et al. (2023) where 0 = 0% (no browning), 1 = 1–20% (internal browning), 2 = 21–40% (internal browning), 3 = 41–60% (internal browning), and 4 = >60% (internal browning).

Measurement of weight loss

Each fruit sample was weighed using a digital balance to record its initial weight, which was later compared with the final weight after storage. Weight loss (%) was calculated using the formula: $(N_0 - N_1) / N_0 \times 100$, where N_0 is the initial weight and N_1 is the final weight.

Measurement of disease incidence and severity

The incidence of fruit rot during storage was assessed based on the presence of visible fungal growth on the peduncle, crown, or peel surface. Fruits showing any visible fungal growth were considered diseased. Disease incidence (%) was calculated using the formula: $(F_0 / F_1) \times 100$, where F_0 represents the number of infected fruits and F_1 the total number of fruits examined. Disease severity was evaluated following a modified method of Jiragittidoon et al. (2023), using a 0–5 scale: 0 = no visible mycelial growth; 1 = mycelial growth on the peduncle and crown cut surface only; 2 = mycelial growth on the peduncle, crown, and 1–5% of the peel; 3 = mycelial growth on the peduncle, crown, and 6–10% of the peel; 4 = mycelial growth on the peduncle, crown, and 11–15% of the peel; 5 = mycelial growth on the peduncle, crown, and more than 15% of the peel.

Experimental design and statistics

The experiment was arranged in a completely randomized design (CRD). Each treatment consisted of ten replicates, with one fruit per replicate. Data were analyzed using analysis of variance (ANOVA) at a 5% significance level with SAS statistical software version 9.0 (SAS Institute, USA), and treatment means were compared using Duncan’s Multiple Range Test (DMRT).

Results

Effect of ozone fumigation on peel color and internal browning

Ozone fumigation significantly affected peel color development during storage. Control fruits showed a sharp increase in *L** (lightness) and *b** (blue-yellow axis) values, indicating rapid yellowing, whereas fruit fumigated for 40 and 60 min retained lower values, reflecting delayed peel discoloration (Figure 1A and 1C). For a* (green–red axis), control fruits shifted toward positive values, indicating loss of greenness, while ozone-treated fruit retained negative values (Figure 1B), confirming a slower transition from green to yellow (Figure 2). These results demonstrate that ozone fumigation delayed senescence-related color changes in pineapple (Figure 4).

Internal browning was also notably reduced by ozone treatments. At the end of storage, the control fruits exhibited the highest mean internal browning score (3.5), while the 40- and 60-min ozone treatments maintained much lower scores (Figure 1D), representing a substantial reduction in internal browning by ozone treatment (Figure 3)..

Effect of ozone fumigation on weight loss

Weight loss increased steadily across all treatments, although ozone-treated fruits showed numerically lower weight loss; the differences were not statistically significant ($p > 0.05$).

Effect of ozone fumigation on disease severity and incidence

The control group exhibited yellow to brown discoloration with dark, sunken lesions around the eyes and white fungal mycelia on the surface, indicating surface rot and fungal infection. The affected areas appeared dull and softened, reflecting postharvest decay and senescence during storage. The crown and stem-end cut surfaces also showed heavy fungal colonization, with dense mycelial growth and sporulation around the cut surfaces of both the stem and crown. In contrast, ozone treatments effectively suppressed disease development throughout storage, reducing both severity and incidence. By day 20, fruits fumigated with ozone for 60 min showed a 60% reduction in disease severity compared with the control, while the 40-min treatment showed a 46.7% reduction (Figure 5A). A similar trend was observed for disease incidence: on day 10, only the control showed incidence, with up to 40% of fruits infected, whereas no incidence was observed in ozone-treated fruits. By day 15, 60-min ozone fumigation reduced disease incidence by approximately 60% compared with the control (Figure 5B). Visual observations confirmed these findings, showing reduced mycelial growth on the peel, crown, and peduncle.

Discussion

The present study investigated the effect of ozone gas fumigation on the postharvest quality of pineapple, focusing on its potential to delay senescence, internal browning, and decay. The results demonstrated that ozone fumigation, particularly at 40-60 min exposure, significantly delayed senescence, as evidenced by slower peel discoloration and reduced disease incidence and severity compared to the control. The effectiveness of ozone fumigation in suppressing postharvest decay was demonstrated by reductions in both disease incidence and severity. Consistent with findings in blueberries infected with *Penicillium* sp. (Wu et al., 2022). The oxidative nature of ozone damages pathogen cell membranes, disrupting their integrity and inhibiting spore germination. A comparable mechanism was reported in table grapes, where ozone inhibited *Talaromyces rugulosus* growth and reduced ochratoxin A accumulation (Li et al., 2025).

In the current study, 60 minutes of ozone treatment reduced disease severity by 60% at day 20, which is in line with results in jackfruit, where fumigation with 325–350 ppm ozone for 60 minutes decreased fruit rot by 53.4% (Kartika et al., 2025). These findings highlight the broad-spectrum antifungal potential of ozone fumigation across different fruit species. Ozone not only exhibits direct antimicrobial activity but also indirectly enhances fruit resistance by stimulating defense-related enzymes. Kartika et al. (2025) reported that ozone exposure in jackfruit increased the activities of phenyl ammonia lyase (PAL), peroxidase (POD), chitinase (CHI), and **β**-1,3-glucanase (GLU), which play key roles in cell wall reinforcement and fungal cell wall degradation. This enzymatic induction, triggered by ozone-generated reactive oxygen species (ROS), promotes the synthesis of phenolic compounds and antioxidants, thereby strengthening host tissues and restricting pathogen invasion. Consequently, ozone-treated jackfruit exhibits reduced disease severity and enhanced postharvest defense, reflecting its role in activating endogenous protective mechanisms in addition to direct microbial inhibition.

The observed delay in the color change of pineapple peel is also consistent with previous studies. For example, in jackfruit, Kartika et al. (2025) found that ozone fumigation suppressed ethylene production by reducing the precursor 1-aminocyclopropane-1-carboxylic acid (ACC) and the activities of ACC synthase (ACS) and ACC oxidase (ACO), thereby slowing senescence. Although ozone fumigation conferred strong benefits in delaying senescence and reducing decay, it had no significant effect on pineapple weight loss. However, a marked reduction in internal browning score was observed after 25 days of storage. This finding is consistent with previous reports indicating that ozone treatment suppresses polyphenol oxidase (PPO) activity, a key enzyme responsible for phenolic oxidation and tissue browning. Similar ozone-mediated reductions in PPO activity have been documented in blueberry (Wu et al., 2022), jackfruit (Kartika et al., 2025), and a fresh-cut apple treated with aqueous ozone (Liu et al., 2016).

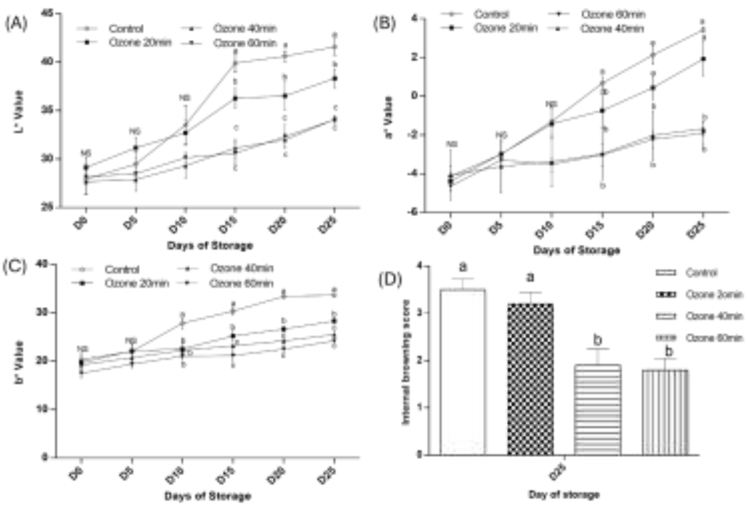

Figure 1 L* (A), a* (B), and b* (C) values of the peel, and internal browning score (D) of 'Pattavia' Pineapple after ozone fumigation at 325–350 ppm for 0 (control), 20, 40, and 60 min during storage at 13 °C for 25 days. Values represent means ± standard deviation (n = 10). Error bars indicate standard deviation. Different lowercase letters represent statistically significant differences between treatments on the same day ($p < 0.05$, DMRT).

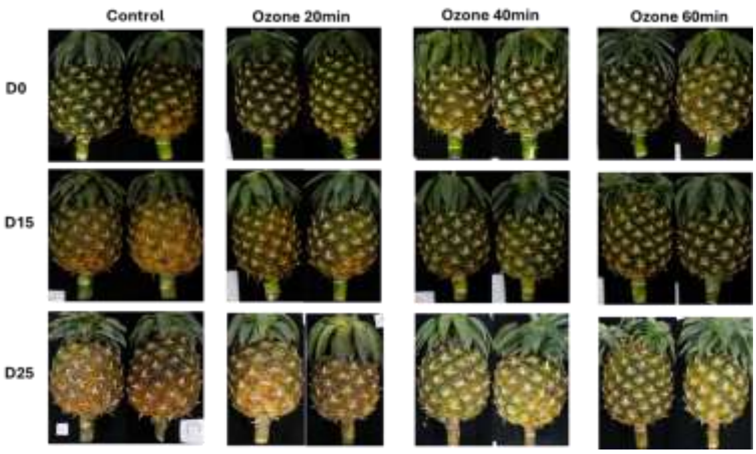

Figure 2 Peel appearance of pineapple fruits after ozone fumigation at 325-350 ppm for 0, 20, 40, and 60 min, during storage period at 13 °C for 25 days.

Figure 3 Longitudinal cross-section of pineapple fruits after ozone fumigation at 325-350 ppm for 0 (control), 20, 40, and 60 min, during storage period at 13 °C for 25 days.

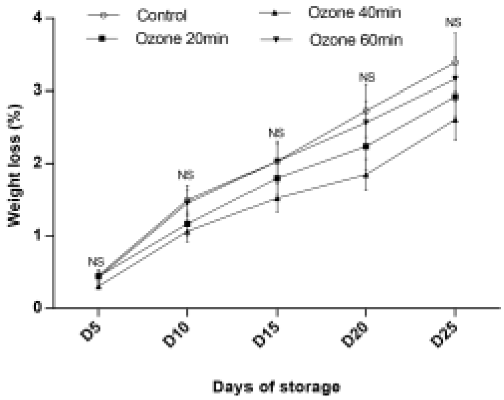

Figure 4 Weight loss of 'Pattavia' pineapple after ozone fumigation at 325–350 ppm for 0 (control), 20, 40, and 60 min during storage at 13 °C for 25 days. Values represent means ± standard deviation (n = 10). Error bars indicate standard deviation. Different lowercase letters represent statistically significant differences between treatments on the same day (p < 0.05, DMRT).

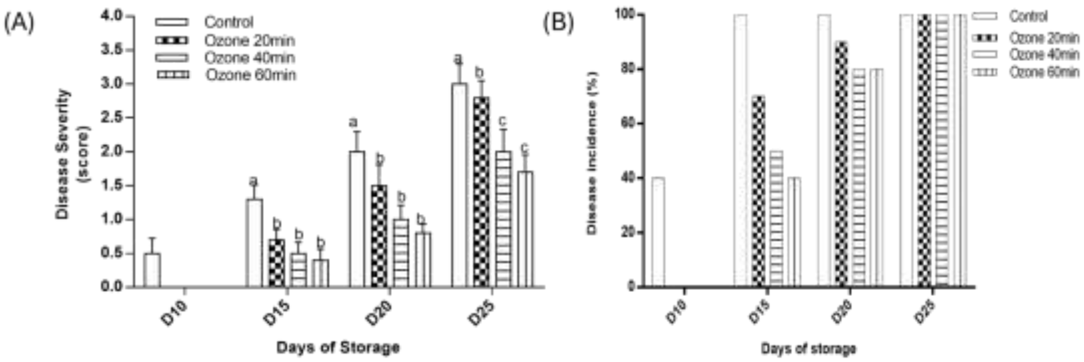

Figure 5 Disease severity (A) and incidence (B) of pineapple after ozone fumigation at 325-350 ppm for 0, 20, 40, and 60 min, during storage period at 13°C for 25 days. Values represent means ± standard deviation (n = 10). Error bars indicate standard deviation. Different lowercase letters represent the statistically significant differences between the control and treatments on the same day (p<0.05, Dunnett's test).

Conclusion

Ozone fumigation at 325–350 ppm with an exposure time of 40-60 minutes effectively maintained the postharvest quality of 'Pattavia' pineapple stored at 13 °C and 95 % relative humidity for 25 days. The treatment delayed peel yellowing and internal browning, reduced decay incidence and severity, and prolonged storage life, demonstrating its potential as a promising and eco-friendly alternative for postharvest management.

However, further optimization of ozone concentration and exposure duration, as well as evaluation of its long-term effects on fruit nutritional quality, are recommended to enhance its practical application in the postharvest industry.

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