Physicochemical and Physiological Properties of Okra [*Abelmoschus esculentus* (L.) Moench] Fruits Coated with Polysaccharide-Based Edible Coatings

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Abstract

Okra is highly perishable due to its high respiration rate and high-water content, thus reducing its marketability. Hence, this study was conducted to evaluate the effect of different polysaccharide-based edible coatings on the physicochemical and physiological properties of okra fruits. The experiment was laid out in a completely randomized design with nine treatments and three replications. Four edible coatings were assessed at two different concentrations. The treatments comprised T0: uncoated (control), T1: 1% sodium alginate (AL), T2: 2% sodium alginate, T3: 1% pectin, T4: 2% pectin, T5: 1% carboxymethyl cellulose, T6: 2% carboxymethyl cellulose, T7: 1% cornstarch and T8: 2% cornstarch. Okra fruits were stored in refrigerated conditions with the temperature ranging from 9 to 11 °C and relative humidity of 76 to 85%. Samples were collected on days 0, 3, 6, 9, 12 and 15 for analysis of weight loss, firmness, shriveling, pH, total soluble solids (TSS), titratable acidity (TA), vitamin C, respiration rate, ethylene production and microbial growth. The results indicated that the use of polysaccharide-based edible coatings significantly influenced moisture and dry matter content, weight loss, firmness, shriveling, pH, TSS, TA, vitamin C, respiration and microbial count of okra fruits. The various coatings, including alginate, pectin, carboxymethyl cellulose and cornstarch, significantly preserved the quality of okra compared with the control treatment. Among the four coatings used, 2% alginate (w/v) demonstrated the most effective preservation of the fruit quality of okra.

Keywords*:* carboxymethyl cellulose, okra, pectin, polysaccharide-based edible coating, starch

1. Introduction

Okra (*Abelmoschus esculentus*) is a crop with essential nutritional value comprising a high percentage of water (averaging 85%), fat and protein in minute and varied amounts. A just proportion of carbohydrates exists as cellulose in small amount and also sugar. Additionally, it contains non-cellulose, non-starch, polysaccharides (Fellows, 1989). Okra serves as a source of protein, vitamins C and A, iron, calcium (Ihekoronye and Ngoddy, 1985) and dietary fiber (Adom *et al*., 1996). Furthermore, it is highly perishable because of its higher moisture content and respiratory activities (Boonyaritthongchai *et al*., 2012). Okra is very susceptible to water loss, color fading and deterioration leading to a decline in its commercial value and eventual transformation into a mushy state (Huang and Jiang, 2012). Thus, it is essential to conserve this commodity.

Edible coatings are used not only as enhancers for food quality and shelf life but also as potential carriers of additives and bioactive compounds (Zambrano-Zaragoza *et al*., 2018; Jafarzadeh *et al*., 2021). In addition, compared with other technologies or traditional packaging materials, edible coating technology is regarded as a more user- and environmentally-friendly form of packaging (Nešić *et al*., 2019; Sharma *et al*., 2019).

Polysaccharides (e.g., chitosan, alginate, cellulose, starch and pectin), lipids (e.g., wax and oil) and proteins (e.g., collagen, zein and casein) are the most often utilized substances in edible coatings (Suhag *et al*., 2020). Additionally, several polysaccharides, namely alginate, cellulose, starch, gums (e.g., guar gum and gum arabic) and carrageenan have been accepted and generally recognized as safe (GRAS) by the Food and Drug Administration (FDA) of the United States of America (FDA, n.d.). According to Cruz-Monterrosa *et al.* (2023), the use of polysaccharide-based edible coatings on fruits and vegetables has some positive effects, such as extending shelf life, decreasing respiration rate, maintaining firmness, reducing weight loss, safeguarding sensitive compounds, securing bioactive compounds, minimizing microbial growth, preserving sensory properties, maintaining antioxidant enzyme activity, providing antioxidant activity and decreasing oxidative stress.

Despite the foregoing, there is very limited information on current postharvest management as well as coating techniques applied for extending the shelf life and minimizing losses of fresh okra. Thus, the present study determined the effects of polysaccharide-based edible coating formulations on the

physicochemical and physiological parameters of okra fruits. The study also aimed to find best edible coating that could enhance the fruit quality, improve biochemical attributes, reduce physiological disorders and induce disease resistance in okra fruits. The researchers employed alginate, carboxylmethyl cellulose, pectin and starch in their work since these materials are readily available on the market and have been proven successful in various kinds of horticultural crops.

2. Methodology

2.1 Fruit Source

The okra "smooth green" variety (Filipinas Kaneko Seed Corporation, Lipa City, Philippines) was grown and procured from Barangay Igang, Baybay City, Leyte (N 10° 39' 7.7076", E 124° 51' 9.2268"). The okra fruits were picked when they reached market maturity and immediately transferred to the Visayas State University's (VSU) Postharvest Technology Laboratory in Visca, Baybay City, Leyte (N10° 44' 39.8292", E 124° 47' 31.4556"), where the okra fruits were selected for size uniformity and freedom from defects for the trials.

2.2 Chemicals Used

Food-grade biopolymers such as sodium alginate (Modernist Pantry, United States), carboxymethyl cellulose (Eisen-Golden Laboratories, United States), apple pectin (Solgar, United States) and cornstarch (Cream Cornstarch, Philippines) were used in the coating formulations. Calcium chloride (WillPowder, United States) was utilized to induce a cross-linking reaction, and ascorbic acid (Kemrad, Philippines) was added as an anti-browning agent and glycerol (Green Leaves, Philippines) as a plasticizer.

2.3 Edible Coatings Preparation

The coating-forming solutions based on food-grade sodium alginate, carboxymethyl cellulose, pectin and starch powders were dissolved into distilled water by gentle stirring at 70 °C until the solution became clear (Rojas-Graü *et al.*, 2008). The coating solutions were kept at 4 °C until they were used. Glycerol was added as a plasticizer in a concentration of 1.5 g/100

mL (1.5% [v/v]) (Moreira *et al*., 2015). Ascorbic acid at 1 g/100 mL (1% [v/v]) was added as an anti-browning agent in the edible coating solutions (Robles-Sánchez *et al.*, 2009) and $CaCl_2$ at 1 g/100 mL (1% [w/v]) was used as the final dip for cross-link (Robles-Sánchez *et al.*, 2013; Guerreiro *et al*., 2015). Selected okra fruits were distributed at random into nine groups, each with 45 okra fruits. One group was used as a control, whose samples were untreated and the other four were treated with each one of the coatings (sodium alginate [AL], pectin [PE], carboxymethyl cellulose [CMC], and corn starch [CS]). Four edible coatings were evaluated at two different concentrations. The usage of 1 and 2% concentrations of different edible coatings was based on the study of Guerreiro *et al.* (2015), which yielded promising results.

2.4 Storage Condition

A chiller (Fujidenzo, Philippines) was utilized for the storage of okra fruits. The chiller's temperature ranged from 9 to 11 °C, with a relative humidity of 76 to 85%.

2.5 Experimental Design and Treatment

The study was laid out in a completely randomized design (CRD) with nine treatments and three replications. There was a total of 405 okra fruits with 45 fruits per treatment and 15 fruits per replication. This experiment was repeated twice. The treatment was composed of different polysaccharide-based edible coatings at different concentrations.

The treatments were the following: T0 = control (fruit not coated or dipped in any treatment); T1 = AL 1% (fruit coated with sodium alginate (10 g/L); T2 = AL 2% (fruit coated with sodium alginate at 20 g/L); T3 = PE 1% (fruit coated with pectin at 10 g/L); T4 = PE 2% (fruit coated with pectin at 20 g/L); T5 = CMC 1% (fruit coated with carboxymethyl cellulose at 10 g/L); T6 = CMC 2% (fruit coated with carboxymethyl cellulose at 20 g/L); T7 = CS 1% (fruit coated with cornstarch at 10 g/L); and T8 = CS 2% (fruit coated with cornstarch at 20 g/L).

The treatments were prepared in two steps (Guerero *et al*., 2015). First, the fruits were immersed for 2 min in an edible coating solution including ascorbic acid and plasticizer; the excess coating material was allowed to drip out for 30 s before being immersed for 1 min in a calcium chloride solution. The temperature of the edible coating solution was set to 25 °C (Kaur *et al*., 2018). The amount of coating on the fruit at any time was the difference between the

initial weight of the edible coating solution and the weight recorded at the respective draining time. Then, 15 fruits were placed in polypropylene plastic trays and stored at chilling temperature until analysis. The data gathering started from day 0 to 15 with a 3-day interval. The chiller's relative humidity and temperature were measured regularly until the study ended.

2.6 Data Collection

2.6.1 Physicochemical Characteristics

Moisture Content

Okra fruit moisture content (%) was determined using sample fruit from each treatment. The sample fruit was weighed using a weighing scale before oven drying (Gallenkamp, BS OV-160, United Kingdom). Moisture content determination was done by drying the samples in an oven at 105 °C for 16 h or two days until the weight becomes constant (American Society for Testing and Materials [ASTM], 2007). Percent moisture content was measured as the weight loss during drying and is expressed as a percentage of the wet sample. Percent moisture content was identified using Equation 1.

$$\%MC = \frac{FW - DW}{FW} \times 100 \quad (1)$$

where *MC* is the okra moisture content, *FW* is the fresh weight and *DW* is the dried weight.

Dry Matter Content

Okra fruit dry matter content (%) was determined using sample fruit from each treatment. The sample fruit was weighed using a weighing scale before oven drying. The samples were then oven-dried at 105 °C for 16 h until constant weight and re-weighed (ASTM, 2007). Percent dry matter content was measured as the remaining weight of the sample after drying and was expressed as a percentage of the wet sample. This was determined using Equation 2.

$$\%DMC = \frac{DW}{FW} \times 100 \quad (2)$$

where *DMC* is the dry matter content of the okra, *DW* is the dried weight, and *FW* is the fresh weight of the sample fruit.

Weight Loss

Weight loss (%) was measured using separate samples from three replicates of each treatment and calculated using Equation 3. The same samples were examined for weight loss at three-day intervals until the end of the trial.

$$Weight\ loss\ (\%) = [(A\text{-}B)/A] \times 100 \quad (3)$$

where *A* is the weight of the fruit upon harvest and *B* is the weight of the fruit after storage intervals (Akhtar *et al*., 2010).

Firmness

The firmness (kg/force) of the fruit was measured with a penetrometer. For this reason, sample fruits from each replication were obtained, and the penetration force was determined by gently inserting the probe into the equatorial area of the fruit. The data from each sample fruit was averaged, and the value was provided in kg/force to indicate the appropriate treatments. This was done in the Postharvest Laboratory, Department of Horticulture, VSU utilizing a hand-held penetrometer (FT 327 Pressure Tester, Wagner Instruments, United States).

Shriveling

The shriveling index (SI) (Table 1) was used to determine whether or not fruits exhibited shriveling (Acedo, 1999).

Table 1. The shriveling index

Shriveling index	Description
1	No symptom of wilting/shriveling
2	1-10% surface wilting/shriveling
3	11-30% surface wilting/shriveling
4	31-50% surface wilting/shriveling
5	Extensive wilting/shriveling

pH

Okra fruits were sliced into tiny slices and pooled from each treatment. To determine the quality, samples were homogenized in a blender (Super Blender 1.5-L HJB 115, Hanabishi, Philippines), and samples of the homogenate were taken. A digital pH meter (Hanna HI98108 pHep+ Waterproof Pocket pH Tester, Canada) was used to measure the pH of the fruits.

Total Soluble Solid (TSS)

The okra fruits in each treatment were chopped into thin slices and pooled. Samples were homogenized in a blender, and pieces of the homogenate were taken. Using a digital hand refractometer (Atago N1, Japan), standardized with pure water and one to three drops of juice on the prism of the instrument, TSS (°Brix) was measured in Brix percent (Acedo, 1999).

Titratable Acidity (TA)

A 5-mL juice extract (aliquot) was measured and put into an Erlenmeyer flask or beaker and added with 2 drops of 1% phenolphthalein indicator. This was titrated with 0.1% NaOH until the faint pink color and the volume of NaOH was recorded and TA was calculated (Acedo, 1999) using Equation 4.

$$\%\ TA\ of\ predominant\ acid\ = \frac{V\ \times N \times M}{W} \times 100 \quad (4)$$

where V is the volume of NaOH added (mL); N is the concentration of NaOH, normality (N); M is the milliequivalent weight of predominant acid (g/meq) (citric acid: 0.064 and malic acid: 0.067); and W is the weight equivalent of aliquot (g), which was obtained using Equation 5.

$$W\ = \frac{Weight\ of\ sample\ (g)}{Weight\ of\ sample\ +\ volume\ of\ water\ added} \times vol.\ of\ the\ aliquot \quad (5)$$

Vitamin C Analysis (mg. 100 g fresh fruit^{-1})

This was done using the iodometric titration method with the volumetry technique as described by Acabal *et al.* (2015).

2.6.2 Physiological Characteristics

Respiration Rate

This was measured by using a portable CO_2 and O_2 gas analyzer (Dansensor CheckPoint 3, Ringstead, Denmark). After allowing okra fruits to respire for 1 h, the rubber tubing from the CO_2 and O_2 analyzer was inserted into the glass tubing of the respiration jars and the CO_2 and O_2 reading was recorded. The respiration rate was calculated using Equation 6.

$$Respiration\ rate\ (mg\ CO_2.kg^{-1}h^{1}) = net\ (\%)\ CO_2 \times \frac{V}{(W)(T)} \times 1.83 \qquad (6)$$

where *Net (%)* CO_2 is the final (%) CO_2 reading (0.03% CO_2); *V* is the volume of free space (mL); *W* is the weight of the sample (kg); and *T* is the time of sealing in respiration jar (h).

2.6.3 Ethylene Production

This was measured using gas chromatography-mass spectrometry (GC-MS) (GCMS-QP2010 Ultra, Shimadzu, Japan) for an ethylene analyzer at the Harvested Products Regulation Laboratory, Philippine Root Crops Research, and Training Center (PRCRTC). After allowing the okra fruits to respire for one hour, the rubber tubing was injected with a syringe and inserted into the gas chromatograph to collect ethylene vapor for analysis. Equation 7 was used to calculate ethylene.

$$C_2H_4\ (mL/g/h) = \frac{R1}{R2} \times C \times \frac{VF}{(T) \times (W)} \qquad (7)$$

where *R1* is the ethylene reading for sample; *R2* is the ethylene reading for standard; *C* is the concentration of standard (ppm); *VF* is the volume of headspace (mL) (mL = volume of respiration jar – volume of commodity); *T* is the time interval (h); and *W* is the weight of the commodity (g).

2.6.4 Microbial Analysis

For the microbial load analysis, samples were sent to the Microbiology Laboratory of the College of Veterinary Medicine, VSU. Experiments were carried out in triplicate. Results were expressed as $\log_{10}$ CFU/g of fresh weight.

2.7 Statistical Analysis

The Statistical Tool for Agricultural Research (STAR) (International Rice Research Institute, 2014) program was used to perform the statistical analysis. For comparisons between treatments, one-way analysis of variance (ANOVA) and Tukey's honest significance (HSD) test were used at a 5% level of significance.

3. Results and Discussion

3.1 Moisture Content and Dry Matter Content

The moisture content in all samples decreased gradually during the experiment (Figure 1). After harvest, the moisture and dry matter content of okra fruit were 91.93 and 8.07%, respectively. Significant ($p < 0.05$) decrease in moisture content and increase in dry matter content were reported during 15 days of storage. Concerning the moisture content, the highest value was exhibited by uncoated fruit with 88.50%, while the lowest was found in the fruit coated with 1% pectin with a value of 86.59%.

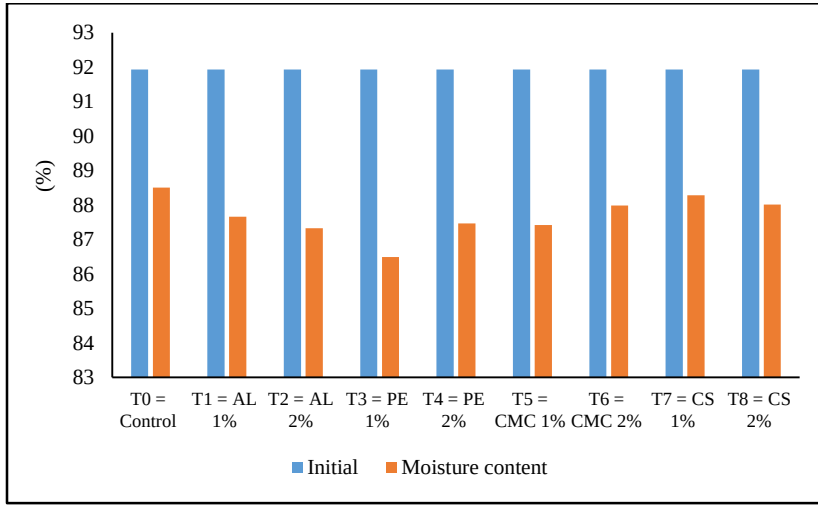

Figure 1. Moisture content of okra fruits as influenced by different polysaccharide-based edible coating after 15 days

Likewise, in terms of the dry matter content, fruit coated with 2% alginate observed the highest value with about 12.68% (Figure 2). On the other hand, the uncoated fruit obtained the lowest dry matter content of about 11.50%. The decrease in moisture contents and dry matter was more pronounced in the control samples though it was statistically comparable with other treatments and was similar to the findings of Amati *et al.* (1989), who reported that due to postharvest physiological processes such as respiration and transpiration, the moisture is lost in fruit and vegetables.

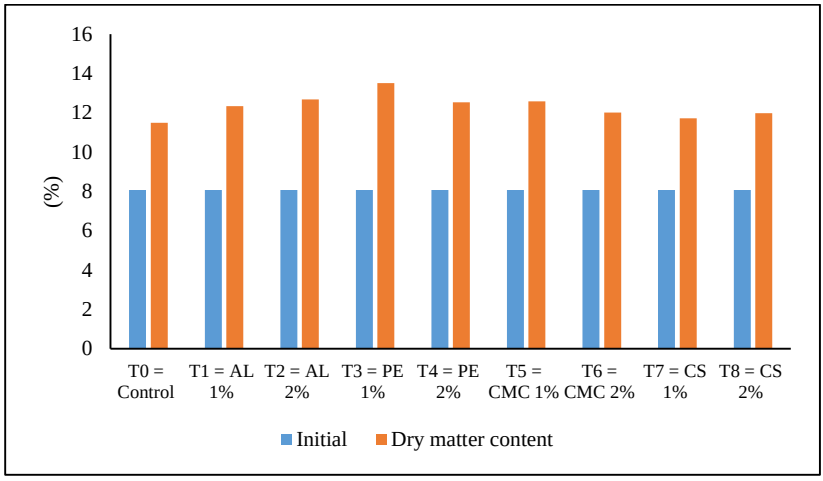

Figure 2. Dry matter content of okra fruits as influenced by different polysaccharide based edible coating after 15 days

3.2 Weight Loss

The result showed that the weight loss increased as the storage period increased and reached a maximum of 15 days (Figure 3). In this study, all treatments showed a gradual loss of weight during the storage period. All treatments coated with polysaccharide-based edible coating exhibited lesser weight loss compared to the control from day 3 to 15 days of storage. The fruit coated with 1% alginate lost the least weight after three days, followed by fruit coated with 2% carboxymethyl cellulose after 6 days, 1% carboxymethyl cellulose after 9 days, 2% alginate after 12 days, and 1% carboxymethyl cellulose after 15 days of storage. These weight losses ranged from 2.38 to 36.84%. In contrast, the control treatment consistently lost more weight than the other treatments over the course of the storage period, with weight loss ranging from 3.28 to 41.85%. The ANOVA revealed that okra fruit coated with different polysaccharide-based edible coating showed a highly

significant result after 3 to 15 days of storage. The HSD test further revealed that fruit coated with different polysaccharide-based edible coating significantly reduced the weight of okra fruit from 3 to 15 days of storage compared with the uncoated fruit.

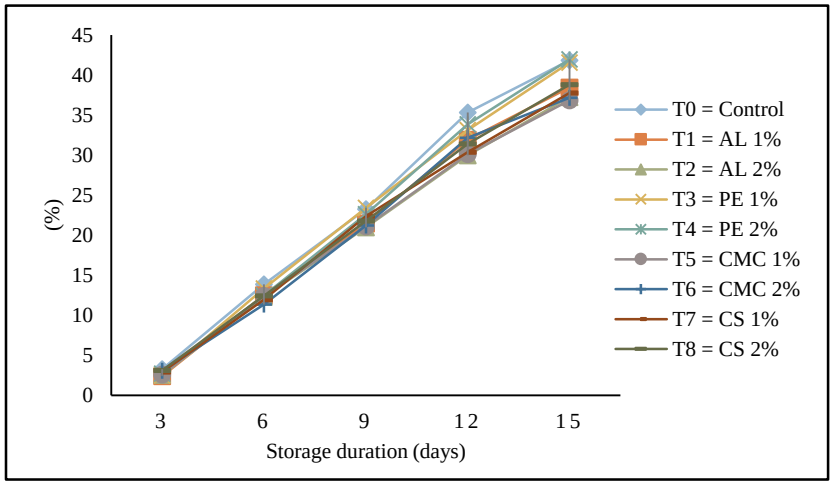

Figure 3. Weight loss of okra fruits as influenced by different polysaccharide-based edible coating from day 3 to 15

Reduced weight loss of okra fruits coated with sodium alginate, pectin and carboxymethyl cellulose could be due to the blockage of stomata and guard cells that ultimately slowed down the active metabolic processes and respiration. Moreover, reduced weight loss in sodium alginate-coated fruit could be attributed to blocking the moisture loss, respiration and movements of solutes across the membrane owing to the semipermeable nature of the coatings (Ullah *et al*., 2017).

The transpiration process causes a difference in water vapor pressure between the fruit and the surrounding air, which results in the fruit's weight loss. The rate of transpiration of a commodity is influenced by the nature of both the epidermal cell layer and the cuticle (Valero *et al*., 2013). Besides, as demonstrated in a wide range of fruits including apricot, pepper, peach and sweet cherry, edible coatings act as an extra layer that also coats the stomata leading to a decrease in transpiration and a reduction in weight loss (Valero *et al*., 2013).

3.3 Firmness

Fruit firmness was significantly affected by the different treatments applied (Figure 4). The result revealed that firmness reduced as time passed. Before coating, the okra fruit had a firmness of about 8.59 kg/force. However, there was a rapid decline in firmness from day 3 to 15 of storage, with values ranging from 8.49 to 5.35 kg/force. On the other hand, fruit firmness differed significantly from day 3 to day 15 of storage. Furthermore, from day 3 to 15, fruit coated with 2% alginate showed the maximum firmness values (8.49 to 6.26 kg/force). Moreover, uncoated control exhibited the lowest firmness all throughout the storage period, with values ranging from 8.10 to 5.35 kg/force. The different coatings significantly maintained the firmness compared with the control treatment, particularly after 15 days of storage. All other treatments particularly alginate 2% were comparably better in maintaining fruit firmness relative to the control.

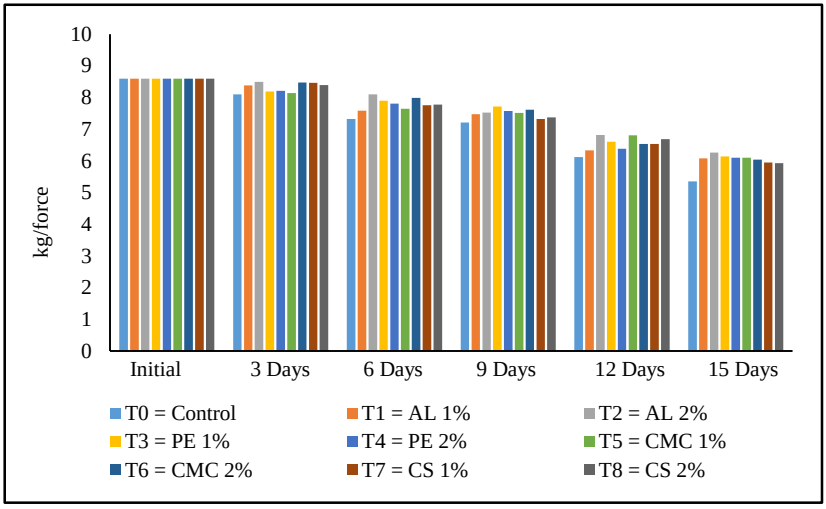

Figure 4. Firmness of okra fruits as influenced by different polysaccharide-based edible coating from day 3 to 15

This is in agreement with the results of the study of Tanada-Palmu and Grosso (2005) showing the effect of coating in slowing down metabolism, prolonging the storage life and retaining fruit firmness. Edible coating maintains firmness by regulating respiration and transpiration, which results in the loss of storage reserves. Furthermore, the edible coating improves fruit firmness by delaying

the ripening process and lowering the activity of cell wall breakdown enzymes (Dang *et al*., 2008).

Cell turgidity, structure and composition of the cell wall polysaccharide also affect the fruit firmness (Nasrin *et al*., 2017). Pectin solubilization, changes in the pectin molecular weight (Koh and Melton, 2002) and decrease of hemicelluloses in the cell wall are associated with loss of fruit firmness. Furthermore, the softening of okra fruits is brought on by cellular disintegration, which increases membrane permeability, or by the degradation of insoluble protopectin into soluble pectin (El-Shaieny *et al*., 2022).

3.4 Shriveling

Shriveling as affected by different edible coating is presented in Figure 5. The research results showed that from day 3 up to 15 of storage, shriveling increases progressively. The degree of shriveling appeared to be not significant in all treatments after 3 to 6 days of storage. However, after 9, 12, and 15 days, the ANOVA revealed significant differences among treatment means. This means that the application of different polysaccharide-based edible coatings influences the shriveling of okra fruit starting from day 9 up to 15 days of storage. HSD test further revealed that okra fruits from T5 (CMC at 1%) had significantly the lowest rating of the degree of shriveling but were only comparable with the ratings of fruits applied with other coatings. However, it was statistically different and better compared to the control fruits.

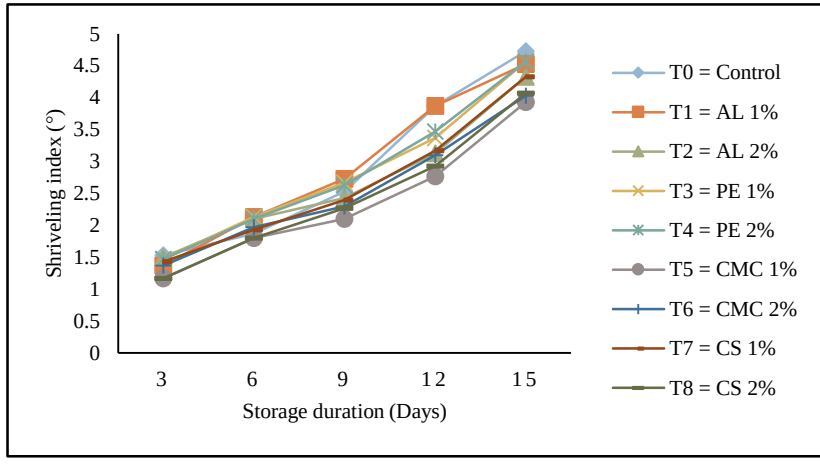

Figure 5. Shriveling of okra fruits as influenced by different polysaccharide-based edible coating from day 3 to 15

Okra fruit's increased shriveling may be linked to the fruit's active metabolic processes, such as transpiration and respiration, which result in water loss and are a contributing factor in shriveling (Abbasi *et al*., 2011).

3.5 pH

The pH of Okra fruits was significantly ($p < 0.05$) affected by the application of different coatings (Figure 6). The pH values decreased with time of storage irrespective of the coatings. At the beginning of the storage period, the pH values showed a sharp decrease from day 3 to day 9, then started to increase from day 12 and started to slow down during 15 days of storage. Significant differences were observed from day 3 to 15 of storage. However, the pH of fruits in all treatments followed a similar pattern of effect which was more likely similar across treatments. The significance was observed on carboxymethyl cellulose (1 and 2%) and cornstarch (1%) which showed a comparable lower pH than other treatments; in other words, the values were more acidic. On the other hand, fruit covered with 1% alginate had the highest pH value of approximately 5.95. However, comparable results were obtained with fruit coated with 2% alginate, pectin at 1 and 2%, 1% carboxymethyl cellulose, 2% starch and a control after 15 days of storage.

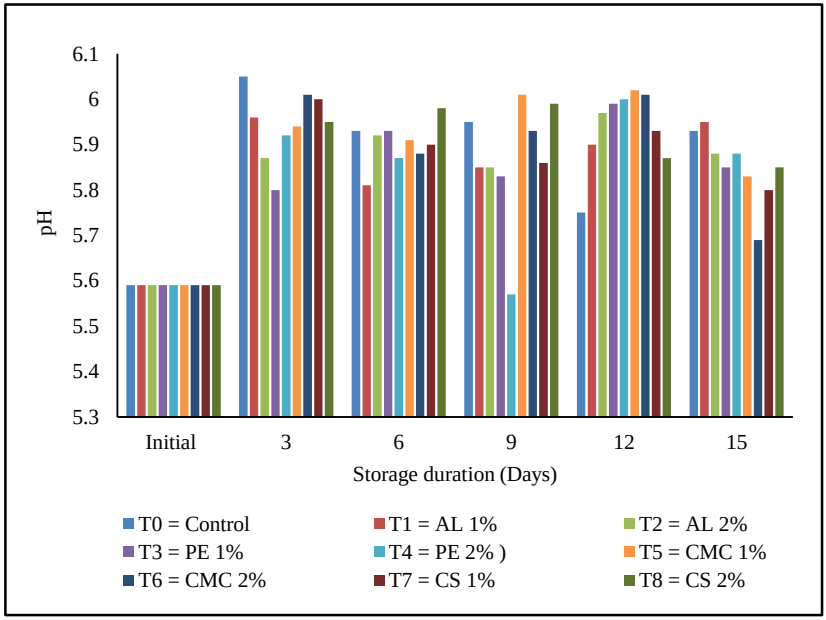

Figure 6. pH of okra fruits as influenced by different polysaccharide-based edible coating from day 3 to 15

The pH change was induced by several factors. It could be due to senescence delays caused by a slower rate of metabolic activity, as well as the influence of treatment on the vegetable's biochemical condition (Adetunji *et al*., 2014).

Dávila-Aviña *et al.* (2011) showed that with increasing pH, organic acids provide most of the hydrogen ions in tomatoes and normally decrease with ripening.

3.6 Total Soluble Solids (TSS)

It is evident from the data presented in Figure 7 that the TSS of the fruits increased with the increase in storage period from day 3 to 12, and decreased thereafter indicating a rapid metabolic breakdown in those fruits. Moreover, greater TSS values were detected in fruit coated with 2% alginate (5.66 °Brix) after 3 days of storage, 1% starch (5.73 °Brix) after 6 days, both alginate at 1 and 2%, and 2% pectin after 9 days (5.80 °Brix), 1% alginate (5.96 °Brix) after 12 days, and 1% alginate (5.86 °Brix) after 15 days of storage. Similarly, the uncoated control had the lowest TSS value throughout the storage period. It was also observed that some coated okra fruits had only statistically comparable TSS with that of the control treatments. Furthermore, on the 15th day, fruits from alginate (1%) and pectin (2%) had the highest TSS which was statistically different from the fruit TSS of fruits subjected to coating treatments.

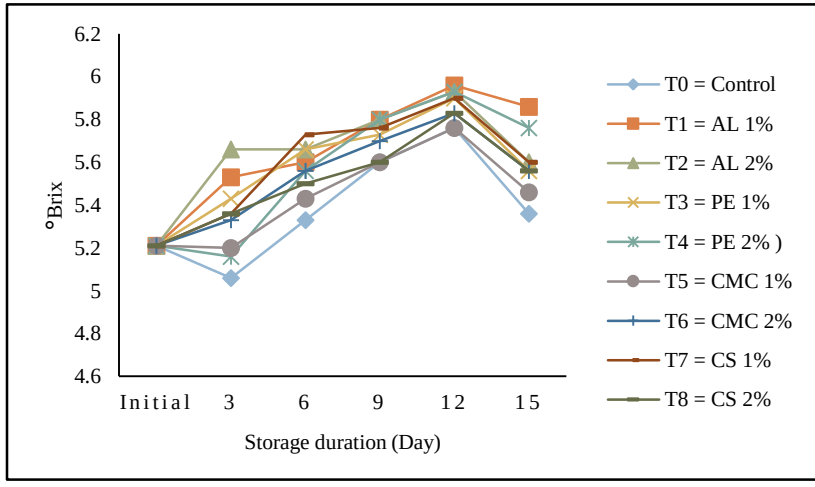

Figure 7. TSS of okra fruits as influenced by different polysaccharide-based edible coating from day 3 to 15

Due to the breakdown of complex organic metabolites into simple molecules or the hydrolysis of starch into sugars, the TSS increases during storage (Hazarika *et al*., 2017). Additionally, it might be linked to the hydrolysis of starch into sugars. Once this process was complete, there was no further growth in sugars, and as a result, there was a clear fall in these parameters. Starch and other organic acids are the main substrates for respiration (Sakhale *et al*., 2018).

Moalemiyan and Ramaswamy (2012) had a similar observation: cucumbers stored up to 5-10 days had an increase in TSS and then a decrease until the 15th day. Kluge *et al.* (2002) suggested that the soluble solids decrease due to the oxidative decomposition of complex substances such as polysaccharides, sugars, organic acids, proteins and lipids present in fruits and vegetables into simple molecules and energy.

3.7 Titratable Acidity

Okra fruit titratable acidity increased up to 6 days of storage and then decreased until 15 days of storage (Figure 8). On day 3, the uncoated control had a higher TA value of 0.68%. In addition, both fruits coated with 2% carboxymethyl cellulose and 2% cornstarch had a higher TA value of 0.97% after 6 days of storage. Furthermore, fruit coated with 2% cornstarch recorded the highest TA value of 0.94% after 9 days of storage. Likewise, the TA value at 12 to 15 days did not differ significantly. The titratable acidity of okra was revealed to be significantly affected by the different coatings used after 3, 6 and 9 days of storage. After 3 days of storage, the HSD test revealed that the control was statistically higher in TA than the other treatments, but comparable with the okra coated with alginate and cornstarch (1%). Moreover, all other coatings were significantly similar to TA. Besides, results on TA after 12 and 15 days of storage were not significant. This indicated that the TA was comparable among treatments at 12 and 15 days of storage.

Applying an edible coating to okra can slow down its respiration rate delaying the depletion of organic acids used in enzymatic reactions (Debeaufort *et al*., 1998). On the other hand, a reduced rate of oxidation occurs due to decreased respiration during the ripening process. This leads to the subsequent accumulation of organic acids caused by the decreased hydrolysis of organic acids in the pyruvate decarboxylation reaction. This results in a decrease in TA as storage time increases (Hazarika *et al*., 2017).

Less respiration prevents organic acids from oxidizing, resulting in higher TA in coated fruit, whereas higher respiration and oxidation of organic acids may cause a significant reduction in TA in uncoated fruit (Ullah *et al*., 2017).

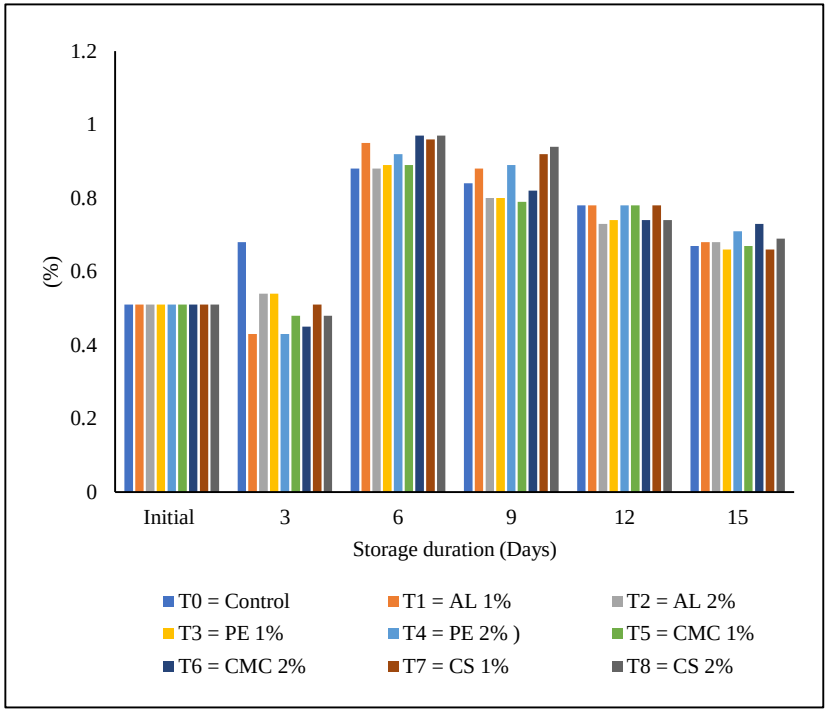

Figure 8. Titratable acidity of okra fruits as influenced by different polysaccharide-based edible coating enriched with essential oils from day 3 to 15

3.8 Vitamin C

Data on vitamin C of Okra as affected by the different coatings applied at a varying rate is presented in Figure 9. Before coating, the okra fruit contained 1.98 mg/100 g of vitamin C. After 15 days of storage, it was found that the content of vitamin C decreased. Furthermore, fruit coated with 2% alginate and containing 1.75 mg/100g of vitamin C showed greater vitamin C levels after 15 days. However, the uncoated treatment had the lowest result (1.16 mg/100 g). The ANOVA revealed that the application of different coatings significantly ($p > 0.01$) affected the percent decrease in vitamin C. The control treatment showed the greatest percent reduction although it was comparable with fruit coated with 2% pectin, which ranged from 39.23 to 41.46%. The percent reduction in vitamin C was substantially smaller in fruit coated with

2% sodium alginate but the result was comparable with that of 1% sodium alginate, 2% carboxymethyl cellulose and 1 and 2% starch ranging from 11.43 to 25.66 mg/100g.

Strongly dependent on the pH of the vegetable, the loss in vitamin C may be a result of the activity of the enzyme ascorbate oxidase. The enzymes convert ascorbic acid to dehydroascorbic acid in stored produce (Adetuyi *et al*., 2008). The highest level of reduction was observed in uncoated okra with a 41.46% loss in vitamin content, whereas okra fruits coated with 2% alginate had the least loss in vitamin C content (11.44%). The increased respiration and oxidation of acids into sugars result in a decrease in ascorbic acid (Shiri *et al*., 2011).

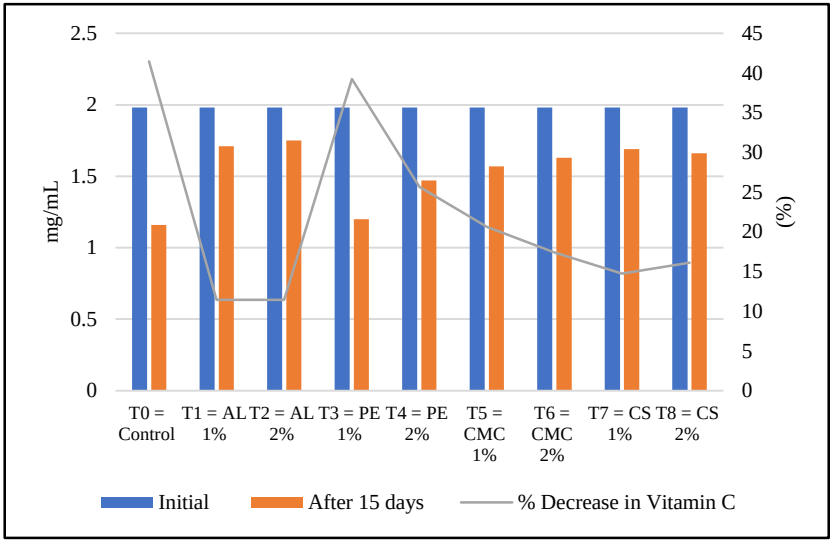

Figure 9. Vitamin C of okra fruits as influenced by different polysaccharide-based edible coating from 15 days of storage

3.9 Respiration Rate and Ethylene Production

The rate of respiration increased as time proceeded (Figure 10). From day 3 to 12, the respiration rate increased across all treatments but reduced after 15 days of storage. From day 3 to 12, fruit coated with 2% alginate had the lowest respiration rate, with readings between 31.12 and 75.14 mg $CO_2.kg^{-1}$ h^{-1}. On day 15, however, fruit coated with 1% carboxymethyl cellulose had the lowest value of 52.40 mg $CO_2.kg^{-1}$ h^{-1}. Moreover, the data on the respiration rate showed significant results among the treatments tested. The control treatment

had the highest respiration rate at 3, 6 and 9 days although it was comparable with other treatments like pectin, CMC and cornstarch coatings. Furthermore, after 12 days of storage, all treatments' respiration rates reached their highest levels (85.77 to 108.88 mg $CO_2.kg^{-1}$ $h^{-1)}$. It was noted that only cornstarch at 1% was comparable with the control treatment and statistically higher than other treatments. After 15 days of storage, the mean respiration rate reduced at a range of 52.40 to 92.12 mg $CO_2.kg^{-1}$ h^{-1} and revealed that the control treatment was statistically different and higher compared with all other treatments tested.

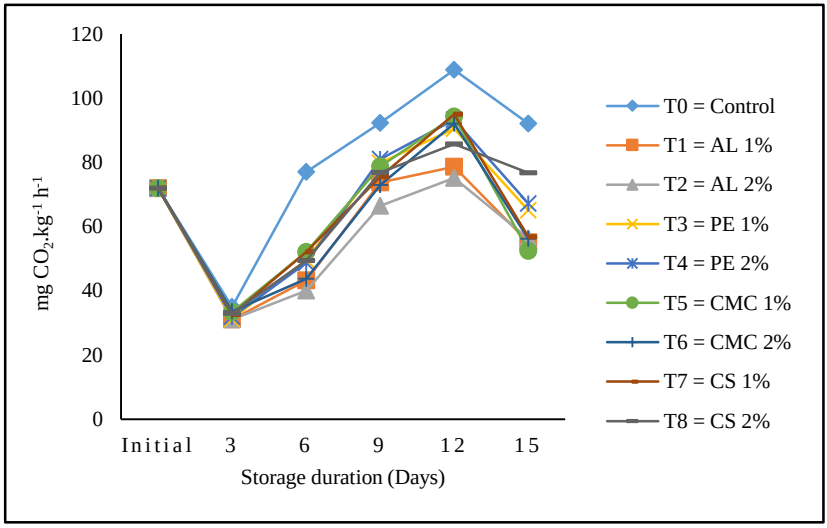

Figure 10. Respiration rate of okra fruits as influenced by different polysaccharide-based edible coating from day 3 to 15

On the other hand, prior to coating, ethylene production of okra fruit was only about 0.37 mL/g/h (Figure 11). However, after 15 days of storage, ethylene production increased in the uncoated control having a value of 1.49 mL/g/h. Furthermore, the rate of ethylene production during the final reading revealed no significant differences.

The lesser the value on respiration and ethylene production the better since the fruit can stay longer in storage condition. The main factors that contribute to the deterioration of fruits and vegetables are respiration, transpiration and ethylene production (González-Aguilar *et al*., 2009).

All kinds of coatings performed well in reducing the respiration and ethylene production of okra fruits. The depletion of endogenous O_2 and a rise in CO_2 without achieving anaerobiosis make a coating a gas barrier between the fruit tissue and the surrounding environment that modifies the internal atmosphere of the fruits. It depends on the product's coating formulation and storage temperatures, as well as the intensity of gas exchange (CO_2 and O_2) in the fruits (Nasrin *et al*., 2017).

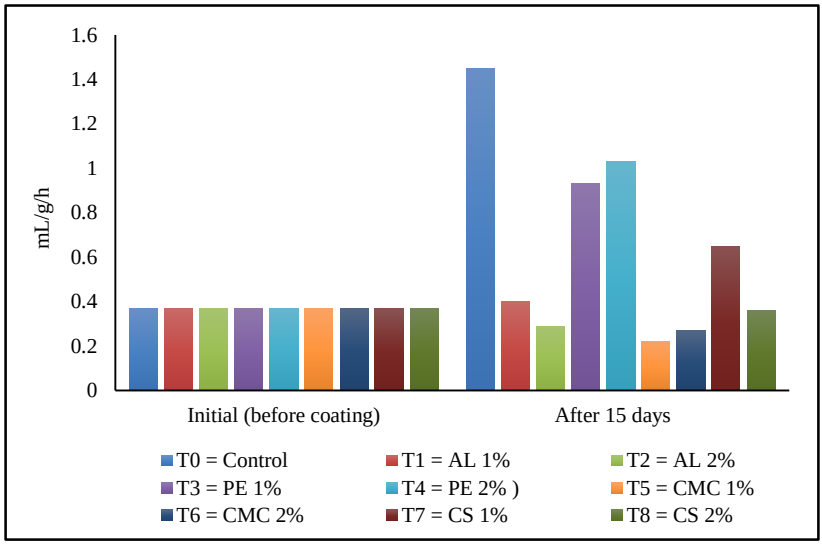

Figure 11. Ethylene production of okra fruits as influenced by different polysaccharide-based edible coating at 15 days of storage

3.10 Microbial Count

Figure 12 depicts the influence of coatings on the microbiological count of okra fruit. After 15 days of storage, the uncoated treatment had the highest number of microbial counts with a 79.67 x 10^5. Fruit coated with 2% sodium alginate, on the other hand, had the lowest microbial count of 3.33 x 10^5. Furthermore, an increase in microbial count was detected in the uncoated treatment and a decrease in the 2% sodium alginate coating. The ANOVA revealed a highly significant result. This indicates that the microbial count of okra fruit at 15 days of storage was significantly reduced by the application of several edible polysaccharide coatings. It was also observed that alginate (2%), pectin (1 and 2%), CMC (2%) and cornstarch (2%) were effective in reducing the microbial growth as against the control and other coatings, which

increased in the microbial count. It indicated that most of the edible coating inhibited the growth of bacteria.

Coatings caused a decrease in O_2 concentration and a rise in CO_2 concentration, which reduced respiration and inhibited the production of ethylene, delaying ethylene, ripening, senescence and microbial development (Mahfoudhi *et al*., 2014).

On the other hand, the increase in microbial growth in some coatings particularly T1 and T7 is supported by Oms-Oliu *et al.* (2008), who mentioned that edible coating reduces the microbiological growth, decreases the wounding stress of fresh-cut melon, provides antioxidant properties and maintains quality attributes.

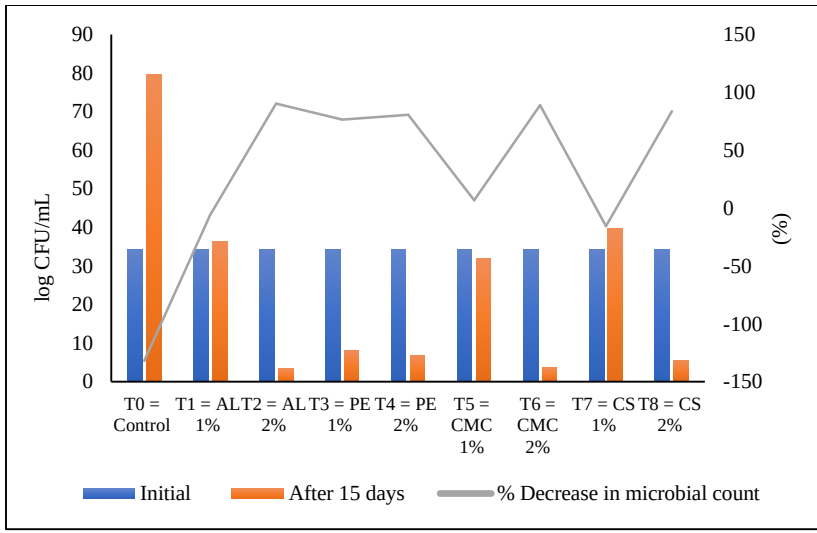

Figure 12. Total microbial count of okra fruits as influenced by different polysaccharide-based edible coating from 15 days of storage

4. Conclusion and Recommendation

The okra fruit's physicochemical characteristics (percent weight loss, firmness, shriveling, pH, total soluble solids, titratable acidity, and moisture and dry matter contents), vitamin C, physiological properties (respiration rate) and microbiological aspect (microbial count) were all significantly affected by

different polysaccharide-based edible coatings. When compared with the control treatment, the different polysaccharide-based edible coatings were effective in preserving the quality of okra. Notably, among various coatings, 2% alginate edible coating was the best in retaining the quality of okra fruit. To validate the efficiency of this edible coating, a larger scale investigation should be done in the future to confirm the study's findings.

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