



Journal home page: <http://ajarcde-safe-network.org> ISSN 2581-0405

Design and Evaluation of a Ventilated Corrugated Cardboard Box for Papaya Fruit Transportation

Khandra Fahmy¹, Irriwad Putri¹, Mislaini Rahman¹, Melidawati² and Wahyu Kamilatul Fauziah²

¹ Department of Agricultural and Biosystem Engineering, Faculty of Agricultural Technology, Universitas Andalas, Padang, Indonesia.

² Study Program of Agricultural Mechanisation, Department of Agricultural Technology, Lampung State Polytechnic, Lampung, Indonesia.

ARTICLE INFO

Article History:

Received: 24 September 2026

Final Revision: 12 October 2026

Accepted: 14 October 2026

Online Publication: 15 October 2026

KEYWORDS

papaya; cardboard box; corrugated board; transportation; fruit quality.

CORRESPONDING AUTHOR

*E-mail: khandrafahmy@ac.unand.ac.id

A B S T R A C T

Papaya is a horticultural commodity with considerable economic value and promising market potential. However, improper postharvest handling can damage fruit, particularly during distribution and transportation. Harvested papaya fruits are generally placed directly on the vehicle floor on a base of newspaper or tarpaulin. This practice may cause mechanical damage during transportation and increase postharvest losses. Cardboard boxes are expected to reduce mechanical damage; however, unventilated boxes may promote heat accumulation due to limited air exchange, affecting respiration rate and fruit quality. Therefore, this study aimed to design and evaluate a ventilated cardboard box to maintain papaya fruit quality during transportation. The cardboard box used in this study was a Regular Slotted Container (RSC) made of corrugated board, consisting of an outer packaging (41 × 31 × 22 cm) and an inner packaging (40 × 30 × 21 cm). Ventilation openings were designed to have a total area of 1% and 2% of the box wall area, while a box without ventilation served as the control. Each box contained 12 papaya fruits. We evaluated mechanical injury after transportation, visual damage, weight loss, respiration rate, and total soluble solids. The results showed that a ventilation area equivalent to 1% of the cardboard box wall area yielded the lowest numerically observed damage and maintained papaya fruit quality during transportation.

Contribution to Sustainable Development Goals (SDGs):

SDG 12: Responsible Consumption and Production

SDG 9: Industry, Innovation and Infrastructure

SDG 8: Decent Work and Economic Growth

SDG 2: Zero Hunger

SDG 1: No Poverty

1. INTRODUCTION

1.1. Research Background

Papaya is recognized as a high-value agricultural commodity owing to its broad market access, ranging from traditional markets to modern retail outlets such as supermarkets. It is a highly familiar fruit in daily life and is utilized for a wide range of purposes. When ripe, people commonly eat papaya fresh as a refreshing fruit, and it provides a rich source of nutrients,

particularly vitamins A and C. In addition to direct consumption, papaya is widely used in the food processing industry, for example, as an ingredient in tomato sauce production to enhance flavor, improve color, and increase nutritional content [1].

Papaya is a fruit commodity with considerable potential in West Sumatra. Papaya production in the province reached 43,027 tons in 2024, rising from 39,633 tons in 2023 [2]. This high production requires appropriate postharvest handling and transportation systems to minimize mechanical damage and maintain fruit quality during distribution.



This work is licensed under a Creative Commons Attribution-NonCommercial-ShareAlike 4.0 International License

Published under licence by SAFE-Network

Postharvest handling encompasses the entire sequence of activities performed on a commodity from harvest to the final consumer, including harvesting, sorting, processing, packaging, transportation, marketing, and storage. Proper papaya harvesting timing is key to maintaining fruit quality, as respiration, transpiration, and other physiological processes continue after harvest until the fruit deteriorates. Therefore, applying appropriate postharvest handling technologies is essential to maintain papaya quality longer.

Transportation and distribution are important stages in the papaya postharvest chain that require particular attention [3;4]. Improper handling during distribution can trigger fruit damage. The transportation method used significantly influences postharvest fruit quality; inappropriate handling can reduce quality while increasing losses from mechanical damage during transport [5;6].

To date, papaya distribution practices have generally paid insufficient attention to the influence of packaging type. Newly harvested fruits are often placed directly in the cargo bed of a pickup truck and covered only with newspaper or tarpaulin before being transported to traders. Meanwhile, for distribution to supermarkets or fruit stores, papayas are commonly packed in baskets with additional cushioning materials such as cement bags or newspaper. Unfortunately, these packaging practices can cause mechanical damage, which contributes to a decline in fruit quality after transportation [7;8]. Researchers have investigated alternative packaging designs, such as partition-based packaging, to reduce mechanical damage during papaya transport [9].

One potential solution to reduce the risk of mechanical damage is to use cardboard boxes for packaging. The use of cardboard boxes is expected to protect the fruit from impacts during transportation [3;11]. Nevertheless, even when enclosed in cardboard packaging, papaya fruit continues to undergo biological processes, including respiration and transpiration, which can lead to heat accumulation inside the box [12;4]. To address this issue, ventilation openings are required in cardboard boxes to facilitate heat dissipation from the package [12]. The influence of vent-hole design on the thermal performance of fruit packaging boxes has also been examined using computational fluid dynamics [13]. However, excessively large ventilation openings may increase oxygen supply within the package, potentially accelerating the fruit's respiration rate. Therefore, further investigation is required to determine the optimal ventilation size so that cardboard box packaging can not only effectively reduce mechanical damage but also minimize physiological deterioration of papaya fruit [12;14].

Unlike routine community service interventions that merely distribute packaging materials without systematic evaluation, this study was designed as an applied research initiative that experimentally evaluates a packaging design before it is recommended for adoption by farmer communities. The central research question was: how does the ventilation area of a corrugated cardboard box affect mechanical damage and the physiological quality of papaya fruit during transportation, and which ventilation level is most suitable to recommend to smallholder farmers and local traders? Low-cost and practical postharvest technologies are particularly relevant for small-scale farmers [15;16]. We compared three treatments: a non-ventilated control and ventilation areas equivalent to 1% and 2% of the box's total wall area. It was hypothesized that the ventilation area would influence heat dissipation and gas exchange within the package,

and that a smaller ventilation area (1%) would provide a more favorable balance between heat dissipation and moisture retention than the non-ventilated control and the larger ventilation area (2%).

1.2. Literature Review

Papaya cultivation has long been practiced by farmers in Indonesia and is believed to have originated from the region around Mexico and Costa Rica. One variety that is currently gaining popularity and being increasingly cultivated by farmers is California papaya, as it is considered to offer promising economic returns. This variety has an average fruit weight of 1.24 kg, a cylindrical shape, and a slightly concave base. The fruit skin is bright green and smooth, while the flesh is reddish-orange, firm, and fairly sweet, with a total soluble solids content of 10–11 °Brix. California papaya is the result of a breeding program conducted by the Center for Tropical Fruit Studies at Bogor Agricultural University (PKBT-IPB), known by the name IPB-9 or Calina [17].

Improper postharvest handling during distribution can cause fruit damage, particularly mechanical injury resulting from inadequate packaging materials, poor road conditions, and unsuitable transport equipment [18;19]. Such mechanical damage is a major contributor to postharvest losses in horticultural commodities, including papaya, and can significantly reduce product quality after transportation [20]. The mechanical properties and compression behavior of papaya fruit determine its susceptibility to damage during handling and transport [21;22].

Corrugated cardboard boxes, commonly referred to as cartons, are the most widely used transport packaging material for a broad range of products, from fresh fruits and vegetables to consumer goods, household and industrial machinery, and even semi-bulk transportation of various commodities in large quantities. The primary purpose of cardboard boxes is to protect enclosed products during distribution from environmental conditions, moisture, and mechanical forces. Although cardboard boxes provide good protection against mechanical forces—owing to the corrugated structure between the medium and kraft liners that functions as a cushioning material to absorb impact during transportation [23]—their main weakness lies in protection against water and humidity, as their compressive strength decreases significantly under high-humidity conditions [24].

Corrugated cardboard packaging comes in various types, with three being the most commonly used: Regular Slotted Container (RSC), Half Telescopic Container (HTC), and Full Telescopic Container (FTC).

1.3. Research Objective

This study aimed to determine the effect of ventilation area in the packaging on papaya fruit quality, including mechanical damage, visual damage, weight loss, respiration rate, and total soluble solids. In addition, this study aimed to evaluate how ventilation area affects temperature distribution within the package during transportation.

2. MATERIALS AND METHODS

2.1. Materials and Equipment

The material used in this study was California papaya (*Carica papaya* L.) harvested at the mature-green stage, characterized by

green skin color, from a farmer's orchard in Padang Pariaman Regency, West Sumatra, Indonesia. We used 108 fruits, with an average weight of 1.1–1.2 kg per fruit (Table 1). The equipment used in this study included a force gauge to measure fruit firmness, a refractometer to measure total soluble solids, a digital balance, a thermometer to measure temperature at different points, and other supporting equipment required to conduct the study.

2.2. Cardboard Box Design

The dimensions and capacity of the cardboard boxes were designed based on packaging commonly used for distribution to local markets. Fruit size, number of layers, packaging type, and material thickness were considered in determining the box dimensions. Table 1 presents the weight and dimensions of five representative papaya fruits. Based on these fruit dimensions, we selected corrugated cardboard as the primary packaging material because it can cushion impacts between the fruit and the box walls. The box consisted of an outer and an inner packaging. The outer packaging (41 × 31 × 22 cm) was made of C-flute corrugated board (4 mm thick) in a Regular Slotted Container (RSC) design. In contrast, the inner packaging (40 × 30 × 21 cm) was made of B-flute corrugated board (3 mm thick) in a modified RSC design equipped with additional dividers.

Table 1. Measurement data of papaya fruit weight and dimensions

Number	Measurement Data	Average
1	Weight (kg)	1.1-1.2
2	d _{average} (cm)	9.62 ± 0.26
3	d _{mayor} (cm)	20.74 ± 0.15

Ventilation openings were incorporated into the cardboard packaging based on the wall area [25]. We applied three ventilation treatments: 1% and 2% of the total wall area (3,168 cm²) using circular ventilation openings, and no ventilation as the control treatment. Based on the calculations, the ventilation opening radius was 1 cm for the 1% treatment and 1.4 cm for the 2% treatment, relative to the side-wall area of both the inner and outer boxes. Figure 1 shows the design of the cardboard packaging.

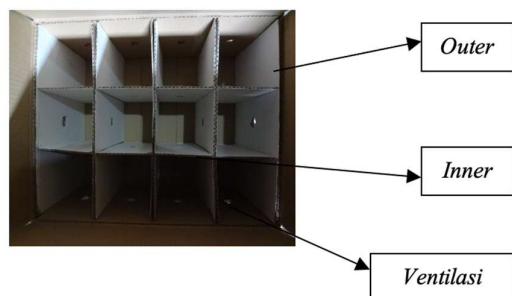


Fig. 1. Open isometric view of the cardboard box

2.3. Fruit Preparation and Packaging

The harvested papaya fruits were sorted, and those free of defects and uniform in size were selected. The fruits were then placed into the designed cardboard boxes: control (no ventilation), 1% ventilation, and 2% ventilation. The

effectiveness of the cardboard packaging was evaluated based on the percentage of mechanical damage to papaya fruits. The papaya fruits were systematically arranged vertically using the pattern pack arrangement. The packaged fruits were then transported to Padang, one of the main marketing areas for the fruit. Upon arrival in Padang, the fruits were transferred to the laboratory and stored at room temperature for quality evaluation.

2.4. Temperature Distribution Measurement

The temperature distribution inside the cardboard packages during storage was measured using a thermometer. Temperature measurements were taken at 12 points in each package, with the positions of these points shown in Figure 2.

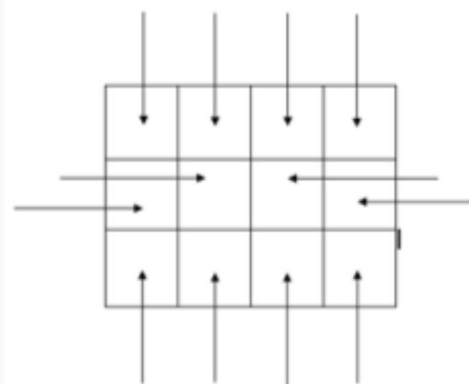


Fig. 2. Temperature Measurement Point Locations
Figure legend: —→ = temperature measurement point

2.5. Observations

Observations were conducted during storage at room temperature. The parameters evaluated included mechanical damage, visual condition, respiration rate, weight loss, fruit firmness, and total soluble solids of the papaya fruit. Mechanical damage after transportation was determined based on the ratio of the number of damaged fruits to the total number of fruits in the package.

Visual damage of the papaya fruit after storage was assessed using a numerical scale of 0–3 based on the proportion of the fruit surface affected: 0 = 0–25% (intact or minor damage), 1 = >25–50% (bruising), 2 = >50–75%, and 3 = >75% or severe damage.

We calculated the damage index using the equation proposed by Pesis et al. [26] by summing the products of the damage severity index and the number of fruits at each damage level, then dividing by the total number of fruits observed. The closed-system method, as described by Fahmy and Nakano [27], was used to measure the respiration rate. Weight loss was determined from changes in fruit weight throughout the storage period. Total soluble solids (TSS) were measured using a refractometer (Atago, Japan) [28].

2.6. Statistical Analysis

A two-factor factorial Completely Randomized Design was used, with ventilation area (K1: no ventilation; K2: 1%; K3: 2%) and storage time as factors, and three replicate boxes of 12 fruits per treatment. Data were analyzed by two-way ANOVA ($\alpha = 0.05$), followed by Tukey's HSD test when significant effects were found. Mechanical damage, assessed once after transportation, was analyzed by one-way ANOVA. All analyses were performed in R version.

3. RESULT AND DISCUSSION

3.1. Temperature Distribution Within The Cardboard Box

Based on Figures 3, 4, and 5, the temperature distribution patterns for the three packaging treatments during papaya storage fluctuated. Ambient temperature, packaging ventilation, and the fruit's physiological activity during ripening influenced these temperature variations. Papaya is a climacteric fruit that continues to increase respiration after harvest, generating metabolic heat that can affect package temperature [11]. In addition, the size and number of ventilation openings in the packaging play an important role in regulating air exchange, heat transfer, and the balance of gas concentrations surrounding the product during storage [3]. This is consistent with studies showing that vent-hole design affects the thermal behavior of fruit packaging boxes [13].

Based on these observations, the package with 1% ventilation showed a more stable temperature pattern than the control package (no ventilation) and the package with 2% ventilation. In the control package, the temperature tended to be higher because inadequate air exchange pathways allowed heat generated by fruit respiration to accumulate more readily inside the package, slowing heat dissipation. The absence of ventilation may also create a microenvironment characterized by heat accumulation and the buildup of respiratory gases, which can affect the fruit's ripening process [11].

Meanwhile, the greater temperature fluctuations observed in the 2% ventilation treatment were likely associated with the larger ventilation area, which allowed faster air exchange and made the package interior temperature more readily affected by ambient temperature changes. According to [4], packaging ventilation design should balance dissipating respiratory heat with protecting the product against water loss from transpiration. Thus, the 1% ventilation treatment provided a more balanced condition to maintain temperature stability by regulating air circulation and heat dissipation during papaya storage.

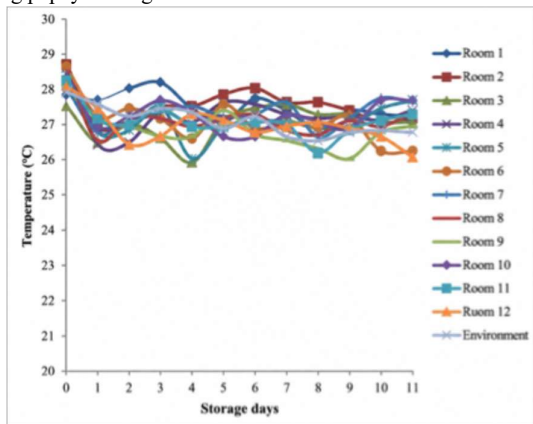


Fig. 3. Temperature Distribution in Cardboard Boxes without Ventilation During Storage at Room Temperature After Transportation.

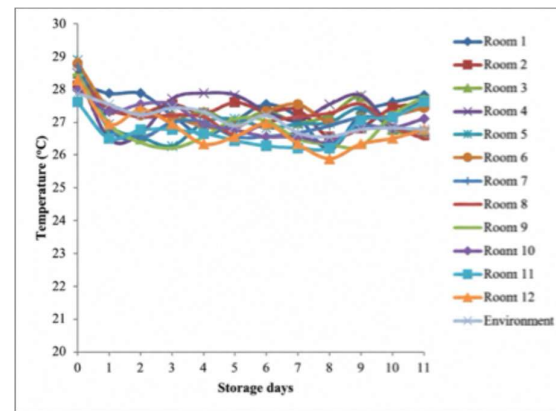


Fig. 4. Temperature Distribution in Cardboard Boxes with 1% Ventilation During Storage at Room Temperature After Transportation

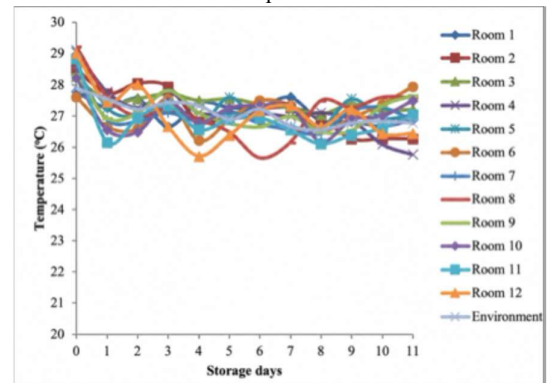


Fig. 5. Temperature Distribution in Cardboard Boxes with 2% Ventilation During Storage at Room Temperature After Transportation

3.2. Mechanical Damage

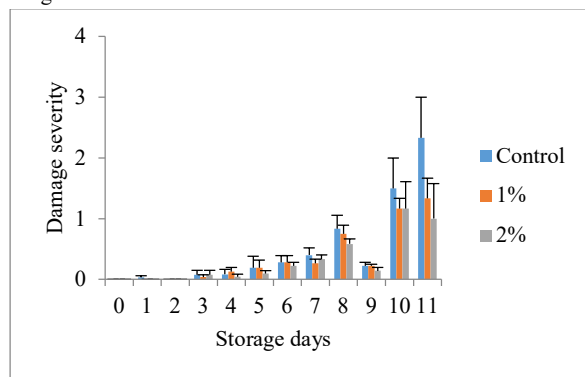
We assessed mechanical damage to the papaya fruit immediately after transportation from the farmer's orchard. Prior to packaging, the fruits were fresh and relatively uniform in size. After transportation, we evaluated damage by the presence of scratches, bruises, and cracks on the fruit surface; scratches generally resulted from friction between the fruit and the packaging. As shown in Table 2, mechanical damage was highest in the non-ventilated control ($27.78 \pm 4.81\%$), followed by the 2% ventilation ($22.22 \pm 4.81\%$) and the 1% ventilation ($19.45 \pm 4.81\%$). Although the ventilated packages showed numerically lower damage, the ventilation area had no significant effect on mechanical damage ($p = 0.178$). The 1% ventilation treatment corresponded to approximately one fewer damaged fruit per 12-fruit box than the control. However, this difference should be interpreted as a trend given the small number of replicate boxes ($n = 3$). The numerically lower damage in the ventilated packages should be interpreted with reference to the mechanical behaviour of papaya under compression [21;22] and to packaging designs that reduce mechanical damage in transported papaya [9].

Table 2. Percentage of mechanical damage to papaya fruit after transportation

Treatments	Mechanical Damage			Average
	Replication I (%)	Replication II (%)	Replication III (%)	
No ventilation	33.33	25.00	25.00	27.78
1% ventilation	25.00	16.67	16.67	19.44
2% ventilation	25.00	25.00	16.67	22.22

3.3. Visual Assessment

Papaya fruit damage tended to increase during storage after transportation (Figure 6). The ANOVA results showed that ventilation area had no significant effect on the degree of damage ($p = 0.0803 > 0.05$), and the interaction between ventilation and storage time was also not significant ($p = 0.5939 > 0.05$). In contrast, storage time had a highly significant effect on the degree of damage ($p < 0.001$). Based on the Tukey HSD post hoc test conducted using R, the degree of damage increased particularly on days 10 and 11. On day 11, the damage scores reached 2.333 in the control treatment, 1.333 in the 1% ventilation treatment, and 1.000 in the 2% ventilation treatment. Although the ventilated packages tended to show lower damage levels than the control, the overall differences did not indicate a significant effect of ventilation area.

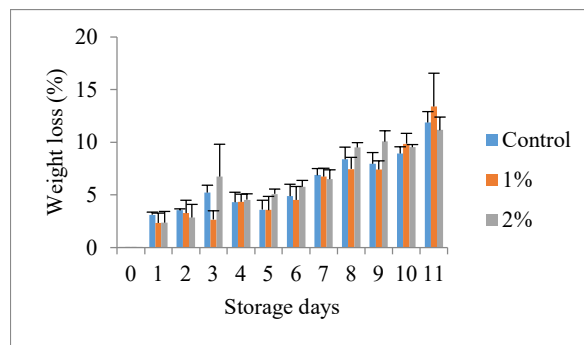
**Fig. 6.** Damage Severity of Papaya Fruits After Transportation Using Cardboard Boxes without Ventilation, 1% Ventilation, and 2% Ventilation During Storage at Room Temperature

3.4. Weight Loss

Weight loss was measured daily with three replications. As shown in Figure 7, papaya fruit weight loss tended to increase throughout storage in all treatments. This increase was primarily attributed to water loss through transpiration and respiration. After harvest, the fruit continues to lose water through its surface, decreasing weight during storage [29]. In addition, respiration and transpiration during storage contribute to fruit mass loss [30]. In addition, respiration and transpiration during storage contribute to fruit mass loss [30]. Postharvest conditions strongly influence weight loss and softening during papaya ripening [31].

The ANOVA results showed that ventilation area had no significant effect on weight loss ($p = 0.294$), whereas storage time had a highly significant effect ($p < 0.001$). The interaction between ventilation area and storage time was also not significant ($p = 0.884$). Based on the Tukey HSD post hoc test, weight loss increased particularly toward the end of the storage period. On day 11, weight loss reached 11.9% in the control treatment, 13.4%

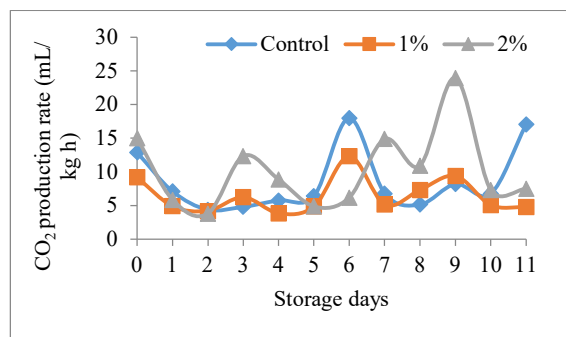
in the 1% ventilation treatment, and 11.2% in the 2% ventilation treatment. Although weight-loss values differed among treatments, ventilation area did not significantly affect papaya fruit weight loss.

**Fig. 7.** Weight Loss of Papaya Fruits After Transportation Using Cardboard Boxes without Ventilation, 1% Ventilation, and 2% Ventilation During Storage at Room Temperature.

3.5. Respiration Rate

As shown in Figure 8, the CO_2 production rate of papaya fruit fluctuated during storage after transportation. These fluctuations were associated with changes in respiration activity during ripening. Papaya is a climacteric fruit that shows increased respiration during ripening, followed by a decline as ripening progresses and the fruit senesces [32].

In the control treatment, the CO_2 production rate increased until day 6, whereas the 1% and 2% ventilation treatments showed several increases between days 6 and 9. The highest value was observed in the 2% ventilation treatment on day 9, reaching approximately $24 \text{ mL CO}_2 \text{ kg}^{-1} \text{ h}^{-1}$. Differences and fluctuations in respiration rate were likely associated with changes in temperature and the fruit's physiological condition during storage. Mechanical damage caused by transportation may also accelerate physiological changes and increase respiration activity in damaged tissues [32]. After reaching its peak, the CO_2 production rate decreased again as ripening and senescence progressed.

**Fig. 8.** CO_2 Production Rate of Papaya Fruits After Transportation Using Cardboard Boxes without Ventilation, 1% Ventilation, and 2% Ventilation During Storage at Room Temperature

3.6. Total Soluble Solid (TSS)

We measured total soluble solids (TSS) daily at three locations within the fruit: the stem end, middle, and blossom end, and then

averaged the measurements. As shown in Figure 9, the TSS values of papaya fruit fluctuated throughout storage across all treatments.

The ANOVA results showed that ventilation area had no significant effect on TSS ($p = 0.560$), whereas storage time had a significant effect ($p = 0.006$). The interaction between ventilation area and storage time was not significant ($p = 0.919$). Fluctuations in TSS during storage were associated with physiological changes during ripening, including changes in sugar content and its utilization during respiration. Shattir and Abu-Goukh [33] reported that papaya TSS changes during ripening and tends to increase as it progresses. In addition, storage duration and conditions can affect changes in papaya fruit TSS [34].

On day 11, the TSS values were 5.1 °Brix in the control treatment, 6.7 °Brix in the 1% ventilation treatment, and 5.1 °Brix in the 2% ventilation treatment. Although the 1% ventilation treatment showed a numerically higher TSS value at the end of storage, ventilation area overall did not significantly affect papaya fruit TSS.

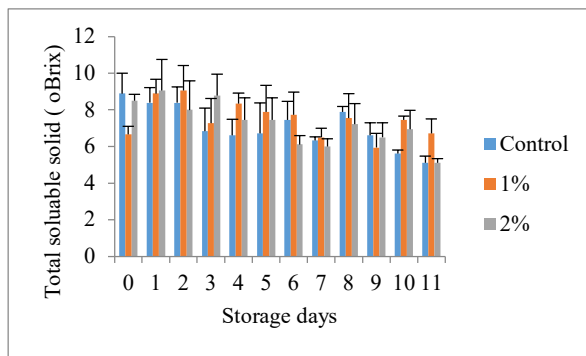


Fig. 9. Total Soluble Solids of Papaya Fruits After Transportation Using Cardboard Boxes without Ventilation, 1%

Table 3. Comparison of mechanical damage, visual damage, and weight loss of papaya fruit under 1% and 2% ventilation relative to the non-ventilated control.

Parameter	Control (no ventilation)	1% ventilation	2% ventilation	Relative change vs. control, 1% (%)	Relative change vs. control, 2% (%)	Effect of ventilation (p-value)
Mechanical damage after transportation (%)	27.78	19.44	22.22	-30.0	-20.0	0.178 (n.s)
Visual damage score, day 11 (0–3 scale)	2.333	1.333	1.000	-42.9	-57.1	0.080 (n.s.)
Weight loss, day 11 (%)	11.9	13.4	11.2	+12.6	-5.9	0.294 (n.s.)

Note: Relative change = (treatment – control) / control × 100; negative values indicate a lower value than the control. n = 3 boxes (12 fruits each) per treatment. n.s. = not significant ($p > 0.05$).

This study contributes to SDG 12 (target 12.3) by evaluating a packaging design intended to reduce mechanical damage and postharvest losses of papaya during transport, and to SDG 9 through a packaging innovation based on corrugated board. Contributions to SDG 2, SDG 8, and SDG 1 are indirect: lower postharvest losses may improve the availability of fresh produce [20] and the incomes of smallholder farmers and local traders. These links are inferred from the numerical reductions in damage observed (Table 3) and were not measured directly as food availability, income, or productivity outcomes.

Ventilation, and 2% Ventilation During Storage at Room Temperature.

3.7. Summary of Ventilation Effects and Practical Implications

Table 3 summarizes the differences between the ventilated packages and the non-ventilated control. Relative to the control, 1% ventilation numerically reduced mechanical damage from 27.78% to 19.44% (a 30.0% relative reduction, equivalent to approximately one fewer damaged fruit per 12-fruit box), while 2% ventilation reduced it to 22.22% (a 20.0% reduction). On day 11, visual damage scores were also lower in the 1% (1.333) and 2% (1.000) ventilated packages than in the control (2.333); however, ventilation area had no significant effect on visual damage ($p = 0.0803$). Weight loss was not reduced by ventilation ($p = 0.294$), with the 1% ventilated package showing a slightly higher value (13.4%) than the control (11.9%).

These results indicate that ventilation primarily reduced damage and stabilised package temperature, rather than retaining moisture. Because the differences were small, based on three replicate boxes per treatment, and mostly not statistically significant, they should be interpreted as numerical trends rather than confirmed treatment effects. Nevertheless, these trends suggest potential for reducing transport losses for smallholder farmers and local traders. Before wide-scale adoption, validation with larger sample sizes, comparison with current farmer practices, and a cost-benefit analysis are required. Such low-cost packaging approaches align with recommendations for postharvest technologies suited to small-scale farmers [15;16].

4. CONCLUSION

Based on these results, the packaging ventilation area did not significantly affect papaya fruit quality during storage. However, numerically, packaging with 1% ventilation tended to maintain fruit quality better than 2% ventilation and the non-ventilated control. This finding was based on observations of temperature distribution, mechanical damage, visual damage, weight loss, respiration rate and total soluble solids of papaya fruit. These findings suggest that a corrugated cardboard box with 1% ventilation is a promising packaging option for small-scale

papaya farmers and distributors, pending validation against current farmer practices and a cost analysis.

REFERENCE

- [1] Redaksi Agromedia, *Buku Pintar Budi Daya Tanaman Buah Unggul Indonesia*. Jakarta, Indonesia: Agromedia Pustaka, 2009.
- [2] Badan Pusat Statistik Provinsi Sumatera Barat, *Produksi Tanaman Hortikultura Provinsi Sumatera Barat 2024*. Padang, Indonesia: BPS Provinsi Sumatera Barat, 2025.
- [3] A. K. Thompson, *Fruit and Vegetables: Harvesting, Handling and Storage*, 3rd ed. Chichester, U.K.: Wiley-Blackwell, 2015, doi: 10.1002/9781118653975.
- [4] E. M. Yahia, Ed., *Modified and Controlled Atmospheres for the Storage, Transportation, and Packaging of Horticultural Commodities*. Boca Raton, FL, USA: CRC Press, 2009, doi: 10.1201/9781420069587.
- [5] P. L. Ismaya, H. Y. Faturachman, E. Darmawati, and Setyadjit, "Perubahan mutu buah pepaya varietas IPB 9 (Calina) selama penyimpanan pasca simulasi transportasi," *J. Teknol. Pangan Hasil Pertanian*, vol. 18, no. 2, pp. 39–46, 2023, doi: 10.26623/jtphp.v18i2.7746.
- [6] A. S. Rauf, R. Kasim, S. A. Dahlan, W. R. Saman, L. Ahmad, and A. Engelen, "Pengaruh jenis bahan pengisi kemasan pada transportasi darat terhadap mutu pepaya (*Carica papaya* L.) selama penyimpanan," *Jambura J. Food Technol.*, vol. 7, no. 3, pp. 453–460, 2025.
- [7] H. Sukorini and Ishartati, "Different maturity phases and types of wrapping material on the quality of papaya fruit (*Carica papaya* L.) var. Calina," *Universitas Muhammadiyah Malang, Malang, Indonesia*, 2024.
- [8] S. Subedi et al., "Effect of wrapping materials and maturity stages on postharvest loss reduction of papaya," *J. Nepal Agric. Res. Counc.*, vol. 8, pp. 7–15, 2022, doi: 10.3126/jnarc.v8i.44811.
- [9] D. S. S. Marpaung, M. Fauzi, A. O. Y. Sinaga, N. Anika, and S. Gumaran, "Mechanical damages reduction of transported papaya using alternative partition packaging and its physiological changes in storage," *Int. J. Postharvest Technol. Innov.*, vol. 9, no. 3, pp. 244–256, 2024, doi: 10.1504/IJPTI.2024.143185.
- [10] Sutrisno, E. Darmawati, and D. Sukmana, "Rancangan kemasan berbahan karton gelombang untuk individual buah manggis (*Garcinia mangostana* L.)," *Institut Pertanian Bogor, Bogor, Indonesia*, 2011.
- [11] A. A. Kader, *Postharvest Technology of Horticultural Crops*, 3rd ed., Publ. 3311. Oakland, CA, USA: Univ. California Div. Agric. Natural Resour., 2002.
- [12] M. A. Delele, M. E. K. Ngcobo, S. T. Getahun, L. Chen, J. Mellmann, and U. L. Opara, "Studying airflow and heat transfer characteristics of a horticultural produce packaging system using a 3-D CFD model. Part II: Effect of package design," *Postharvest Biol. Technol.*, vol. 86, pp. 546–555, 2013, doi: 10.1016/j.postharvbio.2013.08.015.
- [13] A. Ilangovan, J. Curto, P. D. Gaspar, P. D. Silva, and N. Alves, "CFD modelling of the thermal performance of fruit packaging boxes: Influence of vent-holes design," *Energies*, vol. 14, no. 23, Art. no. 7990, Nov. 2021, doi: 10.3390/en14237990.
- [14] P. B. Pathare, U. L. Opara, C. Vigneault, M. A. Delele, and F. A. Al-Said, "Design of packaging vents for cooling fresh horticultural produce," *Food Bioprocess Technol.*, vol. 5, no. 6, pp. 2031–2045, 2012, doi: 10.1007/s11947-012-0883-9.
- [15] A. Jarman et al., "Postharvest technologies for small-scale farmers in low- and middle-income countries: A call to action," *Postharvest Biol. Technol.*, vol. 206, Art. no. 112491, 2023, doi: 10.1016/j.postharvbio.2023.112491.
- [16] M. H. B. Gouda and A. Duarte-Sierra, "An overview of low-cost approaches for the postharvest storage of fruits and vegetables for smallholders, retailers, and consumers," *Horticulturae*, vol. 10, no. 8, Art. no. 803, Jul. 2024, doi: 10.3390/horticulturae10080803.
- [17] S. Sujiprihati and K. Suketi, *Budi Daya Pepaya Unggul*. Jakarta, Indonesia: Penebar Swadaya, 2009.
- [18] F. Etefa Obse, F. Forsido Sirawdink, and T. Kebede Mathewos, "Postharvest loss, causes, and handling practices of fruits and vegetables in Ethiopia: Scoping review," *J. Hortic. Res.*, vol. 30, no. 1, pp. 1–10, 2022, doi: 10.2478/johr-2022-0002.
- [19] E. Kefas, B. Aliyu, and Y. Tashiwa, "Postharvest losses, causes and mitigation in tomato transportation: A systematic review," *J. Hortic. Postharvest Res.*, vol. 7, no. 3, pp. 223–236, 2024, doi: 10.22077/jhpr.2024.7460.1370.
- [20] A. A. Kader, "Increasing food availability by reducing postharvest losses of fresh produce," *Acta Hortic.*, vol. 682, pp. 2169–2176, 2005.
- [21] A. M. Aina, H. Harith, N. Hashim, and M. F. M. Shukery, "The influence of papaya shape on its mass model and mechanical properties," *J. Food Process Eng.*, vol. 47, no. 5, Art. no. e14627, May 2024, doi: 10.1111/jfpe.14627.
- [22] A. M. Aina, H. H. Harith, N. Hashim, and M. F. M. Shukery, "Finite element modelling of the mechanical behavior of papaya fruit under compression," *Postharvest Biol. Technol.*, vol. 226, Art. no. 113565, 2025, doi: 10.1016/j.postharvbio.2025.113565.
- [23] C. Ge, "A review and update of the corrugated fibreboard cushioning," *Packag. Technol. Sci.*, vol. 35, no. 9, pp. 701–715, 2022, doi: 10.1002/pts.2687.
- [24] D. M. Wang, H. Gong, and Z. Bai, "Effect investigation of relative humidity and temperature on multi-layer corrugated sandwich structures," *J. Sandw. Struct. Mater.*, vol. 15, no. 2, pp. 156–167, 2013.
- [25] D. Kusniati, "Kajian pengaruh tipe ventilasi dan suhu penyimpanan terhadap perubahan mutu buah alpukat (*Persea americana* Mill.) dan sebaran suhu dalam kemasan," *Undergraduate thesis, Fak. Teknol. Pertanian, Institut Pertanian Bogor, Bogor, Indonesia*, 2011.
- [26] E. Pesis, D. Aharoni, Z. Aharon, R. Ben-Arie, N. Aharoni, and Y. Fuchs, "Modified atmosphere and modified humidity packaging alleviates chilling injury symptoms in mango fruit," *Postharvest Biol. Technol.*, vol. 19, no. 1, pp. 93–101, 2000, doi: 10.1016/S0925-5214(00)00080-6.
- [27] K. Fahmy and K. Nakano, "Optimal design of modified atmosphere packaging for alleviating chilling injury in cucumber fruit," *Environ. Control Biol.*, vol. 52, pp. 233–240, 2014, doi: 10.2525/ecb.52.233.

- [28] K. Fahmy and K. Nakano, "Influence of relative humidity on development of chilling injury of cucumber fruits during low temperature storage," *Asia Pac. J. Sustain. Agric. Food Energy*, vol. 1, no. 1, pp. 1–5, 2013. [Online]. Available: <http://journal.bakrie.ac.id/index.php/APJSAFE>
- [29] S. U. Kusuma, "Rancangan kemasan tunggal pada buah pepaya (*Carica papaya* L.) varietas IPB 9 (Calina) dengan bahan pengisi selama proses distribusi," Undergraduate thesis, Fak. Teknol. Pertanian, Institut Pertanian Bogor, Bogor, Indonesia, 2014.
- [30] Rahmawati, "Peningkatan kinerja pengemasan pisang ambon (*Musa paradisiaca* L.) selama transportasi dengan penataan posisi pisang dan jenis bahan pengisi," Undergraduate thesis, Fak. Teknol. Pertanian, Institut Pertanian Bogor, Bogor, Indonesia, 2010.
- [31] C. Shu, M. M. Wall, P. A. Follett, N. Sugimoto, J. Bai, and X. Sun, "Effect of humidity-triggered controlled-release 1-methylcyclopropene (1-MCP) on postharvest quality of papaya fruit," *Horticulturae*, vol. 9, no. 10, Art. no. 1062, Sep. 2023, doi: 10.3390/horticulturae9101062.
- [32] Y. Jiang, Y. Nie, Y. Pan, X. Li, H. Liu, and S. Tao, "Enhanced cyanide-resistant respiration as the predominant respiratory metabolic pathway in abnormal chilling injury behavior of postharvest papaya," *Postharvest Biol. Technol.*, vol. 205, Art. no. 112505, 2023, doi: 10.1016/j.postharvbio.2023.112505.
- [33] A. E. Shattir and A. A. Abu-Goukh, "Compositional changes during papaya fruit ripening," *Univ. Khartoum J. Agric. Sci.*, vol. 20, no. 1, 2023, doi: 10.53332/uofkjas.v20i1.1904.
- [34] C. Matsuane, A. M. Kavoo, B. N. Kiage, J. Karanja, and F. K. Rimberia, "Quality changes in papaya fruit under different storage temperatures and duration," *J. Agric. Sci. Technol.*, vol. 22, no. 3, pp. 64–78, 2023.