International Journal on Food, Agriculture, and Natural Resources
Volume 06, Issue 02, Page 08-14
ISSN: 2722-4066
http://www.fanres.org

Original Paper

Effects of packaging materials and ventilation placement on strawberry shelf-life

Maadh F Alani[1], Mohamed G Embaby[1], Prabesh Joshi[1], Prachi Pahariya[1], Ruplal Choudhary[1]*

1) *School of Agricultural Sciences, Southern Illinois University Carbondale, 1205 Lincoln Dr, Carbondale, IL, 62901, United States*

*) *Corresponding Author: choudhry@siu.edu*

Received: 11 March 2025; Revised: 24 June 2025; Accepted: 28 June 2025

DOI: *https://doi.org/10.46676/ij-fanres.v6i2.484*

***Abstract*— The strawberry is a popular fruit known for its color and flavor, but it is highly perishable due to its high respiration rate with rapid ripening and lack of natural protective covering. Existing packaging techniques for strawberries primarily focus on marketing purposes that often do not provide sufficient protection against mechanical and physiological damage. In this study, different packaging techniques were investigated, considering the cushioning and respiration needs of strawberries. The material and design of the packaging were optimized to enhance strawberry storage and preservation. The effects of packaging material on strawberry weight loss and shelf life were investigated. Two types of packaging were investigated at 4°C with a relative humidity ranging from 74% to 84% using two packaging materials in the form of egg-crate made of molded pulp or Styrofoam, which was compared to common clamshell packages made of polyethylene material. Different strawberry attributes were measured including firmness, color, mold, weight, taste, and aroma. Results showed that Styrofoam egg-crate packages had the least weight loss compared to molded pulp and control packages. The ventilation design had a significant effect within the treatment but not between treatments. Sensory test results showed that Styrofoam packages had better attributes in terms of firmness, color, aroma, and overall acceptability compared to molded pulp. The packaging type had a significant effect on strawberry shelf life, while the ventilation location did not. The findings suggest that packaging materials play an important role in prolonging strawberry shelf life.**

Keywords*— *Packaging materials, Packaging techniques, Quality attributes, Strawberry Shelf life, Ventilation locations

I. INTRODUCTION

Strawberry (Fragaria x ananassa) is a commonly consumed fruit known for its nutritional benefits and a high-value specialty crop. With a steady increase in production worldwide as well as expansion in the production area, strawberries have become a common part of the diet [1]. Besides being palatablepalatable, strawberries are also a rich source of flavonoids and ascorbic acid [2]. Strawberries are highly perishable fruits because they ripen quickly after harvest which is associated with a high respiration rate, fungal development, and water loss [3].

The market requirements for higher-gradestrawberries include appropriate size, color, firmness, and absence of damage from handling, dirt, disease, and insects [4]. Post-harvest deterioration results in a decline in taste, nutrition, and appearance which affects the salability [5]. Natural deterioration is unavoidable but post-harvest management of temperature, relative humidity, mechanical damage, and headspace composition can potentially slow the deterioration [6]. Similarly, post-harvest treatments such as UV-irradiation and edible coatings have been shown to improve shelf-life of fruits [7, 8, 9].

Packaging material comes in direct contact with the fruits and therefore can affect the immediate environment of the fruits. Besides influencing the fruit environment and shelf-life, packaging can also be visually appealing to buyers [10]. Clamshell packaging is one of the most common packaging types for strawberries [11]. Clamshell is a hinged thermoformed sheet commonly constituting Polyvinyl chloride (PVC) and polyethylene terephthalate (PET) [12]. Clamshell packaging is often used for packaging high-value fruits, and small fruits such as berries, cherries, and mushrooms. However, the clamshells are frequently disposed of at landfills or require incineration or composting [13]. Molded pulp is another type of packaging material that is commonly used in egg crate packages. It is also biodegradable, recyclable, and compostable [14]. Molded pulp packaging is an alternative packaging material that is the predominant packaging material for fruits and vegetables [15]. Molded pulp provides the advantages of strength, durability as well as easier recycling [16]. shigh-and sare of is an that the sthe

Packaging techniques and storage practices are closely associated with the quality of the product that reaches the consumers. Researchers seek to find a balance between long shelf life and preservation of nutritional value. Clamshell packages have some limitations. Although it provides a transparent view to consumers, it limits the ability of the produce to stay fresh as it fails to hold moisture inside the package, and it does not provide enough protection to the product. In addition to that, it is not an environmentally friendly material and requires efforts to be recycled.

It is necessary to improve ways to reduce decay and to prolong the shelf-life of the fruit by controlling the temperature and humidity. There are multiple packaging techniques for strawberries that to our knowledge are designed for packaging for marketing purposes. These packaging techniques do not provide enough protection to the strawberry as their material and design are focused on storage without considering the ventilation and respiration properties of the strawberry. Therefore, in this experiment, different packaging techniques with different designs will be investigated to evaluate the effect of packaging on the quality of strawberriesstrawberries.

II. Methods And Materials

The effect of packaging material and design on strawberry shelf life and attributes were investigated using two packaging materials- 1. Molded pulp egg crate, and 2. Styrofoam egg crate, and three ventilation locations- 1. top (two holes of 8mm diameter each) 2. Side (two holes of 8mm diameter each 3. Bottom (four holes of 4mm diameter each). Strawberries of Chandler variety were collected in mid-May from BASS farm in Cobden IL. 12 strawberries were stored in each packaging material. Strawberries were placed with the cap downside. The packages were quickly transferred to a walk-in cooler maintained at 4°C, and 80% relative humidity. The initial weight of each box was measured and recorded before refrigerating. Boxes were weighed daily using a digital scale (Cole-Parmer 625 East Bunker Ct Vernon Hills, IL 60061 United States) at 8 pm. Visual observations for mold and other attributes such as color, and texture.Savor testing was performed every 5 days to check for different attributes including Mold formation, firmness, color, odor, palatability, and overall acceptability. The experiment lasted till the visual observation of mold. Samples were collected for mold analysis to check for the fungus species responsible for the infection.

A. *Maintaining the Integrity of the Specifications*

For microbial counts,strawberry samples were weighed and placed in a stomacher bag with 100 ml PBS solution. The strawberries were shaken properly with the hand for 60 sec. Then the 1 ml aliquot was mixed with 9 ml buffer solutions and serial dilutions were prepared. Total aerobic bacterial count (TABC), total coliform count (TCC), and yeast and mold counts (YAMC) were determined by plating appropriately 0.1 ml diluted samples onto plate count agar (PCA), Violet Red bile agar (VRBA) and Dichloran rose Bengal chloramphenicol (DRBC) agar respectively. The PCA and VRBA plates were stored at 37 °C for 24 to 48 h and DRBC plates were stored at 25 °C for 4-5 days. Three replicates were carried out for each packaging treatment and hole location. The results (mean ± standard deviation) were expressed as log CFU g^{-1}.

B. *Total Polyphenol Content (TPC) Determination*

Strawberry fruits were homogenized followed by polyphenol extraction in an extraction buffer consisting of acetone, distilled water, and glacial acetic acid at 70:29.5:0.5 v/v. After leaving the homogenate in the extraction buffer for 2 h in a shaker incubator, the mixture was then centrifuged at 1640 g for 15 minutes. After collecting the supernatant, the remaining pellet was extracted again for 1 h followed by centrifugation. The supernatants were filtered followed by spectrophotometric determination of total polyphenol content. One mL of the strawberry extract was dissolved in 5 mL of Folin-Ciocalteu's reagent and 4 mL of 7% sodium carbonate. The extract was allowed to react with the mixture for 1 h. The absorbance of the resulting final solution was taken at 765 nm (Thermo Scientific Genesys 10S UV- VIS Spectrophotometer). A standard calibration curve from five Gallic acid standards (50, 100, 200, 500, and 1000 mg L-1) with R2 = 0.953 was used to determine the total polyphenol content of the extract. The TPC was adjusted in mg of Gallic acid (mg GAE) equivalents per 100 g fresh weight.

C. *Total Monomeric Anthocyanin (TMA) Content*

The method described by Guisti et al. [17] was used to determine total monomeric anthocyanin content. The strawberry fruits were weighed, homogenized, and extracted in potassium chloride (pH = 1.0) and sodium acetate (pH = 4.5) buffers for 0.5 h. Absorbance was taken from the extracted solution at 520 nm and 700 nm with a Thermo Scientific Genesys 10S UV- VIS spectrophotometer. The results were expressed as mg cyanidin-3-glucoside equivalents per kg of fresh fruits.

D. *Statistical Analysis*

The effect of packaging materials and opening location on strawberry weight loss data were analyzed using augmented factorial analysis (two-way ANOVA plus control) was carried out for each day of storage to compare the treatments for each storage day till the appearance of grey mold. Multiple comparisons were carried out using Tukey's procedure. All the statistical analyses were carried out using GenStat (Twelfth Edition Copyright 2009, VSN International Ltd). In addition to that, the effect of packaging material and opening location on aerobic microbial counts and physicochemical properties was carried out using one-way ANOVA using JMP statistical software, and SAS incorporation.

III. Results

A. *Ventilation Design and Packaging Material*

TABLE I. Effect Of Ventilation Design On Weight Loss (%) Over 16 Days (Time) When Grey Mold Appears.

Packaging/ ventilation placement	**Weight loss %**
Styrofoam- Upper	7.15^{cd}
Styrofoam - Lateral	7.07^{d}
Styrofoam - Lower	8.48^{c}
Molded pulp- Upper	19.77^{ab}
Molded pulp - Lateral	18.67^{b}
Molded pulp - Lower	20.22^{a}
Control	6.55^{d}
mean	13.46
SE±	6.72

Values followed by different letters represent significant differences ($p \leqslant 0.05$)

Table I presents the impact of packaging material and opening location on weight loss (%) over a 16-day period when grey mold appears, showing a statistically significant difference ($p \leqslant 0.05$). The findings indicated that molded pulp treatment yielded higher weight loss values compared to the Styrofoam treatment. The overall mean weight loss percentage was calculated to be 13.46%, with a standard error of ±6.72 across all packaging types.

Specifically, the weight loss % of the molded pulp with an opening at the bottom demonstrated the highest value at 20.22%, followed closely by the molded pulp with an opening at the top at 19.77% (Table II).%. The Styrofoam, with an opening at the bottom, also exhibited a relatively high weight loss of 8.48%. In contrast, the control packaging resulted in the lowest weight loss percentage at 6.55%.

TABLE II. EFFECT OF PACKAGING MATERIAL AND OPENING LOCATION ON WEIGHT LOSS (G) AVERAGE OVER 16 DAYS OF STORAGE

Days	TREATMENTS							MEAN	SD	LSD
	A1	A2	A3	B1	B2	B3	Control			
2	0.28^{c}	0.47^{b}	0.44^{b}	0.41^{b}	0.49^{b}	0.66^{a}	0.51^{b}	0.47	0.12	0.12
3	0.62^{c}	0.85^{b}	0.84^{b}	0.86^{b}	1.28^{a}	1.15^{a}	1.13^{a}	0.96	0.23	0.17
4	0.96^{e}	1.24^{de}	1.28^{d}	1.99^{bc}	2.29^{a}	2.14^{ab}	1.80^{c}	1.67	0.51	0.29
5	1.34^{d}	1.67^{cd}	1.80^{c}	3.34^{a}	3.53^{a}	3.52^{a}	2.84^{b}	2.58	0.95	0.39
6	1.7^{e}	2.09^{de}	2.32^{d}	4.78^{b}	5.06^{ab}	5.29^{a}	3.94^{c}	3.60	1.52	0.47
7	2.16^{f}	2.56^{ef}	2.92^{e}	6.23^{c}	6.90^{b}	7.56^{a}	5.21^{d}	4.80	2.23	0.56
8	2.71^{f}	2.99^{ef}	3.48^{e}	7.77^{c}	8.70^{b}	9.50^{a}	6.55^{d}	5.96	2.86	0.66
9	3.09^{e}	3.49^{de}	4.08^{d}	9.51^{c}	10.42^{b}	11.31	*	6.92	3.48	-
10	3.57^{d}	4.00^{cd}	4.64^{c}	11.16^{b}	12.07^{b}	13.15^{a}	*	7.88	4.12	-
11	3.95^{d}	4.54^{cd}	5.28^{c}	12.89^{b}	13.69^{b}	14.90^{a}	*	8.83	4.78	-
12	4.50^{d}	5.12	5.92	14.65	15.22	16.67	*	9.80	5.41	-
13	5.08^{d}	5.71^{cd}	6.48^{c}	16.32	16.91	18.51	*	10.79	6.09	-
14	5.53^{d}	6.37^{cd}	7.08^{c}	18.04^{b}	18.67^{b}	20.22^{a}	*	11.78	6.78	-
15	6.01^{c}	7.07^{bc}	7.76^{b}	19.77^{a}	*	*	*	12.29	6.83	-
16	6.56^{b}	*	8.48^{a}	*	*	*	*	12.47	6.67	-

A1: Styrofoam Upper, A2: Styrofoam Lateral, A3: Styrofoam Lower; B1: Molded pulp Upper, B2: Molded pulp Lateral, B3: Molded pulp Lower; and Control: polyethylene. The values
*Values followed by different letters represent significant differences ($p < 0.05$)

There were no statistical differences between the upper and lateral holes within each treatment, the weight loss was 7% between the upper and lateral hole locations in the Styrofoam, while it was 19% between the upper and the lateral in the molded pulp. These results emphasize the influence of different packaging materials on weight loss, with molded pulp packaging generally leading to higher weight loss compared to Styrofoam and control packaging.

B. *Sensory test*

The sensory test results showed that in the first week of the experiment, there was a significant effect between Styrofoam packages and both molded pulp and control in terms of firmness ($p<0.005$), while it was not significant in terms of acceptability, color, and odor (Table III). In the second week of the experiment, the control treatment developed mold and was removed fromfrom the experiment, while the Styrofoam and molded pulp treatment remained. There was a significant effect between Styrofoam and molded pulp in terms of firmness, color, odor, and overall acceptability, where Styrofoam has a higher Sensory attribute , $p<0.005$ (Table IV).The comparison of aerobic bacterial count between the strawberries stored with different packaging materials and opening locations during the storage period showed that the effect of the packaging material was statistically significant, p = 0.037. When the data were stratified into separate days, the effect of packaging material was also not statistically significant for 0, 5, and 10th days (figure 1). The aerobic counts for the 20th day of storage were significantly different between the strawberries with different packaging materials, p = 0.0459. Multiple comparisons using Tukey's HSD show that the strawberries stored in Styrofoam and molded pulp eggcrate packaging (3.25 ± 0.66 log CFU/g) had significantly lower aerobic count compared to clamshell control packaged strawberries (4.35 ± 0.44 log CFU/g). However, the hole placement did not have a significant effect on the bacterial count.

TABLE III. THE EFFECT OF TREATMENT OF SENSORY TEST FOR FIRMNESS, COLOR, ODOR, AND ACCEPTABILITY AT WEEK ONE

Treatments	Firmness	Color	Odor	Acceptability
A1	8.83	8.33	8.33	8.67
A2	8.83 A	8.17	8.33	8.5
A3	9:00 AM	8.33	8.33	8
B1	8.5 AB	8.17	7.5	8
B2	8.17 AB	7.83	8.17	8.17
B3	8.5 B	8.17	8.17	8.5
CONTROL	8 B	8	7.67	8
MEAN	8.55	8.14	8.07	8.26
SE				
LSD	0.54	0.79 ^{NS}N.S	0.85 N.S	0.66 ^{NS}N.S

A1: Styrofoam Upper, A2; Styrofoam Lateral, A3: Styrofoam Lower, B1: Molded pulp Upper, B2: Molded pulp Lateral, B3: Molded pulp Lower and Control: polyethylene
NS: Non-Significant
Values followed by different letters represent Significant differences ($p < 0.05$)

TABLE IV. THE EFFECT OF TREATMENT OF SENSORY TEST FOR FIRMNESS, COLOR, ODOR, AND ACCEPTABILITY AT WEEK TWO

Treatments	Firmness	Color	Odor	Overall Acceptability
A1	8.00 ^{aa}	7.50 ^{aa}	7.50 ^{aa}	7.67 ^{aa}
A2	7.83 ^{aa}	7.17 ^{abab}	7.67 ^{aa}	7.33 ^{aa}
A3	7.83 ^{aa}	7.50 ^{aa}	7.50 ^{aa}	7.50 ^{aa}
B1	6.33 ^{bb}	6.33 ^{bcbc}	6.83 ^{abab}	6.00 ^{bb}
B2	6.00 ^{bb}	6.17	6.17 ^{bb}	5.67 ^{bb}
B3	6.00 ^{bb}	5.83	7.50 ^{aa}	5.83
Mean	7	6.75	7.2	6.67s67
LSD	0.78	0.98	1.04	0.69

A1: Styrofoam Upper, A2; Styrofoam Lateral, A3: Styrofoam Lower, B1: Molded pulp Upper, B2: Molded pulp Lateral, B3: Molded pulp Lower and Control: polyethylene
NS: Non-Significant
Values followed by different letter represents Significant difference ($p < 0.05$)

C. Aerobic Microbial (AM) Count, Total Yeast And Mold, And Total Coliform Count

The microbial count on Day 0, before packaging, were found to be 9.86 ± 0.086, 5.89 ± 0.099, and 6.99 ± 0.085 log cfu/g for TABC, TCC and YAMC, respectively. The strawberries were then packed using different types of packaging materials: clamshell (control), foam egg crate (A), and corrugated board (B). Each packaging type had openings positioned at the top (1), side (2), or bottom (3) for ventilation and respiration. The strawberries were stored at 4 °C, and data was collected at 5-day intervals. However, the experiment was discontinued after 15 days due to the observation of fungus and mold growth.

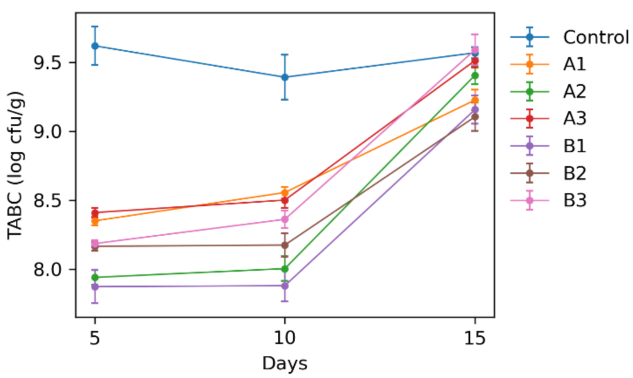

Fig. 1. Total aerobic bacterial count (log CFU/g) of strawberries stored using different packaging materials with respect to storage days. The dot symbolizes the mean log CFU/g, while the error bars indicate the standard deviation (n=3). The control is represented by clamshell packaging commonly found in the market. The letters 'A' and 'B' denote Styrofoam and molded pulp, respectively.

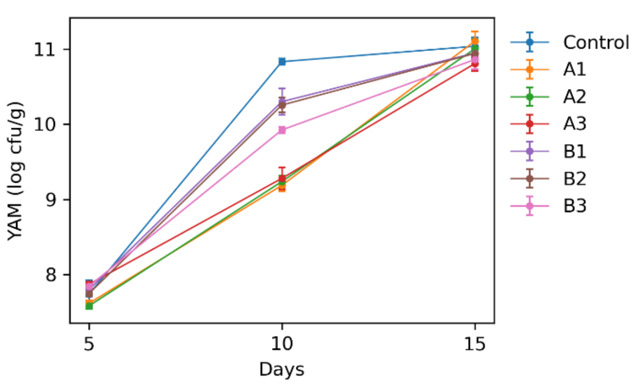

Fig. 2. Total yeast and mold count (log CFU/g) of strawberries during storage using various packaging materials. The mean log CFU/g is shown by dots, and the standard deviation is represented by error bars (n=3). The control is represented by clamshell packaging commonly found in the market. The letters 'A' and 'B' denote Styrofoam and molded pulp, respectively. Additionally, the numbers '1', '2', and '3' signify openings located at the upper, lateral, and lower of the packaging.

D. Aerobic Microbial (AM) Count, Total Yeast and Mold, And Total Coliform Count

The comparison of TABC, TCC, and YAMC between strawberries stored with different packaging materials and hole locations during the storage period showed that the effect of the packaging material was statistically significant ($p < 0.05$).Fig. The total bacterial and yeast and mold count increased with increase in storage days while total coliform count decreased (Fig 1, Fig 2, Fig 3). This could be attributed to various factors, such as nutrient availability, environmental conditions, and the presence of other bacteria.

Strawberries stored in the new packaging (egg foam crates and corrugated boxes) exhibitedCFU significantly lower bacterial counts as compared to clamshell on Day 5 and Day 10 ($p < 0.05$). However, no significant difference in bacterial count was observed between packaging material on Day 15 ($p > 0.05$). Additionally, noCFU significant change in bacterial count was observed on Day 5 and Day 10 for all packing materials It was noted that the total bacterial count decreased more when stored in foam egg crates and corrugated boxes compared to clamshell (9.62 ± 0.040) on Day 5 when compared with the initial count (Day 0). This might be due to factors like moisture absorption capacity, oxygen permeability, or less temperature variation within the new packaging materials. From the result, it was observed that foam egg crate with bottom hole (7.94 ± 0.055) showed significantly lower bacterial counts compared to those with top (8.35 ± 0.034) and side (8.41 ± 0.033) hole. However, the corrugated board hole at top (7.87 ± 0.121) showed lower bacterial count compared to bottom (8.17 ± 0.032) and side (8.19 ± 0.026). Moreover, on Day 15, there was no significant difference in bacterial count between foam egg crates with bottom holes and corrugated board with top holes (Fig 1).

For yeast and mold counts, foam egg crates generally showed lower counts compared to corrugated board and clamshell, with no significant difference observed for hole positions in foam egg crates. On day 5, The YAMC for clamshell was 7.74 ± 0.188, A1 was 7.62 ± 0.040, A2 was 7.58 ± 0.043, A3 was 7.87 ± 0.039, B1 was 7.80 ± 0.020, B2 was 7.74 ± 0.037, B3 was 7.84 ± 0.036 log cfu/g respectively. On comparing the days, yeast and mold count showed significant difference in values on Day 5 and day 10 ($p < 0.05$).

Regarding coliform counts, strawberries stored in clamshell had higher counts compared to those stored in foam egg crates and corrugated boxes on Day 15. The TCC on day 5 for clamshell was 5.20 ± 0.135, A1 was 4.84 ± 0.038, A2 was 5.07 ± 0.073, A3 was 5.19 ± 0.183, B1 was 4.52 ± 0.111, B2 was 4.71 ± 0.209, B3 was 4.73 ±0.106 log cfu/g respectively. In conclusion, both total bacterial and coliform counts decreased after packaging on day 5, when compared to the control. Foam egg crates demonstrated lower yeast and mold counts while corrugated board showed lower coliform counts as compared to clamshell.

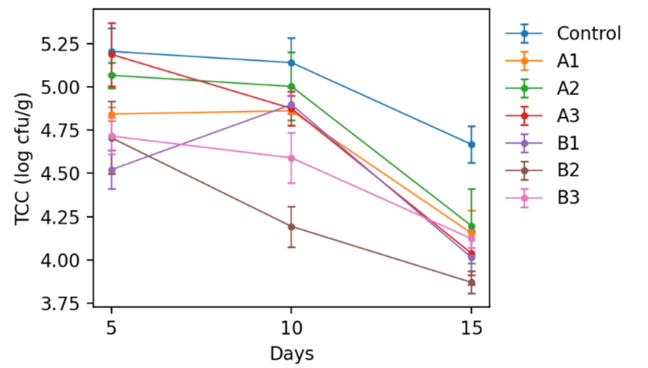

Fig. 3. Total coliform count (log CFU/g) of strawberries stored using different packaging materials with respect to storage days. The dot represents the mean log CFU/g and error bars represent standard deviation (n=3). The control is represented by clamshell packaging commonly found in the market. The letters 'A' and 'B' denote Styrofoam and molded pulp, respectively. Additionally, the numbers '1', '2', and '3' signify openings located at the upper, lateral, and lower of the packaging.

E. Total Phenolic contents (TPC) and Total Monomeric Anthocyanin (TMA)

The average total polyphenol content (TPC) of the strawberries during the storage was 274.5 ± 43.4 mg GAE/g. The effect of storage was highly significant, $p = 0.0001$. There was a general increasing trend in TPC during the storage, with an average increase of 2.3 mg GAE/g per day (Fig. 4). The days of storage explained 15% of the variation in TPC content, R2 = 0.15. For TPC, there was no statistically significant effect on packaging material or hole location on the 5th and 10th days of storage. On the 20th day of storage, the packaging material ($p = 0.0043$) had statistically significant effects on TPC content. The TPC in control was significantly higher than Styrofoam-stored strawberries ($p = 0.014$) but not statistically different from molded pulp-stored strawberries.

The average monomeric anthocyanin content of the strawberries during the storage was 346.6 ± 80.5 mg of cyanidin-3-glucoside equivalent per kg fresh weight. There was a general decreasing trend in anthocyanin content, with an average reduction of 7.7 mg/kg per day (Fig. 55). The effect of storage duration on anthocyanin was highly significant, $p < 0.00001$. The days of storage explained 49% of the variation in anthocyanin content in fruits, R2 = 0.49. There was no statistically significant effect of packaging material or hole placement on the anthocyanin content of strawberries. ResearchR evaluating the effect of modified atmosphere packaging has shown that the anthocyanin content in fruits stored modified atmosphere packaging has been shown to have lower compared to control packaging [18]. The packaging in this research has differences in material and opening location without any intended effect on the headspace gas composition that can result in modified atmospheric packaging.

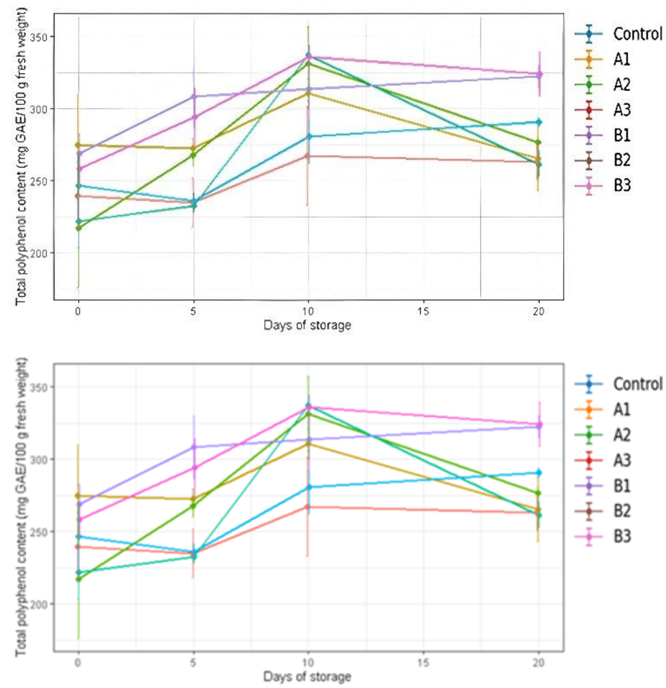

Fig. 4. Total polyphenol contents of strawberries stored with different packaging materials and opening locations. Error bars represent standard deviation (n=3). The control is represented by clamshell packaging commonly found in the market. The letters 'A' and 'B' denote Styrofoam and molded pulp, respectively. Additionally, the numbers '1', '2', and '3' signify openings located at the upper, lateral, and lower of the packaging

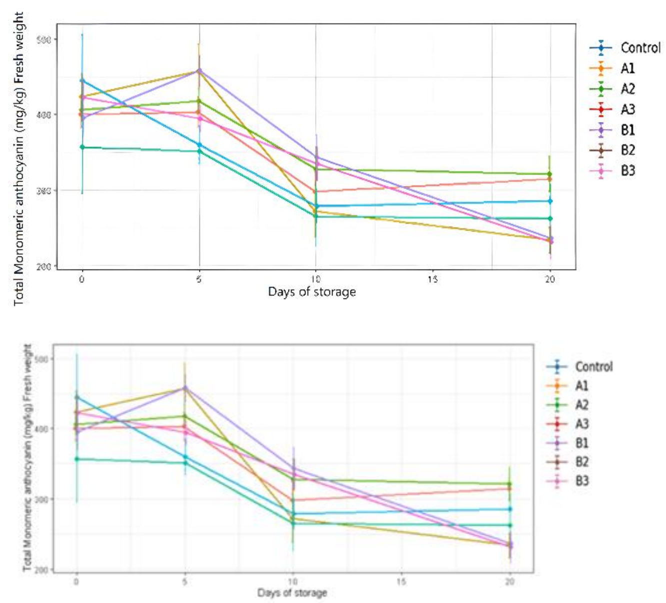

Fig. 5. Total monomeric anthocyanin content of strawberries stored with different packaging materials and opening locations. Error bars represent standard deviation (n=3). The control is represented by clamshell packaging commonly found in the market. The letters 'A' and 'B' denote Styrofoam and molded pulp, respectively. Additionally, the numbers '1', '2', and '3' signify openings located at the upper, lateral, and lower of the packaging

IV. Discussion

The effect of packaging type and ventilation location were investigated in this study. The results showed that the packaging type had a significant effect on the strawberry shelf life in terms of weight loss, microbial count, physiochemical attributes, and sensory attributes, while the ventilation location did not have a significant effect between treatments. The effect of packaging type on strawberry shelf life was investigated by Panda et al. [19], who investigated the effect of low-density polyethylene (LDPE) at different thickness compared to polyethylene high density (HDPE), cellophane paper, and cling. Results showed that LDPE had the best results compared to HDPE, cellophane, and cling in terms of weight loss, while cling maintained the best results in terms of preventing strawberry decay. These results are in compliance with our results where the packaging materials could play an important role in prolonging the strawberry shelf life. Another study by [20] investigated the effect of packaging and storage conditions on the shelf life of strawberries and concluded that packaging material that helps with reaching the cooling temperature rapidly was better in maintaining the quality of strawberries than the ones that slowly reach to the cooling temperature. In this experiment by Luoto [20] used wooden, wax, plastic, and carton boxes. The group concluded that ventilation had an important role in reaching to the cooling temperature and had a significant effect on the quality of strawberriesstrawberries, which is not in accordance with our findings. Nicoletto et al. [21] investigated the effect of packaging and cooling temperature along with a proliferation of the packager on prolonging strawberry shelf life. Results showed that cooling at 4° C combined with the micro proliferation of packages has a significant effect on the strawberry shelf life which was in accordance with our finding regarding the storage temperature, while it was not in accordance with the effect of ventilation. The lower microbial growth in egg crate packaged strawberries could be explained by the absorptive capacity of the pulp in the egg crate packaging [22]. It can also be explained by the isolation of the fruits in the eggcrate shape compared to the mixed design in the control treatment.

During the final days of storage, lower polyphenol content in egg-crate Styrofoam, and molded pulp stored strawberries compared to control packaging made of clamshell was observed, suggesting that the stored fruits were subjected to less abiotic stress, possibly due to preventing microbial growth of Styrofoam storage. However, the anthocyanin content of the fruits was not influenced by the packaging system. Styrofoam packaging also exhibited lower weight loss as well as lower bacterial count. The efficacy of Styrofoam packaging in significantly lowering weight loss and bacterial growth indicates that Styrofoam packaging may provide benefits if improved shelf-life quality in strawberries compared to clamshell packaging or molded pulp packaging. The higher TPC in control strawberries could be due to higher moisture in control strawberries compared to the Styrofoam packaged strawberries. It is possible that the Styrofoam packaging may have higher surface contact with the strawberry which could result in higher moisture absorption. The differences in the effect of surface moisture-induced permeance may have a role in biochemical differences in Styrofoam-stored strawberries [23]. Polyphenol synthesis in plants is associated with stress protection in plants [24]. Another possible reason the egg-crate-stored strawberries had lower total polyphenol content could be the shock resistance capacity of the molded crate [25].

Considering the environmental impact of the packaging material, and the fate of clamshell packaging in landfills, molded pulp can be an effective packaging material for strawberries. The molded pulp material can also be enhanced by the addition of antimicrobials or improved design to gain more benefits from this packaging.

Conclusions

In conclusion, this study provides new approach into the impact of packaging materials and opening locations on strawberry quality during storage. Significant differences in weight loss were observed, with molded pulp packaging resulting in higher weight loss percentages compared to Styrofoam and control packaging. Aerobic bacterial counts were found to be lower in Styrofoam and molded pulp egg-crate packaging compared to clamshell control packaging by the 20th day of storage. Total polyphenol content showed an increasing trend during storage, with packaging material having a significant effect by day 20. Anthocyanin content decreased over time but was not significantly affected by packaging material or hole placement. These findings, supported by statistical analyses ($p \leqslant 0.05$ for various comparisons), demonstrate the interaction between packaging choices and strawberry quality parameters. The study's results, including a 13.46% $\pm$ 6.72 overall mean weight loss and an average increase of 2.3 mg GAE/g per day in total polyphenol content, provide crucial data for optimizing strawberry packaging strategies in the food industry.

Further investigation into the interaction between packaging materials and biochemical changes in strawberries might provide deeper insights into optimizing post-harvest handling techniques. Future research focused on improving environmentally sustainable packaging solutions without compromising fruit preservation. Exploring biodegradable alternatives with enhanced cushioning and moisture retention properties could optimize storage conditions.

Acknowledgment

This study was partially funded by the Illinois Specialty Crop Grant SC-19-07. Mr Alani acknowledges the Iraqi Prime Minister's Scholarship program for doctoral study in USA.

References

[1] J. F. Hancock, "Worldwide strawberry industry.," in Strawberries, CABI Wallingford UK, 2020, pp. 86–108.

[2] H. Wang, G. Cao, and R. L. Prior, "Total Antioxidant Capacity of Fruits," Journal of Agricultural and Food Chemistry, vol. 44, no. 3, pp. 701–705, Jan. 1996, doi: 10.1021/jf950579y.

[3] B. R. Cordenunsi, M. I. Genovese, J. R. O. do Nascimento, N. M. A. Hassimotto, R. J. dos Santos, and F. M. Lajolo, "Effects of temperature on the chemical composition and antioxidant activity of three strawberry cultivars," Food chemistry, vol. 91, no. 1, pp. 113–121, 2005.

[4] USDA, "United States Standards for Grades of Strawberries," 2006.

[5] J. Błaszczyk et al., "The Effect of Harvest Date and Storage Conditions on the Quality of Remontant Strawberry Cultivars Grown in a Gutter

System under Covers," Agriculture, vol. 12, p. 1193, Aug. 2022, doi: 10.3390/agriculture12081193.

[6] G. Romanazzi and E. Feliziani, "Botrytis cinerea (gray mold)," in Postharvest decay, Elsevier, 2014, pp. 131–146.

[7] M. R. Klimchuk and S. A. Krasovec, Packaging design: Successful product branding from concept to shelf. John Wiley & Sons, 2013.

[8] T. Karst, "The Packer," Farm Journal, 2021.

[9] K. Lewandowski and K. Skórczewska, "A Brief Review of Poly(Vinyl Chloride) (PVC) Recycling," Polymers, vol. 14, no. 15. 2022. doi: 10.3390/polym14153035.

[10] T. T. Nguyen, H. Huang, T. A. H. Nguyen, and S. Soda, "Recycling clamshell as substrate in lab-scale constructed wetlands for heavy metal removal from simulated acid mine drainage," Process Safety and Environmental Protection, vol. 165, pp. 950–958, 2022, doi: https://doi.org/10.1016/j.psep.2022.04.026.

[11] M. Didone et al., "Moulded Pulp Manufacturing: Overview and Prospects for the Process Technology," Packaging Technology and Science, vol. 30, pp. 231–249, Feb. 2017, doi: 10.1002/pts.2289.

[12] K. Semple, C. Zhou, O. Rojas, nguegang nkeuwa William, and C. Dai, "Moulded pulp fibers for disposable food packaging: A state-of-the-art review," Food Packaging and Shelf Life, vol. 33, p. 100908, Sep. 2022, doi: 10.1016/j.fpsl.2022.100908.

[13] M. Debnath, R. Sarder, L. Pal, and M. Hubbe, "Molded pulp packaging review," Bioresources, vol. 17, pp. 3810–3870, Apr. 2022, doi: 10.15376/biores.17.2.Debnath.

[14] M. M. Giusti and R. E. Wrolstad, "Characterization and measurement of anthocyanins by UV‐visible spectroscopy," Current protocols in food analytical chemistry, no. 1, p. F1. 2.1-F1. 2.13, 2001.

[15] G. Xiao, M. Zhang, G. Luo, J. Peng, V. M. Salokhe, and J. Guo, "Effect of modified atmosphere packaging on the preservation of strawberry and the extension of its shelf-life," International agrophysics, vol. 18, no. 2, 2004, Accessed: Feb. 22, 2025. [Online]. Available: https://yadda.icm.edu.pl/agro/element/bwmeta1.element.agro-article-0f82d9e7-d146-4b4b-8ea3-7db16558d7a7

[16] A. Panda, R. Goyal, A. Godara, and V. Sharma, "Effect of packaging materials on the shelf-life of strawberry cv. Sweet Charlie under room temperature storage," Journal of Applied and Natural Science, vol. 8, pp. 1290–1294, Jul. 2016, doi: 10.31018/jans.v8i3.955.

[17] L. Luoto, "STRAWBERRY QUALITY: EFFECTS OF HANDLING, PACKAGING AND STORAGE ON SHELF-LIFE," in Acta Horticulturae, International Society for Horticultural Science (ISHS), Leuven, Belgium, Jan. 1985, pp. 79–82. doi: 10.17660/ActaHortic.1985.157.9.

[18] C. Nicoletto, S. Bonato, S. Santagata, G. Zanin, and P. Sambo, "Effect of postharvest temperature and packaging on qualitative traits in strawberry," Acta Horticulturae, pp. 303–310, Jul. 2016, doi: 10.17660/ActaHortic.2016.1120.46.

[19] C. Cutter, "Microbial control by packaging: a review," Critical reviews in food science and nutrition, 2002.

[20] R. Muangrat and C. Nuankham, "Moisture sorption isotherm and changes in physico-mechanical properties of films produced from waste flour and their application on preservation quality of fresh strawberry.," Food science & nutrition, vol. 6, no. 3, pp. 585–593, May 2018, doi: 10.1002/fsn3.589.

[21] L. Cisneros‐Zevallos, "The use of controlled postharvest abiotic stresses as a tool for enhancing the nutraceutical content and adding‐value of fresh fruits and vegetables," Journal of food science, vol. 68, no. 5, pp. 1560‐1565, 2003.

[22] I. M. Taha et al., "Impact of Starch Coating Embedded with Silver Nanoparticles on Strawberry Storage Time.," Polymers, vol. 14, no. 7, Apr. 2022, doi: 10.3390/polym14071439.