Food ScienTech Journal Vol. 6 (2) 2024 ISSN : 2685-4279 DOI:10.33512/fsj.v6i2.25639

Optimizing Fresh-Cut Apple (*Malus sylvestris* (L.) Mill.) Quality Through Combination of Sodium Alginate and Calcium Chloride Coatings

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Submitted: 28.05.2024; Revised: 23.10.2024; Accepted: 13.11.2024

ABSTRACT

Fresh-cut fruit is a fruit product innovation that makes it easier for people to consume fruit, but it is not shelf-stable, which results in a decline in the physicochemical and organoleptic quality of the fruit. For example, cut apples are prone to browning and rotting, reducing their shelf life and quality. Fruit can be preserved in various methods, including covering it with a solution of calcium chloride (CaCl) and sodium alginate (SA). This study aimed to assess the impact of different SA and CaCl combination coating concentrations on the physicochemical properties of fresh-cut apples (*Malus sylvestris* (L.) Mill.). This study is a descriptive experiment with 3 replications with 4 treatments, namely P1: 1% SA+1% CaCl, P2: 2% SA+2% CaCl, P3: 3% SA+3% CaCl, and control (no coating). The study was conducted at the Biochemistry and Food Laboratory of the Biology Study Program of UIN Maulana Malik Ibrahim Malang and the Animal Husbandry Laboratory of Universitas Brawijaya. Parameters observed included physicochemical characteristics (firmness, weight loss, color, moisture content, total soluble solids, and titrated acidity). Data were analyzed by ANOVA followed by Duncan's 95% confidence level test. From the results of the study, it is known that P2 is the best combination coating. We concluded that a coating of 2% sodium alginate and 2% calcium chloride on cut apples led to improved quality, including reduced weight loss, better color, and higher moisture content, compared to other coating combinations

Keywords: fresh-cut apples, edible coatings, sodium alginate, calcium chloride

INTRODUCTION

Fresh-cut fruit is a method of minimal preparation for fruit that does not involve the use of heat (Syamsir, 2010). When processed, fruit tissue gets damaged from being cut, leading to physical and chemical alterations (Purwanto & Effendi, 2016). Apple is a highly popular choice for fresh-cut fruit. Upon being cut, this fruit undergoes oxidation, resulting in browning, which negatively affecting its shelf life. Cut apples stored at low temperatures without any treatment can remain fresh for 3-5 days (Purwanto & Effendi, 2016; Kumar *et al.*, 2018).

An effective approach to preserving the quality and longevity of fruits is through the utilization of natural-based fruit coating techniques, often known as edible coatings. The edible coatings are both cost-effective and environmentally degradable (Chen *et al*., 2019; Armgham *et al.,* 2022). Alginate is considered an edible coating material due to its heat stability, transparency, strength, lack of flavor, flexibility, and its properties as an antioxidant and antibacterial agent (Dhall, 2013). Nevertheless, when employed in significant amounts, it will diminish the coating's quality (Matloob *et al.,* 2023). Due to its high solubility in water, alginate requires the addition of specific divalent ions, such as calcium chloride (CaCl), when used as a coating (Campos *et al.,* 2011; Hassan *et al.,* 2018). Currently, extensive research has been conducted on the utilization of sodium alginate and calcium chloride in the production of edible coatings (Cofelice *et al.*, 2018; Marghmaleki *et al.,* 2021). Nevertheless, utilizing of a mixture containing 1% sodium alginate (SA) and 1% calcium (CaCl) is deemed suboptimal due to the reduced elasticity and fragility of the resulting gel layer, leading to an increased respiration rate. The high respiration process led to a substantial reduction in both weight and moisture content. This study seeks to assess the impact of different concentrations of sodium alginate and calcium chloride combination coatings on the physicochemical properties of cut apples (*Malus sylvestris* (L.) Mill.) in response to the mentioned issues.

MATERIALS AND METHODS

Study Design

The study used a completely randomized design (CRD) with three separate duplicates. According to the findings of prior research carried out by Cofelice *et al*. (2018) and Marghmaleki *et al.* (2021), the concentration of sodium alginate that was utilized was determined by maintaining a constant ratio of 1:1 between calcium chloride (CaCl) and sodium alginate (SA). Four distinct coating formulas were evaluated, namely P1: 1% SA + 1% CaCl, P2: 2% SA + 2% CaCl, and P3: 3% SA + 3% CaCl. Additionally, a control group that did not get any coating was also evaluated.

Preparation of fresh-cut apples (*Malus sylvestris mill.*) samples.

The maturity level of 48 apples from the *Malus sylvestris (L.)* Mill. variety was taken into consideration when selecting them. After that, they were saved at room temperature overnight, and the following day, they were used. The apples were cut into eight crescent-shaped pieces using an apple cutter, and then they were sterilized with a knife made of stainless steel that was perfectly sharp. Using an apple cutter, a single apple was cut into eight identical segments to conduct a control experiment. Following that, each section was immersed in distilled water for one minute, and then it was allowed to drain at room temperature for an additional minute. A total of three repetitions of the sequence of actions were achieved. After completing these procedures, the apple segments were carefully sealed within a box with a thin wall and it was maintained at a temperature of 4±4 ºC (Hibatul, 2018).

Preparation of coating solution

Sodium alginate (SA) powder is added to a glass beaker, and then preheated distilled water is gradually added at different ratios: 1 g per 100 mL, 2 g per 100 mL, and 3 g per 100 mL. Next, the mixture is agitated until fully dissolved and filtered. During the creation of the SA solution, CaCl powder is placed into a separate glass beaker. Distilled water is added while continuously stirring until a uniform mixture is obtained. The ratios of CaCl powder to distilled water added are 1 g per 100 mL, 2 g per 100 mL, and 3 g per 100 mL (Alharaty & Ramaswamy, 2020).

Sample coating

In various glass beakers, SA and CaCl solutions were mixed in a 1:1 ratio. The apple chunks were thoroughly immersed in the SA solution for one minute. The sample was then withdrawn and resubmerged in the CaCl solution for one minute. The sample was then elevated and placed in a mesh container to drip at ambient temperature (25°C) for 60 seconds to remove any excess surface coating solution (Fina, 2017).

Sample storage

Each group of apple segments, consisting of eight samples, was placed in thin-wall box containers and carefully sealed. The box containers were placed in a temperature-controlled environment at 4±4°C for 9 days. Testing was carried out on days 0, 3, 6, and 9.

Sample Observation

Physicochemical measurements were assessed firmness, weight loss, moisture content, total soluble solids, and titrated acidity. Observations of the organoleptic properties included the color of the fruit.

a. Firmness
The firmness of the sample was determined using the method developed by Gardjito and Agung (2003), with some changes. Determination of firmness is carried out by using Braztler shear force.

b. Weight loss
The weight reduction was measured using the AOAC (2016) technique. Determination of Weight loss by weighing the sample using a digital scale every three days. The initial weight is calculated on day 0 and subsequent weight loss is calculated every 3 days.

$$\text{Weight loss } (\%) = \frac{(\text{initial weight} - \text{final weight})}{\text{initial weight}} \times 100$$

c. Water content
The water content is quantified utilizing the methodology established by Sudarmadji *et al.*, (2007) with specific modifications. Measurement of water content by heating method using an oven. The sample was weighed as much as 5 g using a digital scale, then placed on an oven grill, then heated in the oven at 105°C for 4 hours. Samples are measured by calculating the weight reduction before and after being oven until constant.

$$\textbf{water content } (\%) = \frac{(\textbf{initial weight} - \textbf{final weight})}{\textbf{initial weight}} \times \mathbf{100}$$

d. Total soluble solid
Total soluble solids are determined using the methodology established by Gol *et al.* (2013), with specific modifications implemented. The total value of soluble solids is measured using a refractometer and expressed in °brix units.

e. Titratable acidity
Titratable acidity are determined using the method of The Alharaty & Ramaswamy (2020) with specific modifications. The sample that has been filtered is dripped with 0.1% phenolphthalein, 0.1 N NaOH solution slowly from a biuret tube. The titration value is seen from the decrease in the NaOH solution contained in the biuret tube. The measurement is checked until the sample color changes to pink for 30 seconds.

$$\text{Titratable acidity } (\text{g MAE L}^{-1}) = \frac{\text{V(NaOH)}(0,1)(0,067)}{\text{m}} \times 100$$

f. Color of sample
Alternatively, the color of apple slices was assessed using a colorimeter to make sensory observations according to the approach established by

Alharaty & Ramaswamy in 2020. The degree of browning is measured by the L* value and a* value. The L* parameter measures the degree of luminosity or paleness on a scale ranging from 0 to 100, with a value of 100 indicating white and a value of 0 indicating black. A higher L* number signifies more brightness, whereas a lower L* value signifies decreased brightness. The parameter "a*" indicates redness, ranging from -a* to +a* (-a* representing green and a* representing red). If the sample is negative (-), it indicates that the sample has a greenish or brilliant color. On the other hand, if the value of a* is positive (+), it indicates that the sample has a hue that is more reddish or dark, according to Yusuf *et al*. (2018).

Statistical analysis

The data on firmness, weight loss, water content, total soluble solids, color, and titratable acidity were subjected to statistical analysis of variance (ANOVA). If a substantial disparity existed, it was subsequently assessed using Duncan's test at a confidence level of 95%.

RESULTS

Physicochemical Quality of Fresh-Cut Apple Fruit

Table 1 displays the mean values for hardness, weight loss, fruit color, moisture content, total soluble solids, and acidity of fresh-cut apples. The average hardness of chopped apples decreases over time. On day 9, the P3 treatment exhibits superior hardness compared to the other treatments. Over time, the average weight loss value rose. However, the P2 treatment consistently maintained a lower proportion of fruit weight loss on day 9. Over time, the average L* value of chopped apples declined. Among the treatments, P2 was the most effective since it was able to sustain a high L* value until day 9. Over time, there was a progressive increase in the average a* value of chopped apples. The P2 treatment was the most effective treatment since it maintained a low a* value until day 9. With each increase in storage length, the average moisture content consistently declined. Specifically, P2 consistently maintained a larger percentage of moisture content than P1 and P3. The P2 treatment effectively preserved the moisture content percentage till day 9. Contrary to the moisture content, the TPT value of chopped apples consistently increases as the storage duration lengthens. The P2 treatment effectively reduced the TPT value of the fruit compared to P1 and P3, with a TPT value of 16.7°brix on day 9. The titrated acidity value consistently declined with time during storage. On day 9, the P3 therapy exhibited superior acid content titration compared to P1 and P2.

The findings of the one-way ANOVA statistical analysis indicated that P1, P2, and P3 consistently maintained higher hardness values compared to the uncoated control until day 9 (Fig. 1). There was a significant difference in weight reduction between the P3 treatment group and the control group, but it was not significantly different from the P2 and P1 groups (Fig.2). On the ninth day, there was no notable disparity in the L* value among all treatments. Nevertheless, P2 exhibited a higher L* value in comparison to all other treatments (Fig. 3). The a* value of the P2 treatment showed a statistically significant disparity from the control on day 3 but did not demonstrate a statistically significant distinction from the P1 and P3 treatments. There was no notable disparity between P2 and P3 on the ninth day. Nevertheless, both P2 and P3 exhibited substantial dissimilarity compared to P1 and demonstrated a highly notable distinction from the control (Fig.4). The moisture content of the P2 treatment showed a statistically significant difference compared to the control group, but not when compared to the P1 and P3 treatments (Fig. 5). The total soluble solids did not exhibit any significant variation among treatments P1, P2, P3, and the control from day 0 to day 9. However, on day 9, treatment P2 demonstrated the ability to sustain a lower TPT value compared to the other treatments (Fig. 6). The titrated acidity on day 9 showed no significant difference between treatments P1 and P2 compared to treatment P3. However it was considerably different from treatment C, as shown in Figure 7.

The impact of treatment parameters, duration of storage, and the correlation between treatment and storage duration are displayed in Table 2. During a 9-day storage period, it was observed that the hardness of the material was influenced by the coating factor and storage duration, with a significant effect ($p \leq 0.05$). However, the interaction between the treatment and storage duration had no significant effect ($p \geq 0.05$). The study observed that the weight loss of chopped apples during a 9-day storage period was significantly influenced by both the coating component and the duration of storage ($p < 0.05$). During a 9-day storage period, the color of the coating, as measured by the L* value and a* value, was observed. It was determined that the coating factor, storage duration, and the interaction between treatment and storage duration had a significant influence ($p < 0.05$). Moisture content was observed throughout a 9-day storage period. It was determined that the coating factor and storage time had a significant impact ($p < 0.05$), whereas the interaction between treatment and storage duration did not have a significant impact ($p \geq 0.05$). During a 9-day storage period, it was shown that the duration of storage had a significant impact ($p \leq 0.05$) on TPT. However, the treatment factor and the interaction between treatment and storage duration did not have a significant effect ($p \geq 0.05$). The study observed the titrated acidity over 9 days and determined that both the coating factor and storage time had a significant impact ($p < 0.05$). However, the treatment and storage duration interaction had no significant effect ($p \geq 0.05$).

DISCUSSION

When an apple is cut, the tissue experiences stress, causing it to soften. This stress then starts the enzymatic breakdown of the pectic substances in the cell wall and the action of enzymes that break down pectin. This mechanism decreases cellulose's crystallinity and thins the cell wall's structure. Calcium chloride can enhance the structural integrity of apple fruit tissue by reinforcing the cell walls and middle lamellas. The elevated concentration of sodium alginate results in the formation of a thicker layer, while calcium chloride acts as a constricting agent that can bind to the hydrophobic portion of alginate. This binding process leads to the creation of a thick and robust layer, which aids in preserving the firmness of the fruit (Qi et al., 2011). Calcium chloride preserves the firmness of fruit tissue by chemically interacting with pectic acid in the cell wall, resulting in the formation of calcium pectate. This compound enhances the molecular connections between the cell wall constituents (Alharaty & Ramaswamy, 2020).

The process of fruit softening during ripening result of biochemical alterations in the turgidity of cells and the composition of cell walls. The alterations are shown by the degradation of the middle lamella of cortical parenchyma cells and decreased in pectin content due to the breakdown of pectic acid (Velickova *et al*., 2014). The study conducted by Senturk *et al.* (2018) discovered that calcium chloride salt is a highly effective method for preserving the firmness of coated samples throughout storage. Additionally, it works as a firming agent. The impact of cutting on apple fruit in addition to softening is water loss. Softening typically arises from the loss of moisture, resulting in a decline in the turgidity and crispness of fresh-cut fruit products. Consequently, the weight of freshly cut fruit undergoes progressive reduction as time passes.

The weight loss with the uncoated control-cut apples was much greater than with the coated apples. According to Zactiti and Kieckbusch's (2009) study, the cross-linking created by sodium alginate and calcium chloride has grown, which means that the tensile strength between solutions can stop too much transpiration. According to Cofelice *et al*. (2019), a concentration of 2% sodium alginate and calcium chloride is a good way to make the polysaccharides used in the mixture better at blocking water vapor. You can slow down the rate of breathing with coatings. This lowers the number of enzymatic reactions and keeps the sample's color. Also, Kocira *et al*. (2021) said that the stronger the cross-linking power of the coating on the sample, the less likely it is that the sample will change color. This is because the higher the concentration of divalent ions, the thicker the coating protects the sample, and the higher the concentration of polysaccharide coatings used.

The degree of cross-linking affects the ability of the alginate structure in the solvent so that the permeability to solutes and the transpration process will also decrease (Souza *et al.*, 2023). The amount of cross-linking changes how well the alginate structure works in the solution. This means that fewer solutes can pass through and the transpration process slows down (Souza *et al.*, 2023-2103). The total soluble solids value of the fruit did not change after the coating or control treatments. During storage, total soluble solids increase because starch turns into sugar and cell wall polysaccharides break down into glucose. For another thing, the process of transpiration raises the quantity of leftover soluble solids in the tissue. Magri *et al.* (2023) say that these things can change the TPT value of fruit from both inside the fruit and its surroundings. In order to slow down the loss of water and the process of turning starch into sugar, coatings can be used.

During storage, changes in the acidity of apples affect the sugar/acid ratio, which determines the taste of apples. The decrease in titrated acidity observed in the control samples is due to increased respiration, which causes the oxidation of organic acids. This decrease occurs gradually over time (Naqash *et al*., 2022). Additionally, the decrease in titrated acidity can be attributed to the higher respiration rate caused by activities like chopping, peeling, and other minor processing methods (Rocha & Morais, 2003). Organic acids can be used as an alternative respiration source during storage, decreasing titrated acidity.

CONCLUSION

The application of a coating treatment to freshly-cut apples has a notable influence on the physicochemical characteristics of the fruit. The findings indicated that 3% sodium alginate and 3% calcium chloride coatings yielded the best outcomes in preserving firmness and titrated acidity levels. Regarding weight loss maintenance, total soluble solids, moisture content, and color preservation, and applying coatings containing 2% sodium alginate and 2% calcium chloride demonstrated the most favorable outcomes.

ACKNOWLEDGEMENT

We thank our colleagues Mr. Dodik Pranowo from Faculty of Agricultural Technology Universitas Brawijaya and Mrs. Ruri Siti Resmisari from Faculty Science and

Technology who provided assistance in borrowing equipment.

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Table 1. Physicochemical Quality of Fresh Cut Apple Fruit

Parameter	Treatment	Physicochemical Quality of Fresh Cut Apple Fruit Day- 0	3	6	9
Firmness (N)	P1	9,5±0,75[a]	8,4±0,77[b]	6,6±0,50[bc]	5,4±0,50[a]
	P2	9,3±0,80[a]	8,5±0,50[b]	6,0±0,20[ab]	4,9±0,45[a]
	P3	9,9±0,81[a]	8,5±0,40[b]	7,3±0,52[c]	5,7±0,60[a]
	C	9,1±0,85[a]	7,2±0,52[a]	5,2±0,66[a]	4,6±0,78[a]
Weight loss (%)	P1	0±0,00[a]	0,73±0,05[a]	1,47±0,11[a]	2,31±0,11[b]
	P2	0±0,00[a]	0,67±0,03[a]	1,24±0,23[a]	1,91±0,17[a]
	P3	0±0,00[a]	0,74±0,05[a]	1,35±0,0,25[a]	2,13±0,10[ab]
	K	0±0,00[a]	1,36±0,15[b]	2,18±0,13[b]	3,09±0,25[c]
Color (L* value)	P1	65,17±3,53[a]	64,09±8,29[a]	57,46±5,03[ab]	46,34±4,64[a]
	P2	70,94±2,81[b]	66,03±1,17[a]	62,35±2,88[b]	51,15±8,46[a]
	P3	73,78±3,76[b]	64,19±4,72[a]	63,61±2,67[b]	48,52±2,56[a]
	C	71,26±1,19[b]	61,30±7,14[a]	54,16±3,22[a]	42,33±1,77[a]
Color (a* value)	P1	-2,97±0,85[a]	-2,39±0,89[b]	-1,59±0,78[b]	5,44±0,91[b]
	P2	-3,51±0,39[a]	-3,33±0,40[ab]	-2,87±0,17[a]	3,11±0,78[a]
	P3	-4,00±0,69[a]	-3,84±0,38[a]	-2,35±0,91[ab]	3,67±0,40[a]
	C	-0,39±0,37[b]	1,12±0,74[c]	3,17±0,43[c]	7,70±0,431[c]
Water content (%)	P1	87,85±1,60[ab]	87,80±0,62[a]	86,84±0,57[a]	84,87±0,68[ab]
	P2	89,88±1,22[b]	88,35±1,25[a]	87,02±0,37[a]	85,87±0,80[b]
	P3	88,97±0,73[ab]	88,02±1,60[a]	87,27±1,26[a]	84,88±0,40[ab]
	C	87,33±0,88[a]	86,83±1,29[a]	85,73±1,11[a]	83,77±0,32[a]
Total soluble solid (°brix)	P1	13,3±1,15[a]	15,7±0,58[a]	15,7±1,53[a]	16,7±0,58[a]
	P2	13,7±0,58[a]	15,0±1,00[a]	16,0±0,00[a]	16,7±1,15[a]
	P3	14,0±1,15[a]	15,3±0,58[a]	16,3±1,53[a]	17,0±0,58[a]
	K	14,3±1,53[a]	16,0±0,00[a]	16,3±1,53[a]	17,7±1,53[a]

Titratable acidity ($gMAEL^{-1}$)	P1	4,8±0,81[ab]	4,3±0,00[a]	2,9±0,00[b]	2,5±0,28[b]
	P2	4,3±0,00[a]	4,0±0,29[a]	2,7±0,00[b]	2,3±0,64[b]
	P3	5,2±0,35[b]	5,0±0,64[b]	4,5±0,29[c]	3,0±0,29[b]
	C	4,1±0,00[a]	3,8±0,00[a]	2,1±0,29[a]	1,6±0,29[a]

Note: Value with different notation in the same column has a significant differences at 5% (Duncan test)

Table 2. Results of two-way ANOVA analysis (α = 0.05) on physicochemical parameters of fresh-cut apples

Parameter	Treatment		Storage duration		Treatment*Storage time	
	F-ratio	*P-value*	*F-ratio*	*P-value*	*F-ratio*	*P-value*
Firmness	11,75	<0,01	100,29	<0,01	0,65	>0,74
Weight loss	75,11	<0,01	638,60	<0,01	8,16	<0,01
L* value	2,14	<0,03	64,92	<0,01	0,42	<0,04
a* value	67,56	<0,01	541,09	<0,01	4,14	<0,01
Water content	8,91	<0,01	28,00	<0,01	0,39	>0,92
TPT	1,63	>0,25	20,87	<0,01	0,13	>0,99
Acidity	37,45	<0,01	104,47	<0,01	1,91	>0,09

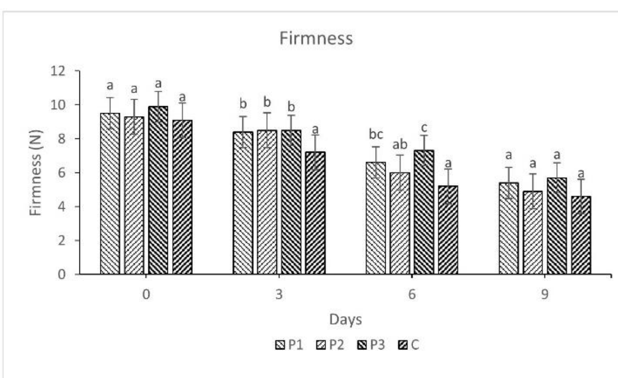

Figure 1. Firmness of fresh-cut apples until day-9

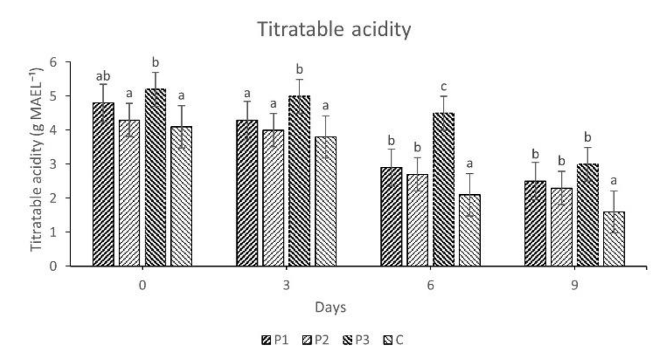

Figure 5. Titratable acidity of fresh-cut apples until day-9

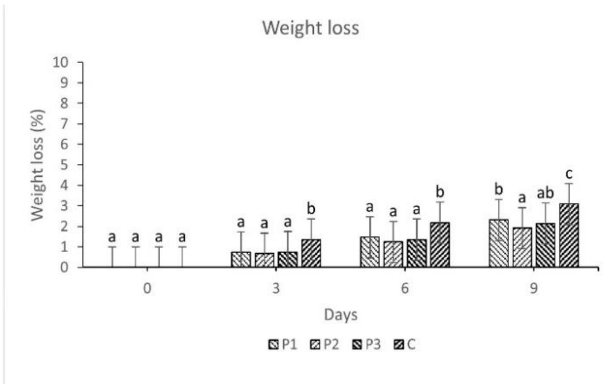

Figure 2. Weight loss of fresh-cut apples until day-9

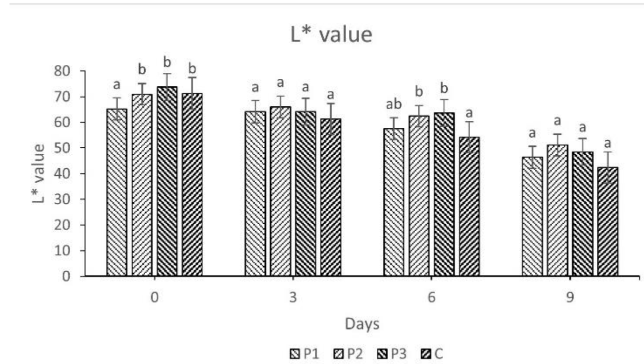

Figure 6. L*value of fresh-cut apples until day-9

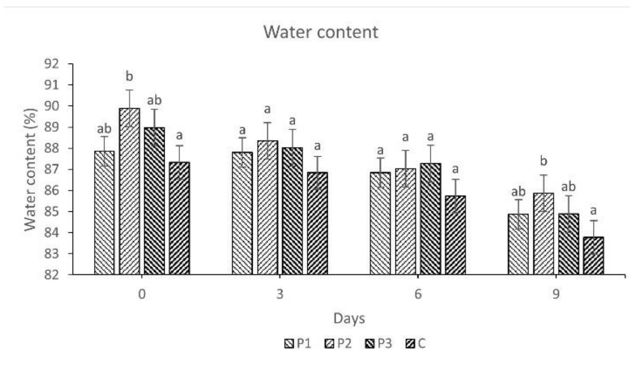

Figure 3. Water content of fresh-cut apples until day-9

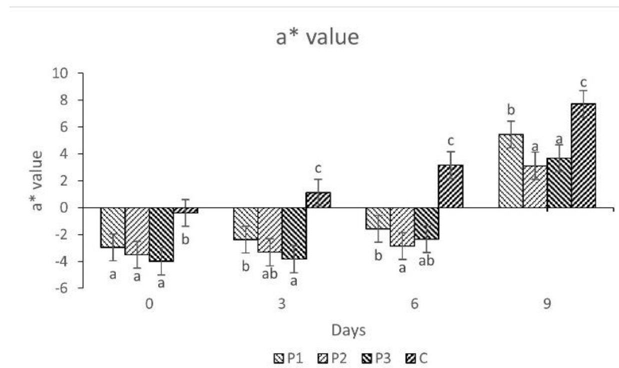

Figure 7. a*value of fresh-cut apples until day-9

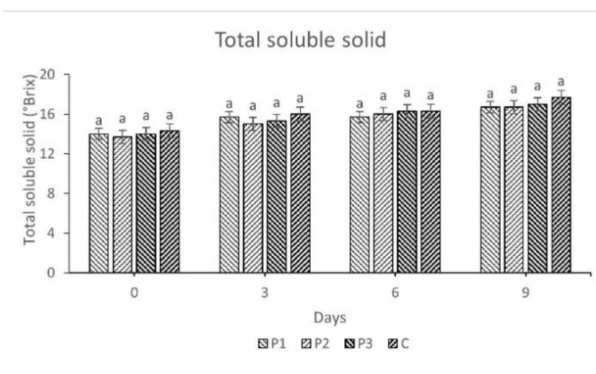

Figure 4. TSS of fresh-cut apples until day-9