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Preparation of edible coating from Cassava Starch and Rosemary essential oil and its effect on shelf life and quality of Muffin

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ABSTRACT

Edible coating solutions prepared using cassava starch in different ratios (100, 50 and 25%), gelatin and chitosan including rosemary essential oil were used to improve the physicochemical and antibacterial properties of edible films, and study the effect of these edible coating solutions on the shelf life and quality of muffins. The results showed that the addition of chitosan, gelatin, and the incorporation of rosemary with cassava starch film has caused a decrease in the tensile strength; an increase was observed in the elongation at the breaking point; and the permeability of the water vapor and gas films has decreased. The changes in the surface of these films were confirmed by film microstructure (SEM) analyses. The muffin samples were divided into uncoated (control) and coated samples with different edible coating solutions and stored at room temperature for 6 weeks. Shelf life was determined by the appearance of undesirable indications on muffin samples during sensory evaluation of color, odor, taste, texture, and overall acceptableness on different storages. The microbiology analysis results revealed the inhibition effect of rosemary essential oil on the growth of spoilage micro-organisms and recorded the lowest load of total bacterial count (TBC), yeast, and molds. Texture Profile Analysis (TPA) showed an increase in firmness, gumminess, and chewiness and a decrease in cohesiveness. The best treatment for the utilization of films using gelatin and chitosan, including rosemary essential oil and cassava starch is due to its ability to minimize weight loss, given the lowest water activity (aw) and having an extended shelf life. This can be attributed to increase the barrier properties of the coating film formed on the muffin surface, which reduces oxidative rancidity and decreases the peroxide value compared to other treatments.

1.Introduction

Costumers have been changing their behavior regarding to the purchase and their use of foods as habits. As a result of costumers requiring fast, comfortable, and easy-to-transport food products, ready-to-eat, comfortable foods have acquired salability, making them a lot more accessible as small products meant for mobile consumption. Bakery products in this group include breadsticks, biscuits, donuts, or muffins, which are now obtainable worldwide (Zahn et al., 2010). Muffins are high-calorie baked products that are highly sought after by consumers due to their taste and soft texture. (Gao, J. 2018). A basic muffin batter contains flour, sugar, baking powder or soda, eggs, fat, and milk, as it is softer and more flexible than cupcakes. Fruit, nuts, chocolate, vanilla, and spices can all be added for flavor and convenience, (Wheat Foods Council, 2010).

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A powerful direction of the industrialized cake market is snacks, small cakes wrapped in singular packaging, also called muffins (Channaiah et al., 2017; Kaur and Kaur, 2018). The appearance of baked products is an important quality that affects the visible perceptions of consumers, and hence; realizing the increasing consumption and high acceptance of bakery products, these offer a significant opportunity for providing and improving the nutrition level among consumers (Doss et al., 2011). The industry has been trying to solve problems and flaws in the manufacturing process in an effort to preserve market value and important problems in muffins. Freezing is a complex process that includes changes in texture, loss of softness, humidity redistribution, and fractional dryness. All these changes contribute to reducing consumer acceptability (Go'mez et al., 2008). Therefore In recent years, food packaging research has concentrated more on edible films; it is the best way to preserve humidity, texture, and softness in muffins and increase consumer acceptance of them. The development of edible films or coatings based on biopolymers has attracted most interest as they are friendly to the environment and their potential exchange for some petrochemicals in the food packaging industry (Zhong and Xia, 2008). An edible coating or film has been defined as a thin layer of biopolymer that can be consumed and is usually used on the surface of a food product by spraying, dipping or brushing (Bourtoom, 2008).

A polymer group can be used to create edible coating films, but the mechanical and physical properties of the film are affected by the difference in the polymer. The polymers used in the preparation of edible films and coatings are proteins (casein, gelatin and wheat gluten), polysaccharides (starch, cellulose and carrageenan, pectin), and lipids (stearic acid and waxes) (Sothornvit & Krochta, 2001). Edible coating films containing polysaccharides are characterized by low oxygen permeability, that can reduce the rancidity of bakery products. Starch is the most important polysaccharide used in the formation of biodegradable films and edible coatings because it is a cheap and abundant material able to form a continuous polymer matrix. Starch is prepared from different botanical sources (cassava, potato, wheat, corn, pea and rice),and it is one of the most favorable natural polymers for packaging applications due to its biodegradability, availability, renewability, low cost, and film forming ability (Sapper et al., 2019). The mechanical properties of starch-based films can be improved by cross-linking, acetylation, oxidation and mixtures with other polymers (Iamareerat et al., 2018). Cassava starch-based coatings are tasteless, odorless, and transparent, not changing the taste, aroma, or appearance of the product (Chiumarelli and Hubinger, 2014). Studies have shown that the use of cassava starch as a raw material in the industry for edible coatings and films provides a good side and a keen brilliance, making the food items more commercially appealing due to the more resistance, transparency, and efficient biodegradable packaging, which acts as barriers against water loss. Thus, it maintains the softness and smoothness of the muffins (Farris et al., 2014; Da Silva et al., 2015; Abreu et al., 2015). In addition, there is concern among consumers about food safety, but since edible films are from natural sources, they are safer for the consumer and can be consumed without any harmness (Karmaus et al., 2018). Other antioxidants and antimicrobials are added to the edible films to improve their physical and chemical properties, increase the desired effect on food preservation, and prolong their shelf life. One of the antimicrobials that is added to edible films is chitosan, as chitosan is a seafood by-product obtained by deacetylation of chitin (Babiker, 2002). It is a cationic polysaccharide with high molecular mass, excellent film-forming ability and antimicrobial activity. We have studied concentrations, molecular mass of chitosan and the degree of deacetylation of chitosan on the mechanical properties and barrier characteristics of chitosan films (Caner et al., 1998). Currently, the interest in extracts and essential oils of rosemary has increased due to their richness in bioactive components. As they are volatile (camphor and α-pinene) and phenolic (rosmarinic acid and carnosic acid) components with a strong antibacterial potential, its leaves have been used as a natural food preserver, flavoring, pharmaceutical, alternative medicine and natural therapies (Yeddes et al., 2021), also reported that film using gelatin and chitosan, including rosemary ethanol extract and essential oil has improved its physicochemical and antibacterial properties. However, sensory techniques are the only ones that make it possible to impose consumer acceptance. Sometimes, consumer rejection of the product occurs before any microbiological spoilage makes it unsuitable for human consumption. In order to assess sensory shelf life based on consumer rejection of a food product, survival analysis can be applied; it has been used to estimate the shelf life of some baked products (Hough et al., 2003). Notably, muffins and cakes also have a porous structure and spongy texture, and these qualities are affected by the process of packing and storage. So, the benefit of using edible films in packing muffins is due to preserving the organoleptic properties of the product, especially the texture and sponginess, as well as reducing fungal growth and delaying microbial spoilage to increase the shelf life as long as possible (Grillo et al., 2014) showed loss of moisture, fat, cohesiveness, springiness, gumminess or chewiness. In contrast, D. macrophylla increased specific gravity, changed rheology and tended to increase the adhesiveness, antioxidant activity and mineral contents of muffins. (Ndinchout et al., 2022); generally, (Nair et al., 2023) reported that the market value of edible packaging materials is expanding. Further research on and developments in edible food packaging materials are needed to increase sustainable, eco-friendly packaging practices that are significant for environmental protection and food safety.

The target of this study was to package muffins, with an edible coating of cassava starch, by spraying and estimate the capacity of this coating to maintain the muffin's sensory characteristics and increase the shelf life of bakery products.

2. Materials and Methods

Materials

Cassava roots were obtained from the Croups Intensification Section of the Field Croups Research Institute (FCRI) in the winter seasons of 2019 and 2020 at the Agricultural Research Center in Giza, Egypt. The roots were cleaned from impurities and foreign materials and then stored in a dry place at room temperature (25 ± 2 °C) until the extraction of cassava starch to produce edible coatings and films. The materials used in this experiment were corn starch, glacial acetic acid and sodium meta bisulfate. They were obtained from El-Gomhouria Chemical Company. Rosemary essential oil, gelatin and glycerol were obtained from Across Organics, Belgium. Whatman No. 1 filter paper and decanter 50 meshes were obtained from Cross-Organics Company in New Jersey; U.S.A. Chitosan was obtained from Jenapharm, Germany. Plate count agar medium and potato dextrose agar medium were obtained from Win Lab Company (U.K.). Wheat flour (72% extraction), sugar, shortening, baking powder, milk, eggs, and vanilla were purchased from a local market in Cairo, Egypt.

Cassava Starch Extraction

Cassava tubers are peeled, washed thoroughly and soaked in 0.3% sodium metabisulfite for 1 hour. Grated to a coarse puree, and then added water (to extract starch) in a ratio of 1:1. Further filtered with filter cloth, and the result is called filtrate I. The obtained residue was added to water and filtered again; the result is called filtrate II. Filtered (filtrates I and II) are then deposited for approximately 3 hours. Clear water is discarded, and the precipitated starch is taken and dried in an oven at a temperature of 40 °C for 48 hours. Sediment that has been dry-blended and sieved is stored in a sealed container (Kurniawan, et al.,2012).

Preparation of the edible coating solutions and films

Corn starch (control) and Cassava Starch was used as a film-forming ingredient. Edible film-forming solutions were obtained by dispersion of Corn starch and Cassava Starch 5% (w/v) in distilled water for 15 min), dispersion were then magnetically stirred at (200 rpm) for 15 min at 75 °C. Chitosan (1%) and gelatin (2%) were prepared separately, where chitosan solution was prepared by dissolving 1 g of chitosan was dissolved in 100 ml of distilled water mixed with 1 ml acetic acid then magnetic stirrer at 1,500 rpm for 15 min at room temperature, Gelatin solution was prepared by dissolving 2 g of gelatin powder in distilled water, and then stirred with a magnetic stirrer at 1,500 rpm for 15 min. starch, Gelatin and Chitosan film forming solution was prepared by mixing with different ratio after that glycerol (1%) was added as a plasticizer and added rosemary essential oil 0.1 %. Table 1. shows the different formulas of the coating solutions and films. For each formula, a specific content of film solution was poured onto rectangular plates (25×25 cm^2 of area) of pecia plate, followed by drying at 35 °C for approximately 24 h in a conventional chamber dryer with forced air circulation forming a film. (Bartolozzo et al., 2016) And the remaining part of edible coating solution is used to cover the muffin.

Table 1. The composition of edible coating from Corn starch, Cassava Starch, Gelatin, Chitosan by different ratio

Edible Coating solution	Edible film components %					
	Corn Starch (Control)	cassava starch	Glycerol	Rosemary essential oil	Chitosan	Gelatin
A	100	-	1.5	-	-	-
B	-	100	1.5	0.1	-	-
C	-	50	1.5	0.1	25	25
D	-	25	1.5	0.1	37.5	37.5

Rheological properties of coating solutions

The rheological properties of coating solutions were studied using a Brookfield Digital Rheometer, model HA DVIII Ultra (Brookfield Engineering Laboratories Inc.), it was used to measure the parameters (shear rate and shear stress) to select the best solutions for edible coatings and films from cassava starch solutions combined with rosemary essential oil. (Brookfield Manual, 1998) The methodology of the work was to put the sample transformer in a water bath at a constant temperature to maintain the desired temperature, and then run the viscosity device between 10 and 60 rpm. The spindle SC4-18 was selected for measurement (Aboul Anean, 2021).

Electronic scanning of edible films

Microscopy and scanning electrons were used to measure edible coatings and films made from cassava starch. A SEM schematic overview was used to examine four solutions of cassava starch in different proportions (Sondari et al., 2018).

Physicochemical properties of edible films

Thickness:

Thickness of the films was measured using a digital micrometer (mitutoyodigimatic Indicator Corporation, model; pk-1012 E, Japan). The film strips were placed between the micrometer jaws, and the gaps were slowly reduced until the first contact was noted (Tien et.al. 2000).

Water solubility

The films were cut into square 1 cm × 1 cm pieces and dried to a constant weight in a vacuum oven at 60° C for 24 hours to obtain the initial film dry weight (W_d). Each film was then placed in a bottle containing 20 ml distilled water for 24 hours under gentle agitation and controlled temperature at 25° C. The films were then dried under the same conditions to obtain the dry weight of water leached film (W_{ws}). The film solubility was calculated using the following equation (1):

$$\% \text{ Solubility} = (W_d - W_{ws}) / W_d \times 100 \quad (1)$$

Water vapor permeability (VWP)

The water vapour transmission rate [g/(s.m2)] and water vapour permeability through the edible films were calculated using the ASTM E96-95 technique, (ASTM E, 1993).

Measurement of gas permeability of film

Gas testing instrument, using Instron 34S5 according to (ASTM D 882-18). (O2/CO2) following the method described by (Zahedia., et al., 2017 and García et. al. 2000).

According to the equation (2)

$$P = Q*X/A*t \Delta p \qquad (2)$$

Where;

P: is the permeability of gas, (m3/m. day .mmHg), Q: is the quantity of gas diffused m^3, X: is the thickness of film, A: is the area of the film, m^2, t: is the time, day, ΔP: is the pressure difference across the film.

Determination of mechanical properties

Mechanical properties of the prepared films tensile strength (TS), and elongation at break (EB) were measured by a Brookfield CT3 Texture Analyzer, Brookfield, USA. The films were cut into strips of 3×5 cm and gripped at each end by a jaw, and then the jaws were moved at the controlled speed until the modulus was automatically recorded according to (Hernandez-Mun et al., 2004).

Preparation of muffins

The muffins were prepared using the following formula: 3000 g wheat flour (72% extraction), 1500 g butter, 345 g sugar, 216 ml milk, 345 g whole fresh eggs, 450 g oil, 5.1 g vanilla and 120 g baking powder. The dry ingredients included wheat flour, baking powder and sugar. The wet ingredients were eggs, milk, oil and butter. The egg was beaten for 2 minutes prior to the addition of milk, oil, butter and vanilla. In a separate bowl, all the dry ingredients were thoroughly mixed. Later, both dry and wet ingredients were combined to obtain a mixed muffin batter, and 40.0 ± 0.3 g of batter was placed in paper cups, which were then backed in and baked at 180 °C for 35 min.

Muffin coating:

After baking, muffin were cooled at room temperature, coated muffins were obtained by spraying the film forming solution on. The upper surface of the muffins was coated and dried at room temperature for 1hr. to form coating film on muffin surface, then muffins were packed in foams trays and wrapped using stretch poly- ethylene film then kept at room temperature for six weeks.

The muffins were divided into five treatments as follows: Control: Muffin without coating

A: Muffins was coated solutions A {100% corn starch}

B: Muffins was coated solutions B {100% cassava starch + 0.1% Rosemary essential oil (RO)}

C: Muffins was coated solution C {50% cassava starch+25% chitosan+25% gelatin +0.1% Rosemary Essential oil (RO)}

D: Muffins was coated solution C {25% cassava starch+37.5% chitosan+37.5% gelatin + 0.1% Rosemary Essential oil (RO)}

Chemical analysis of Muffin

Moisture, ash, protein, crude fiber and fat were determined according to (AOAC, 2010). Carbohydrate content was calculated by (James, 1995) as follows:

Energy (kcal) = [Fat × 9 + Protein × 4 + Total carbohydrate × 4]

Peroxide value

As meq/kg fat of the extracted oil from the produced muffin was determined according to the methods described by American oil Chemists' Society (AOCS, 1991).

Physical properties of muffin

Weight loss

Weight loss percentage was estimated according to the method of AOAC (2010). The water activity (aw) of muffins were measured using Rotronic Hygrolab 3 CH-8303, Switzerland as mentioned by (Cadden, 1988)

Textural profile analysis (TPA) of muffin

Texture measurements of uncoated and coated muffin were carried out with Universal Testing Machine, Cometech, B type, Taiwan provided with software according to (Bourne, 2003). The texture measurement of each sample was formed to 50 mm diameter cylinder with 40 mm height. From the resulting forced time curve, firmness (N), cohesiveness, gumminess (N), chewiness (N), springiness and resilience .

Total Microbiological count

Total microbiological counts including total bacterial, yeast and mould were determined in muffins samples at according to the methods of (ISO, 2008) by using plate count agar for total bacterial colonies, Moulds and yeast were determined by using mould & yeast agar. All the microbiological counts were carried out in duplicates. The total colonies of bacteria were estimated.

Sensory evaluation

Muffins were assessed for their sensory attributes after coating according to (Chen, et al, 1999). Twenty trained panelists from the staff of the Food Technology Research Institute, Agricultural Research Center. The panelists were asked for their decision concerning, color, odor, taste, texture (hardness and softness) and overall acceptability, maximum score is 20 for each sample.

Statistical analysis

Data were expressed as the means ± SD. Statistical analysis was carried out using one – way analyses of variance, ANOVA (Raovand Blane, 1985).

3. Results and Discussion

Rheological properties of coating solutions:

The flow property of coating solutions is useful technologically to identify the most appropriate coating system design as well as to optimize operating conditions. The flow curves (shear rate versus shear stress)

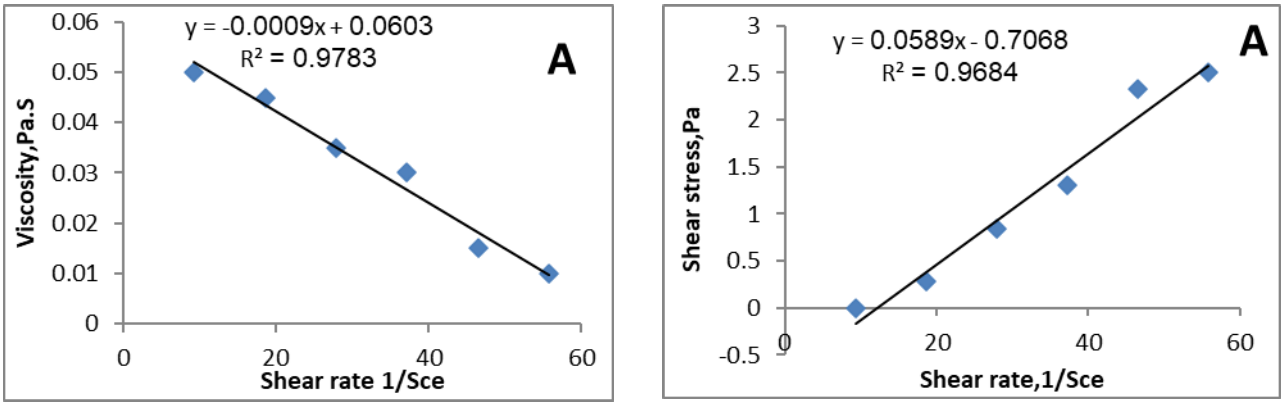

Figure 1. Flow behavior and Shear rate/viscosity relation of coating solution A

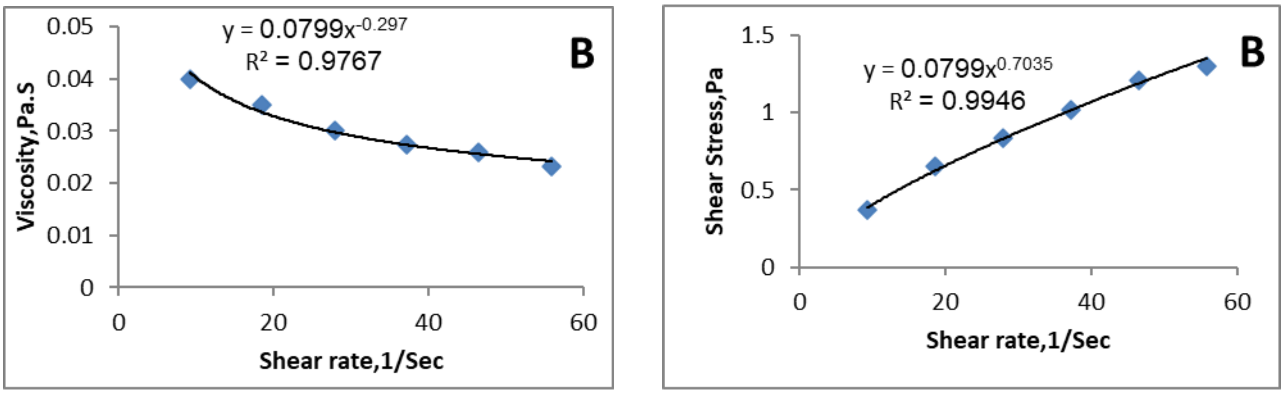

Figure 2. Flow behavior and Shear rate/viscosity relation of coating solution B

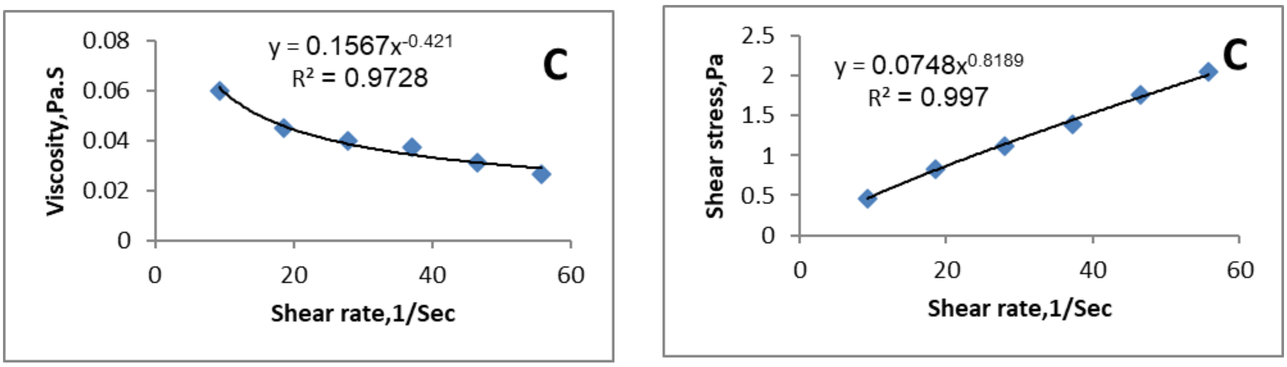

Figure 3. Shear rate/viscosity relation of coating solution C

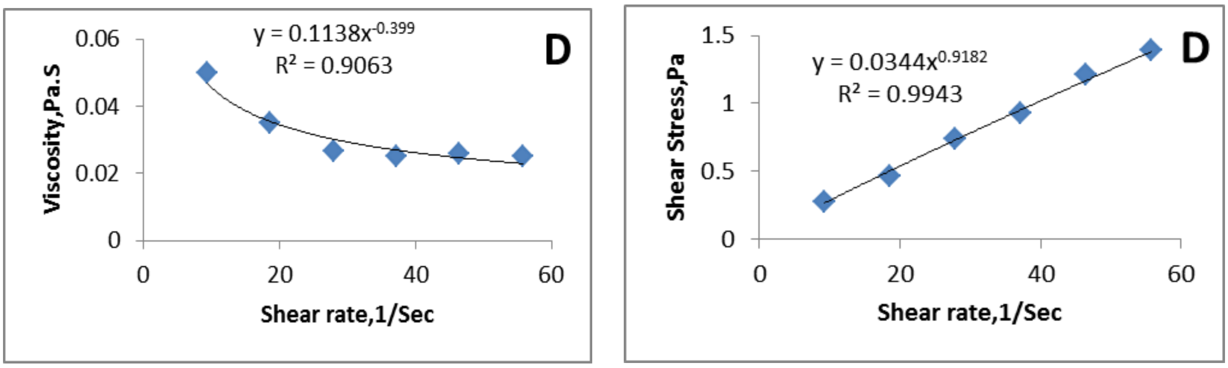

Figure 4. Shear rate/viscosity relation for coating solution D

Figures 1, 2, 3, and 4 show the flow behavior of coating solutions, The results showed that the forming solution exhibits a trend of non-Newtonian pseudoplastic behavior at different treatments from the edible coating solution (A, B, C, and D), as previously reported for chitosan/starch blends (Abdou et al., 2009). The shear stress-shear rate properties of coating solutions obey the following power law relationship (3):

$$\tau = k\gamma^{n} \qquad (3)$$

where, τ: is the shear stress (Pa), k: is the consistency index, γ: is the shear rate (sec^{-1}) and n: is the flow behavior index, and that showed the shear stress was increasing by increasing the shear rate at different edible coating solutions (A, B ,C, and D) from Table 1. On the other hand, it was observed that the relation between viscosity and shear rate decrease with different (A, B, C, and D). It can be observed that apparent viscosity decreases by increasing shear rate, as noted that the shear rate increases with increasing shear stress (Phuapradit et al., 2002 and Ding et al., 2005). The results indicated that as the shear rate increased, apparent viscosity decreased. K (consistency index) decreased as the concentration of edible film from cassava starch solutions increased (A, B, C, and D). The relation between viscosity and shear rate was fitted to the following equation these results agree with the study of (Lin et al., 2003):

$$\mu = K\gamma^{n-1} \qquad (4)$$

Where, μ: apparent viscosity (Pa.s), shear rate (s^{-1}), k: is the consistency index and n: is the flow behavior index.

Scanning electron microscopy (SEM)

There are four microscopic images of starch and cassava starch edible coatings, and the films used in this experiment were: edible coating solution from Table 1. (A, B, C and D) to produce edible film. After taking the cross-section, the morphology of the surface was investigated using SEM images Figure 5., and the surface roughness was predicted using cassava starch edible films in treatment. The SEM images showed that the cassava starch edible films were granules and crystals of starch and smooth without any noticeable delamination on the surface, which was found to rise with increasing the concentration upon different treatments. In Figure 5., prepared edible coatings and films are combined with film with cassava starch treatments:

- 100% cassava starch + 0.1% Ro (B),
- film with 50% cassava starch + 25% chitosan + 25% gelatin + 0.1% Ro (C),
- and film with 25% cassava starch + 37.5% chitosan + 37.5% gelatin + 1% Ro (D).

It was found that the % film corn starch control (A), a 0% treatment, has cracks in the edible film due to poor treatment that does not contain cassava starch, chitosan, or gelatin.

Treatment C was homogeneous with bubble drops compared to a spherical morphological droplet. In general, the edible film consists of a homogeneous solution with some compact, fine grains and intact, smooth crystal morphology in a continuous matrix. It can be concluded that these studies are useful for learning about the microstructure and membrane morphology, which can help in selecting the edible film formulas for coating and packing. Our results agree with those obtained by (Maria-Ioana Socaciu et al., 2000).

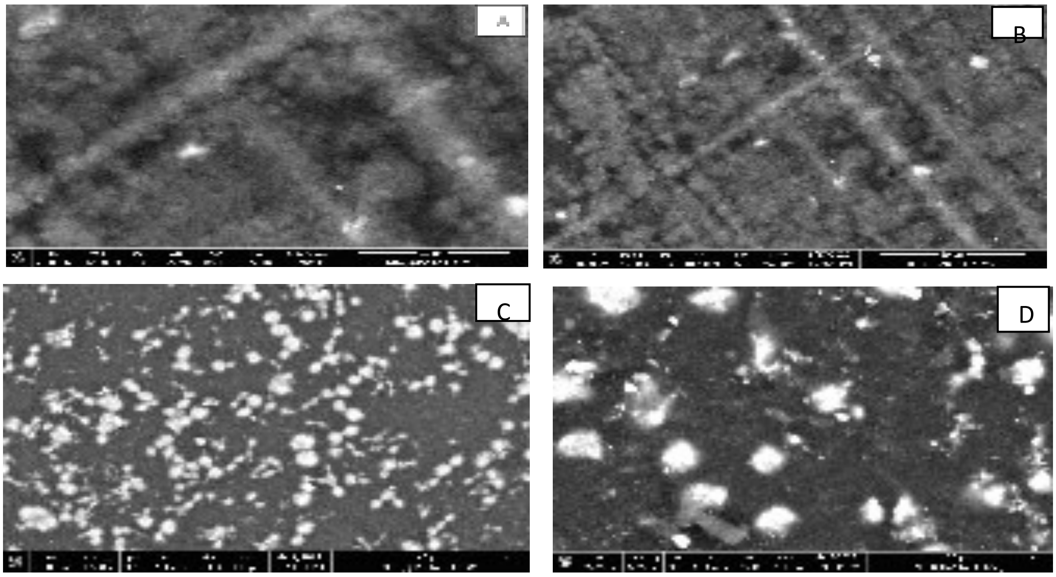

Figure 5. Microstructure of prepared films from cassava starch combined with gelatin and chitosan to produce edible films using scanning electron microscopy (SEM) to treatment A, B, C and D.

Physicochemical, permeability and Mechanical properties of the films:

The tensile strength and elongation of different edible coating films are shown in Table 2. The effect of cassava starch and gelatin on the tensile strength is shown, where it can be seen that tensile strength decreases by increasing cassava starch in the film solutions. However, the increasing tensile strength values of the blended films are attributable to the formation of intermolecular hydrogen bonds between the NH4+ of the chitosan and the OH- of the cassava starch (Xu et al., 2005). There was a negative engagement between polymer chains and tensile strength. Regarding the elongation at the breaking point, lower concentrations of starch have increased elongation values (formula C and D). The high elongation of the film is always a desirable characteristic for use in food applications. (Roy and Rhim, 2021) The addition of cassava starch at a medium rate improved its permeability to gases and water vapor (formula C) (Zhong and Xia, 2008).

Table 2. Physicochemical, permeability and Mechanical properties edible coating films

Edible Coating solution	Thickness µm	Tensile strength (N/M^2)	Elongation (%)	Oxygen (O2) Permeability m^3.m/m^2× $^{7-}$10 day.mmHg	CO2 Permeability m^3.m/m^2 ×$^{8-}$10 day.mmHg	Water vapors Permeability [g/m^2.24hr]	% Solubility loss in weight after dipping in water and drying
A	0.204	0.845	4.250	19.72	15.16	1.438	52 %
B	0.218	2.047	16.25	5.141	9.528	1.402	46.17 %
C	0.278	3.2087	23.25	2.825	2.62	1.036	47.86%
D	0.225	2.369	48.50	4.004	5.54	1.121	50.02 %

Chemical analysis of muffin:

Chemical composition of muffin is shown in Table 3., it could be noticed that the muffin had contained 21.23, 13.92, 18.11, 0.66, 1.36 and 49.7 %, respectively of moisture, crude protein, fat, ash, crude fibers and carbohydrates, with a mean energy value 417.47 k cal (on dry weight). These results agree with (Rahman et.al., 2015).

Table 3. Chemical composition of muffin calculated on (%D W) at zero time

Sample	Moisture %	Protein %	Fat content %	Ash %	Crude fiber %	Carbohydrate %	Energy (KCA)
Muffin	21.23	13.92	18.11	0.66	1.36	49.7	417.47

Changes in Peroxide value of muffin during storage period

Table 4. shows the effect of edible coating films on the peroxide value of all muffin treatments during the storage period from zero time up to 6 weeks at room temperature (25± 2 °C). It must be noticed that the peroxide value was 0.60 mg/kg of fat at zero time for all muffin treatments. An increase was observed in the peroxide value in all muffin treatments with an increased storage period, especially in the control treatment, followed by treatment (A) 100% corn starch film, followed by treatment (B) 100% cassava starch + 0.1% Ro. as the maximum peroxide reached 13.21 meq kg fat at the 4th week and 12.36 meq kg fat and 10.87 meq kg fat at the 5th week for the three treatments, respectively. While treatments C (50% cassava starch + 25% chitosan + 25% gelatin) and D (25% cassava starch + 37.5% chitosan + 37.5% gelatin) extended the shelf life of muffins, it may be due to chitosan and gelatin improvement of gas barrier properties and low permeability of gas, which reduces lipid oxidation. These results agree with Zhong and Xia (2008), who reported that chitosan and gelatin improved the gas barrier properties of the blended films with cassava starch.

Table 4. Effect of edible coating solution on the peroxide value (meq/kg fat) of muffin during storage period (6 weeks at 25± 2 °C)

Storage Period Treatment	Zero time	One Week	Tow Week	Three Week	Four Week	Five Week	Six Week
Control	0.60	1.24	4.06	8.68	13.21**	---	---
A	0.60	1.17	2.54	5.72	9.91	12.36**	---
B	0.60	1.08	1.76	4.84	8.25	10.87**	---
C	0.60	0.75	0.96	1.06	3.42	4.79	5.41
D	0.60	0.92	1.27	3.73	5.11	7.85	8.67

(---) reject samples ** Rancid reject sample

Physical properties of muffin

Changes in weight loss (%) of muffin during storage period

The effect of the edible coating solution on the weight loss (%) of muffins is shown in Table 5. The data showed that weight loss increased as the storage period increased for all tested muffins (coated and uncoated), whereas results showed lower weight loss for coated samples, dependent on coating type, compared to the control. Chitosan percent in coating solutions (treatments C and D) causes a decrease in weight loss percent compared with treatments A and B. This can be attributed to the fact that the addition of chitosan to starch in coating solutions increases the barrier properties of the coating film formed on the muffin surface. (Xu et al., 2005)

Table 5. Effect of edible coating solution on weight loss (%) of muffin during storage period (6 weeks at 25± 2 °C)

Storage Period Treatment	One Week	Two Weeks	Three Weeks	Four Weeks	Five Weeks	Six Weeks
Control	2.87	4.65	5.82	6.54	7.28	7.89
A	2.31	4.11	5.24	5.92	7.21	7.63
B	1.51	2.73	3.22	5.36	5.81	6.12
C	0.06	0.25	0.46	0.51	1.62	2.68
D	0.37	0.96	1.55	2.14	2.81	3.22

Changes in water activity (a_w) of muffin during storage period

The a_w is an important reference for the shelf life of foods, as it strongly affects the growth of microorganisms. Water activity plays an important role in the safety, quality, processing, shelf life, texture and sensory properties of confections. The water activity values of muffins are illustrated in Table 6. The results indicated that a_w ranged from 0.765 to 0.319 for all samples. It could be observed that there was a decrease in a_w level during the storage period; this could be due to microbiological activity during the storage, and it was observed that water activity was high with treatments (C and D). This result may be due to low water vapor permeability (Chochkov et al., 2018). The water activity decreased rapidly in the uncoated sample (control), with an increase in the storage period of from 0.765 at zero time to 0.328 at three weeks, compared to the coated muffin samples in treatments A,B, C and D (Prastuty et al., 2021).

Table 6. Effect of edible coating solution on water activity (a_w) of muffin during storage period (6 weeks at 25± 2 °C)

Storage Period / Treatment	Zero time	One week	Two weeks	Three weeks	Four weeks	Five weeks	Six weeks
Control	0.765	0.525	0.328	---	---	---	---
A	0.765	0.582	0.486	0.427	0.389	0.319	---
B	0.765	0.585	0.491	0.459	0.432	0.383	---
C	0.765	0.678	0.671	0.662	0.624	0.589	0.523
D	0.765	0.675	0.669	0.656	0.586	0.537	0.508

(---) spoiled reject sample

Microbial analysis

The effects of edible coating solutions on total bacteria, yeast and mold are shown in Table 7. These results illustrated that the lowest amount of total bacteria, yeast and mold was noticed in coated muffins by using edible coating solutions A,B, C and D. Compared to the control, which was excluded after two weeks of storage a result of its spoilage because it is uncoated with solutions and is more exposed to atmospheric air directly, which allows easy microbial growth and deterioration of its quality, unlike samples of muffins covered with solutions, which were acceptable and with a high quality until the end of the storage period as a result of the formation of a film from the edible solutions on the surface, which was an insulating layer for the muffin from the atmospheric air, which reduced the microbial growth, especially with treatment C (50%cassava starch +25% chitosan +25% gelatin +0.1% Ro) and D (25% cassava starch + 37.5% chitosan + 37.5 % gelatin + 0.1% Ro) as a result of adding chitosan and gelatin to cassava starch, which improved the mechanical properties and reduced the permeability of gases and water vapor and extended the shelf life of the muffin. general, It was observed that all coated muffin treatments (Solutions A, B, C and D) significantly reduced microbial growth compared to the control as a result of adding rosemary essential oil to the treatments Table 1., as it has an antimicrobial effect. This result is in agreement with (Walid et al. 2022), who reported that rosemary ethanol extract was mainly characterized by the predominance of carnosic acid (58.71 mg/g) and rosmarinic acid (16.51 mg/g). The antibacterial activity of rosemary essential oil and ethanol extract was determined against *Escherichia coli*, *Staphylococcus aureus, and Pseudomonas.*

Table 7. Effect of edible coating solutions on Total Bacterial and Yeast, Mold (10^2 cfu / gm) of muffin during storage period (6 weeks at 25± 2 °C)

Storage Period / Treatment	Zero time		One Week		Two Weeks		Three Weeks		Four Weeks		Five Week		Six Week	
	T.C	Y& M	T.C	Y& M	T.C	Y& M	T.C	Y& M	T.C	Y& M	T.C	Y& M	T.C	Y& M
Control	1	ND	40	3	120	8	-	-	-	-	-	-	-	-
A	1	ND	25	2	70	6	135	12	-	-	-	-	-	-
B	1	ND	13	2	37	4	73	8	140	13	-	-	-	-
C	1	ND	2	ND	2	1	5	2	8	4	12	5	16	6
D	1	ND	1	ND	3	ND	4	2	8	3	12	4	15	6

Textural profile analysis (TPA) of muffin sample

Figure 6. shows the effect of edible coating solutions on the texture profile analysis (TPA) of muffins. Whereas texture measurements can be very valuable for quality control and process optimization as well as for the development of products with desirable properties (Balestra, 2009) From these data, it could be observed that hardness increased continuously in all muffin treatments when the storage period was prolonged, especially in control, followed by treatments of (A) 100% corn starch and (B) 100% cassava starch compared to other treatments. Where hardness values increased gradually from 17.95 N at zero time up to 41.50, 26.33 and 23.35 N after two weeks of storage in control and treatments A and B, respectively, On the other hand, muffin samples coated with treatments C (50% cassava starch + 25% chitosan + 25% gelatin + 0.1% Ro) and D (25% cassava starch + 37.5% chitosan + 37.5% gelatin + 0.1% Ro) showed low hardness values compared to the samples uncoated (control). The lowest decrease in hardness of the muffins was due to the high barrier of coating solutions or low permeability (C and D treatments). Similar results were obtained by (Hematian et al. 2010). The texture profile analysis (TPA) results showed an increase in gumminess and chewiness in the control sample (uncoated) compared to the coated muffin samples. Our present findings are in accordance with (Hematian et al., 2010), who stated that both gumminess and chewiness are parameters dependent on hardness; therefore, their values followed a similar trend to that of hardness. From the texture profile analysis (TPA), it could be noticed from the results of muffin samples that there were erratic changes in all springiness texture attributes. Briefly, cohesiveness is the ability of a material to stick to itself (Go´mez et al., 2007 and Martin et al., 1991) suggested that bread firming might be a result of starch-gluten interactions, where gluten is cross-linked by gelatinized starch. The TPA results showed a decrease in cohesiveness between control and treatments (A and B) of muffin samples compared to treatments C and D, which may be due to the diffusion of rosemary essential oil into the muffin. These results agree with (Pratuty et al., 2021), who reported that the slow diffusion of essential oils present in the coating into the muffin network to recapture softness is the prime reason behind the observed softness in the muffins during storage. Springiness measures elasticity by determining the extent of recovery between the first and second compressions. Resilience is the ratio of recoverable energy as the first compression is relieved (Lu et al., 2010). TPA results showed a decrease in the springiness of control (uncoated) muffin samples, which reached 3.72 after two weeks of storage. Muffin resilience reflects a different fluctuating trend compared to springiness. Overall, hardness, gumminess, and chewiness increased, whereas cohesiveness and springiness decreased in uncoated muffin samples compared to coated samples. (Ndinchout et al., 2022) In general, coated samples are the best at extending the shelf life and protecting Rheological properties of muffins during storage compared with uncoated samples.

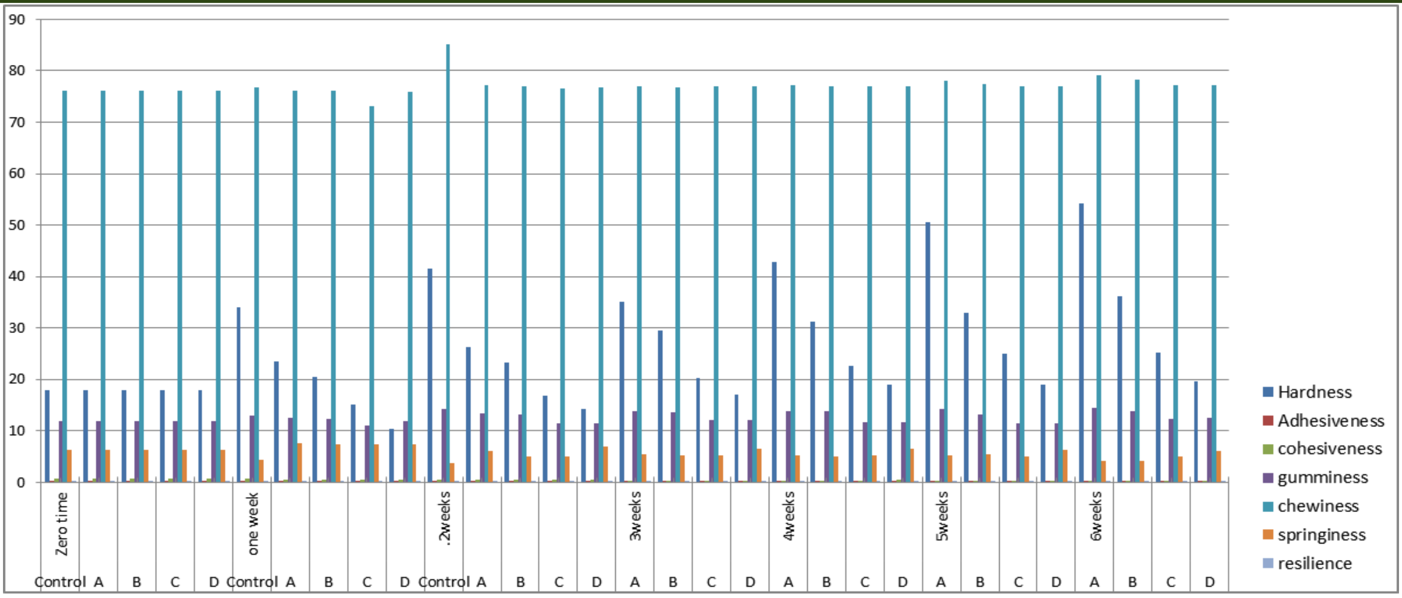

Figure 6. Effect of edible coating solutions on textural profile analysis (TPA) of muffin samples during storage period (6 weeks at 25± 2 °C)

Sensory evaluation of all coated and uncoated muffin treatments during storage

Table 8. shows the effect of the edible coating solution on the sensory evaluation of all muffin treatments during the storage period (zero time up to 6 weeks at room temperature (25± 2 °C). At zero time, no significant differences (p > 0.05) were observed among all treatments regarding taste, color, texture and overall acceptableness. After two weeks of storage, a significant decrease was observed in the control treatment, which recorded the lowest score in taste and texture. Increased muffin hardness caused unacceptable taste by trained panelists (not rancid taste). After four weeks, we noticed significant differences (p > 0.05) between samples, as treatment A (100% corn starch) obtained the lowest sensory attribute score, followed by the muffin coated with treatment B (100% cassava starch + 0.1% Ro). It was noted that the taste and flavor found good acceptance by the consumer throughout the storage period, especially in treatments C and D, as a result of adding the essential oil of rosemary to the edible coating solutions, which gave a distinctive taste and flavor to the muffin and improved its texture and smoothness (Walid et al., 2022). At the end of the storage period (6 weeks), treatments with C (50% cassava starch + 25% chitosan + 25% gelatin + 0.1% Ro) were superior in all sensory attributes score and high acceptability, followed by treatment D (25% cassava starch + 37.5% chitosan + 37.5% gelatin + 0.1% Ro). This may be due to coating solutions containing chitosan increasing the barrier properties of the coating film formed on the muffin surface, which delayed the deterioration (Xu et al., 2005). (Polovnikova et al., 2022) reported that high-calorie baked products have a typical porous structure and high volume, which confer a spongy texture. These products are highly valued by consumers due to their texture and good taste. The sensory results from a consumer evaluation indicate that both samples (coated) were characterized by texture and sensory characteristics accepted.

4. Conclusion

The objective of this study was to prepare edible coating solutions from cassava starch, studying flow behavior, which was found to be pseudoplastic and improving the permeability of gases and the physical and mechanical properties of edible films. Chitosan, cassava starch, and gelatin edible coatings successfully extended the shelf life of muffin samples coated with treatments (50% cassava starch + 25% chitosan + 25% gelatin) and (25% cassava starch + 37.5% chitosan + 37.5% gelatin), extending the shelf life to 6 weeks. Also, coating samples with chitosan, cassava starch, or gelatin solutions decreases the weight loss percent and peroxide value of coated samples compared with uncoated samples. The results of the present research also showed that edible coatings based on antimicrobial materials like rosemary essential oil and chitosan effectively inhibited microbial growth, enhanced quality and general appearance, and improved the sensory evaluation of muffins.

Table 8. The effect of edible coating solution on sensory evaluation of muffin treatments during storage period from (zero time up 6weeks) at room temperature (25± 2 °C)

Treatments		Taste	Oder	Texture	Color	Overall acceptable
Control		20.0 ± 0. 12^{a}	19.75 ± .45^{a}	19.84 ± 0.31^{a}	20.0 ± 0.12^{a}	19.89 ± 0.13^{a}
A	Zero time	18.65 ± 1.17^{a}	19.12 ± 0.74^{a}	18.79 ± 1.16^{a}	19.32 ± 0.98^{a}	18.83 ± 1.18^{a}
B		19.16 ± 0.12^{a}	18.81 ± 1.12^{a}	18.73 ± 1.12^{a}	19.45 ± 0.79^{a}	19.01 ± 0.82$_{a}$
C		19.92 ± 0.14^{a}	19.88 ± 0.91^{a}	19.61 ± 0.34^{a}	19.95 ± 0.27^{a}	19.87 ± 0.13^{a}
D		19.25 ± 0.43^{a}	18.74 ± 0.93^{a}	18.85 ± 1.12^{a}	19.71 ± 0.39^{a}	19.34 ± 0.69^{a}
L.S.D		1.07	0.962	1.16	1.02	1.081
Control		13.47 ± 0.94^{C}	15.65 ±1.15^{b}	13.91± 0.96^{C}	17.85± 1.85^{a}	14.64 ± 0.94^{C}
A	One week	15.62 ± 1.43^{b}	18.21 ± 1.69^{a}	15.71 ± 2.64^{b}	18.24 ± 1.98^{a}	16.12 ± 1.61^{b}
B		17.82 ± 1.39^{ab}	18.64 ±1.27^{a}	16.84 ± 2.16^{ab}	19.13 ± 1.26^{a}	17.95 ± 1.03^{ab}
C		19.72 ± 0.82^{a}	18.63.± 1.24^{a}	18.17 ± 1.37^{a}	19.74 ± 0.93^{a}	19.21 ± 0.95^{a}
D		19.93 ± 1.59^{a}	19.19 ± 1.05^{a}	19.11 ± 1.48^{ab}	19.35 ± 1.36^{a}	19.23 ± 1.66^{a}
L.S.D		0.793	1.14	0.745	0.87	1.018
Control		9.59 ± 2.32^{e}	13.27 ± 2.04^{C}	9.43 ± 2.17^{e}	15.23 ± 3.32^{C}	10.32 ± 1.65^{d}
A	2 weeks	14.71 ± 2.15^{bc}	16.46 ±1.23^{bc}	13.96 ± 1.85^{bc}	17.98 ± 1.35^{ab}	15.78 ± 1.75^{bc}
B		17.26 ± 1.16^{ab}	18.21 ±1.72^{ab}	16.81 ± 1.85^{ab}	18.94± 1.02^{a}	17.56 ± 1.67^{ab}
C		19.27 ± 1.04^{a}	19.42 ± 0.93^{a}	17.36 ± 1.54^{ab}	19.26± 0.36^{a}	19.34 ± 0.96^{a}
D		19.21 ± 1.13^{a}	19.61 ± 1.05^{a}	18.01± 1.64^{ab}	19.63 ± 0.52^{a}	19.91 ± 1.41^{a}
L.S.D		0.614	1.472	1.137	1.264	0.897
A		13.86 ± 1.22^{C}	16.15 ±1.41^{bc}	13.12 ± 1.16^{bC}	17.28±1.25ab	15.02 ± 1.39^{bc}
B	3 weeks	17.±14 1.27^{ab}	16.22 ± 1.32^{b}	15.91 ± 1.22^{b}	18.14 ± 1.61b	16.42 ± 1.26^{b}
C		18.92 ± 0.96^{a}	18.75 ± 1.18^{a}	17.13 ±1.58^{ab}	19.03 ± 1.12^{a}	18.99 ± 1.05^{a}
D		18.15 ± 1.38^{a}	18.05 ± 1.36^{a}	17.85 ± 1.67^{ab}	19.15 ± 1.85^{a}	18.71 ± 1.13^{a}
L.S.D		1.27	2.68	1.87	0.95	1.871
A		11.62 ± 1.53c	14.25 ± 1.65c	10.41± 1.26d	15.87± 1.62b	13.84 ± 1.56^{bc}
B	4 weeks	16.12 ± 0.68^{b}	15.73 ± 1.45^{b}	13.83 ± 1.41^{bc}	17.94 ± 1.51^{a}	16.02 ± 1.18^{b}
C		18.37 ± 1.37^{a}	17.34 ± 1.32^{a}	16.3 ± 1.21^{ab}	18.53 ± 1.42^{a}	18.35 ± 1.36^{a}
D		18.55 ± 0.98^{a}	18.12 ± 0.24^{a}	16.26 ± 1.32^{b}	18.34 ± 0.89^{a}	18.42 ± 1.02^{a}
L.S.D		1.082	0.645	1.113	1.06	1.078
A		10.83 ± 1.13^{cd}	12.81 ±1.59^{c}	9.71 ± 2.14^{d}	13.24 ± 1 .96^{c}	11.62 ± 1.81^{cd}
B	5 weeks	14.21 ± 1.29^{c}	12.14 ±1.57^{c}	10.31 ± 2.46^{d}	14.33 ± 1.16^{c}	13.45 ± 1.01^{c}
C		17.34 ± 1.82^{a}	17.11.±1.64^{a}	15.95 ± 1.71^{b}	18.14 ± 0.96^{a}	17.93 ± 0.95^{a}
D		17.92 ± 1.79^{ab}	18.49 ±1.15^{ab}	17.01 ± 1.28^{b}	18.25 .± 1.06^{a}	18.43 ± 1.16^{ab}
L.S.D		0.568	1.187	0.672	0.843	1.019
A		9.71 ± 2.15^{e}	11.28 ± 1.43^{c}	9.66 ± 1.95^{e}	11.63 ± 1.25^{d}	10.18 ± 1.75^{e}
B	6 weeks	11.16 ± 1.12^{cd}	10.11 ± 1.12^{d}	9.78 ± 1.75^{d}	12.44 ± 1.26^{c}	11.26 ± 1.07^{d}
C		16.87 ± 1.34^{b}	17.02 ± 1.03^{a}	15.26 ± 1.84^{b}	17.96 ± 0.65^{a}	17.54 ± 0.96^{a}
D		17.26 ± 1.13^{b}	17.94 ±1.22^{ab}	16.57 ± 1.72^{c}	17.54 ±1.23^{ab}	17.92 ± 1.35^{ab}
L.S.D		1.415	1.654	1.613	2.519	1.624

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