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Effect of antioxidant-enriched microcrystalline cellulose from almond residue on physicochemical and textural characteristics of mayonnaise

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SUMMARY: The purpose of this study was to investigate whether antioxidant-enriched microcrystalline cellulose from almond residue (AE-MCC-AS) affects the physicochemical and textural characteristics of mayonnaise during 56 days of storage at 25 °C. The L^* value of the mayonnaise decreased by increasing the AE-MCC-AS ratio; whereas the redness and yellowness values increased. The emulsion stability and viscosity increased by increasing the AE-MCC-AS ratio from 0.2% to 0.4%; however, they decreased with an increase in the AE-MCC-AS ratio from 0.4% to 0.6%. The largest oil droplets were observed in the micrographs of the control, 0.2% AE-MCC-AS-M and 0.6% AE-MCC-AS-M; while the smallest ones were observed in the micrographs of α-tocopherol-M, BHT-M and 0.4% AE-MCC-AS-M. During the storage period, the total MUFA and PUFA showed a declining trend in all treatments with a higher decrease in the control; while total SFA showed an upward trend with a higher increase in the control. In terms of textural characteristics, a significant declining trend ($P < 0.01$) was observed in firmness and consistency; whereas an upward trend was observed in cohesiveness during the storage in all treatments.

KEYWORDS: *Color; Mayonnaise; Microstructure; Textural characteristics; Viscosity*

RESUMEN: ***Efecto de la celulosa microcristalina enriquecida en antioxidantes de residuos de almendras sobre las características fisicoquímicas y texturales de mayonesas.*** El propósito de este estudio fue investigar si la celulosa microcristalina enriquecida con antioxidantes del residuo de almendras (CM-EA-RA) afecta a las características fisicoquímicas y texturales de la mayonesa durante 56 días de almacenamiento a 25 °C. El valor L^* de la mayonesa disminuyó al aumentar la relación CM-EA-RA, mientras que los valores de rojo y amarillo aumentaron. La estabilidad y la viscosidad de la emulsión aumentaron al aumentar la relación CM-EA-RA de 0,2 % a 0,4 %; sin embargo, disminuyeron al aumentar la relación CM-EA-RA de 0,4 % a 0,6 %. Las gotas de aceite más grandes se observaron en las micrografías del control, 0,2 % CM-EA-RA-M y 0,6 % CM-EA-RA-M, mientras que las más pequeñas se observaron en las micrografías de α-tocoferol-M, BHT-M y 0,4 % CM-EA-RA-M. Durante el almacenamiento, los MUFA y PUFA totales mostraron una tendencia decreciente en todos los tratamientos con una mayor disminución en el control, mientras que los SFA totales mostraron una tendencia ascendente con un mayor aumento en el control. En cuanto a las características texturales, se observó una tendencia significativamente decreciente ($P<0.01$) en la firmeza y consistencia, mientras que se observó una tendencia ascendente en la cohesividad durante el almacenamiento en todos los tratamientos.

PALABRAS CLAVE: *Características texturales; Color; Mayonesa; Microestructura; Viscosidad.*

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1. INTRODUCTION

Mayonnaise is a semi-solid sauce which is well-known all over the world. It is presumed that the origin of mayonnaise is based in Port Mahon, Spain, in 1756. Commercial mayonnaise was first produced in the early 1900s, and since then it has gradually gained popularity in America, Japan and other nations (Mirzanajafi-Zanjani *et al.,* 2019). Mayonnaise is an oil-in-water (O/W) emulsion which generally consists of oil, egg yolk, salt, vinegar, and flavoring materials. The emulsion is formed by slowly blending oil into the water phase which contains egg yolk, salt, and other ingredients. The oil content varies from 65 to 80% in the full-fat mayonnaise formula, and sunflower, corn and/or soybean oil are chosen generally for mayonnaise production. The fatty acid composition of these vegetable oils consists of mostly polyunsaturated fatty acids (PUFA), which increases the possibility of lipid oxidation and reduces the shelf-life of mayonnaise (Gorji *et al.,* 2019).

To inhibit or retard oil oxidation in food emulsions, synthetic antioxidants such as butylated hydroxytoluene (BHT), butylated hydroxyanisole (BHA), tertiary butyl hydroquinone (TBHQ) and propyl-gallate are widely used in the food industry. The low cost, chemical stability and availability of synthetic antioxidants are the main reasons for this preference. However, the toxicity suspicion of the synthetic antioxidants and the consumer demand for natural food ingredients have directed both the industry and researchers to find natural antioxidant sources. Much research has been focused on the use of natural antioxidants extracted from different plants such as fruit, vegetables and their wastes for inhibiting or retarding oil oxidation in mayonnaise (Mihov *et al.,* 2012; Altunkaya *et al.,* 2013; Li *et al.,* 2014; Chatterjee and Bhattacharjee, 2015; Shabbir *et al.,* 2015). However, natural antioxidants also have some disadvantages compared to synthetic antioxidants. Natural antioxidants should be added to food formulas in larger amounts to provide the same oxidative stability as synthetic antioxidants since they are less effective compared to synthetic analogues (Pokorný, 2007). There is no restriction or safety limits of natural antioxidants; however, it should be considered that natural antioxidants may pose a nutritional and health risk as a result of their interactions with proteins when consumed in large quantities (Pokorný, 2007). The long-term stability of natural antioxidants is limited because they are sensitive to temperature, light and oxygen. To reduce the effect of these environmental conditions, we proposed the binding method of phenolic extract to microcrystalline cellulose (MCC) in our previous study (Ünver and Çelik, 2021). We obtained a natural food additive that exhibited good thermal stability, crystallinity, antioxidant, and flow characteristics by means of this method. Besides, AE-MCC-AS at the concentration of 0.6% showed better activity in preventing oil oxidation in mayonnaise than BHT and α-tocopherol.

MCC, listed as GRAS by the FDA, is a white, odorless, renewable, and biodegradable powder. In emulsions, MCC has the ability to form a viscoelastic network which entraps oil droplets (Meirelles *et al.,* 2020). This viscoelastic network can reduce the rate of lipid oxidation in the emulsion by slowing down the mobility of pro-oxidants (Kargar *et al.,* 2012). Most of the studies related to mayonnaise which contained natural antioxidants have focused on their antioxidant effect, the detection and observation of hydroperoxides and their degradation products such as aldehydes, ketones, and volatile compounds (Vahidyan *et al.,* 2012; Altunkaya *et al.,* 2013; Li *et al.,* 2014; Hermund *et al.,* 2015; Alizadeh *et al.,* 2019; Gorji *et al.,* 2019). Few studies have focused on the effect of natural antioxidants on the physicochemical and textural characteristics of mayonnaise (Chatterjee and Bhattacharjee, 2015; Shabbir *et al.,* 2015; Raikos *et al.,* 2016).

The possible interactions between mayonnaise ingredients and antioxidants can also affect the texture, color, rheological and emulsion characteristics, which are important factors for sensory perception and consumer satisfaction. The knowledge about the interactions and effect mechanism is still insufficient due to the complexity of these interactions. Therefore, the purpose of this study was to investigate whether AE-MCC-AS affects the physicochemical and textural characteristics of mayonnaise during 56 days of storage at 25 °C. The investigated parameters of the mayonnaises that contained AE-MCC-AS at three different ratios (0.2, 0.4 and 0.6%) were compared to the negative control (without antioxidant) and two different positive controls (mayonnaise containing 0.02% BHT; mayonnaise containing 0.02% α-tocopherol).

2. MATERIAL AND METHODS

2.1. Material

Almond shell (AS) and almond hull (AH) were supplied from local farmers in Şanlıurfa, Turkey for the production of AE-MCC-AS. Sunflower oil, vinegar, sugar and salt were supplied from a local market in Şanlıurfa for the production of mayonnaise. The egg yolk was supplied from Alfasol® (Gaziantep-Turkey). BHT, α-tocopherol, and FFA standards were obtained from Sigma-Aldrich (St Louis, MO, USA).

2.2. Production of AE-MCC-AS

The production of AE-MCC-AS was carried out according to the method suggested by (Ünver and Çelik, 2021). In brief, the phenolic extract obtained from the almond hull (PE-AH) with ultrasonic-assisted extraction was bound to microcrystalline cellulose obtained from the almond shell (MCC-AS) with acid hydrolysis in a rotary evaporator flask under vacuum at 40 °C. Afterwards, the obtained AE-MCC-AS was dried in an air oven at 40 °C until constant weight.

Green almond hull was extracted with 90% ethanol in an ultrasonic bath to obtain PE-AH. The extraction parameters were as follows: extraction time, 60 min; extraction temperature, 65 °C; and solvent-sample ratio, 50:1, at a frequency of 40 kHz, 100% full power. At the end of the extraction time, PE-AH was separated from the residue by centrifugation at 4000 rpm for 5 min. The extraction procedure was repeated, and the supernatants were combined (Ünver and Çelik, 2021).

2.3. Production of mayonnaise

All mayonnaise samples were formulated from the following ingredients in the percentage (w/w): sunflower oil (65%), egg yolk powder (4%), water (17%), vinegar (8%), sugar (5%) and salt (1%) with a mixer (Tefal Mastermix, İstanbul, Turkey). BHT, α-tocopherol and AE-MCC-AS were used in different samples according to the experimental design shown in Table 1. The mayonnaise was filled into glass jars (80 mL) and stored at 25 °C in the dark for 56 days. The productions were carried out in duplicate.

Table 1. Experimental design of mayonnaise production

Antioxidant	Concentration (%)	Sample code
AE-MCC-AS	0.2	0.2% AE-MCC-AS-M
	0.4	0.4% AE-MCC-AS-M
	0.6	0.6% AE-MCC-AS-M
BHT	0.02	BHT-M
α-tocopherol	0.02	α-tocopherol-M
-	-	Control

2.4. Some physicochemical characteristics of mayonnaise samples

The pH value of mayonnaise samples was measured using a laboratory pH meter (Model HQ40d, Hach Company) at a temperature of 20±0.5 °C (Khalil and Mansour, 1998).

The color values for the mayonnaise samples were measured using a Hunterlab Color Quest Instrument (Hunter Associates Laboratory, Inc., Reston, VA 22090, USA). The instrument calculates the results according to the CIE Lab color space coordinates, as L^*, a^* and b^* values. L^* stands for the axis of lightness, a^* and b^* represent two scales of opponent color pairs (i.e., (-) greenness/ (+) redness–and (-) blueness/ (+) yellowness, respectively).

The viscosity of mayonnaise was measured at 25 °C using a Viscometer (Brookfield DV-II +, USA) with a spindle (No. 5) rotation of 50 rpm. The readings were recorded at the 10th second of the measurement.

The fatty acid composition of the samples was determined in the oil phase of the mayonnaise according to the procedure of ISO 12966–2:2011. Separation of the oil phase from the mayonnaise was performed in freezing-thawing cycles. The samples were subdivided into polypropylene centrifuge tubes (50 mL), and they were frozen at -24 °C for 24 h to break the emulsion. Afterwards, the samples were thawed at 25 °C for 2 h, and they were centrifuged at 10000 rpm for 10 min at room temperature. After the second freezing-thawing cycle, the oil phase (upper phase) was separated and stored at -24 °C for further analysis. Before the analysis, the samples were esterified to their corresponding fatty acid methyl esters. The fatty acid composition was analyzed using a gas chromatography (Thermo Quest Trace GC 2000 Series; Oshawa, Canada) with a flame ionization detector (FID) equipped with a Hewlett Packard (HP-88) capillary column of 60 m×0.25 mm×0.20 µm film thickness purchased from Agilents Technologies Ltd., Santa Clara, CA, USA. The temperatures of the injector and detector were set at 250 and 280 °C, respectively. The carrier gas was helium at a constant flow of 1.6 ml/min. Operating conditions for GC were as follows: Injection mode/volume: Split (1/50)/1 µL at 250 °C, Flow rates: H_2:Air: N_2 = 33:370:30 mL/min. The oven temperature was 100 °C for 1 min, increased to 180 °C at a rate of 10 °C/min, then increased to 220 °C at a rate of 5 °C/min, and held for 5 min.

2.5. Textural characteristics of mayonnaise samples

Texture measurements were carried out using a TA-XT2 Texture Analyzer (Stable Micro System Ltd., UK) based on the back extrusion method at 25 ± 2 °C. A disc probe (diameter: 30 mm, TA-30A) using a 50 kg load cell attached to the instrument was compressed onto a 30 mm depth of the sample with a test speed of 1 mm·s^{-1}. The pre-test speed and post-test speed were set at 10 mm·s^{-1} and the trigger force was 10 g. The force-time curves were analyzed for hardness (g), consistency (g·sec), cohesiveness (g), and work of cohesion (g·sec). The tests were carried out in standard glass jars (50 mm diameter). When the surface trigger of 10 g was reached (i.e. the point at which the disc's lower surface is in full contact with the product), the mayonnaise samples were subjected to compressive force by probe up to the distance of 30 mm, afterwards, the probe returned to its original position.

2.6. Emulsion microstructure

The mayonnaise samples were examined under an optical microscope (Leica Microsystems, Wetzlar, Germany) at a magnification of 40×. First, one drop of mayonnaise sample was placed on the slide and covered with a coverslip. After uniform thickness was attained, the images were captured using LAS-EZ software (Leica Microsystems, Wetzlar, Germany).

2.7. Emulsion stability

The emulsion stability (ES) of the mayonnaise was determined according to the method suggested by Phuah *et al.* (2016), with a slight modification. Briefly, 5.0±0.5 g of each sample were filled into 15 mL centrifuge tubes, and the tubes were incubated in a water bath at 50 °C for 24 hours. At the end of the incubation time, the tubes were centrifuged at 4000 rpm for 20 min. The upward phase was removed, and the remaining phase was weighed to calculate the emulsion stability according to the Equation:

$$ES\ (\%) = 100\ x\ m_1/m_2$$

where m_1 is the weight of the remaining phase, and m_2 is the initial weight of the mayonnaise.

2.8. Statistical analysis

The data obtained from the study were analyzed using one-way ANOVA, and the difference between the significant averages was tested using Tukey's multiple comparison test. Statistical analysis was performed using Minitab software (Minitab, State College, Pa). All experiments were performed in triplicate.

3. RESULT AND DISCUSSION

3.1. Effect of AE-MCC-AS on some physicochemical characteristics of mayonnaise

The physicochemical characteristics of the mayonnaise samples are summarized in Table 2. The pH of mayonnaise plays an important role in emulsion stability (Depree and Savage, 2001; Martillanes *et al.,* 2020). Therefore, the pH value of the mayonnaise samples was monitored during storage. The initial pH value of the mayonnaise samples was in the range of 3.81-3.86. Afterwards, the pH value increased significantly ($P < 0.01$) on the 28th day of storage and then decreased significantly ($P < 0.01$) on the 56th day of storage. We had observed a similar trend in the TBARs value of mayonnaise samples during storage at 25 °C in our previously published study (Ünver and Çelik, 2021). As known, TBARs value is an indicator of the amount of malonaldehyde, which is a major secondary product of the lipid oxidation process. During lipid oxidation, carboxylic acids could form due to the oxidation of the aldehydes (Mohammadi *et al.,* 2016). The various oxidation products such as these carboxylic acids could be responsible for the fluctuation in the pH value during storage. It was reported that the risk of microbial growth of foodborne pathogens in mayonnaise was low since the pH value of mayonnaise was approximately 4.00 (Khalil and Mansour, 1998). However, some species of microorganisms, such as lactic acid bacteria, can grow in the pH range of 4.00-5.00. Another reason for the pH decrease during storage could be related to the activity of these bacteria in the mayonnaise (Kishk and Elsheshetawy, 2013). On the other hand, Depree and Savage (2001) reported that the stability and viscoelasticity of mayonnaise were expected to be at their highest value when a pH value was close to the average isoelectric point of the egg yolk proteins. The mean pH value of the mayonnaise samples containing AE-MCC-AS was found to be significantly ($P < 0.01$) lower than the negative control and positive control samples. This situation might be due to the microbial load of the samples. Martillanes *et al.* (2020), who studied the antioxidant and antimicrobial evaluation of rice bran extracts in a mayonnaise-type emulsion, reported that pH values increased with time and temperature during the storage period of 7 days. However, these differences were not significant in all treatments including a rice bran extract-added mayonnaise-type emulsion, BHT-added mayonnaise-type emulsion or the control sample without antioxidant. Compared to our results, Rasmy *et al.* (2012), who studied the effect of sage extracts on the shelf-life of mayonnaise, found that the pH values of the control and samples treated with BHA and sage extracts at different concentrations increased slightly during the storage period of 4 months.

According to the color results presented in Table 2, there was no significant difference in the lightness index (L^*) of all the treatments on the first day of storage, except for 0.6% AE-MCC-AS-M. The lightness index of the mayonnaise samples containing AE-MCC-AS decreased by increasing the AE-MCC-AS ratio. This case might be due to the pigments in the PE-AH. In our previously published study (Ünver and Çelik, 2021), the L, a^* and b^* values of AE-MCC-AS were found to 71.46, 8.65 and 32.9, respectively. At the end of storage, the highest lightness index was observed in the control, while the lowest lightness index was observed in the 0.6% AE-MCC-AS-M. The lightness value plays a key role in determining the visual acceptability of the mayonnaise (Flamminii *et al.*, 2020). For this reason, the visual acceptability of the mayonnaise samples containing AE-MCC-AS was expected to decrease with the increase in the AE-MCC-AS ratio. In our previous study, the decrease in the lightness index due to increasing the AE-MCC-AS ratio was observed by the sensory panel, and 0.6% AE-MCC-AS-M received the lowest appearance score at the end of storage, followed by 0.4% AE-MCC-AS-M and 0.2% AE-MCC-AS-M (Ünver and Çelik, 2021). The positive a^* and b^* values were the sign of redness and yellowness in the color of mayonnaise. The redness (a^*) and yellowness (b^*) values decreased during storage in all treatments except for 0.6% AE-MCC-AS-M. A slight increase in the redness of 0.6% AE-MCC-AS-M was observed on the 56th day of storage. The redness and yellowness values increased with increasing levels of AE-MCC-AS. This case might be due to the pigments in PE-AH, which had a reddish and yellowish color. Generally, the pale yellowness of mayonnaise is sourced from the main ingredients such as egg yolk and oil. However, adding an unusual ingredient to the mayonnaise formulation could change the color values of the final product (Flamminii *et al.*, 2020). Researchers who studied the effect of several phenolic extracts on the physical characteristics of mayonnaise (Gorji *et al.,* 2019; Abd El-Rahman *et al.,* 2020), reported similar differences in the color attributes of mayonnaise. Nevertheless, a minimal color change was tolerable for consumer acceptability.

The emulsion stability could not be determined on the 1st or the 28th days of storage because all the mayonnaise samples showed high stability (Table 2). However, α-tocopherol-M exhibited the highest emulsion stability at the end of storage, followed by 0.4% AE-MCC-AS-M, 0.2% AE-MCC-AS-M, 0.6% AE-MCC-AS-M, BHT-M and the control. This result showed that the AE-MCC-AS ratio was an important parameter for the emulsion stability of the mayonnaise samples; however, a direct relationship was not determined between the AE-MCC-AS ratio and emulsion stability. The emulsion stability of the mayonnaise increased with the increase in the AE-MCC-AS ratio from 0.2 to 0.4%. However, it decreased as a result of the addition of 0.6% AE-MCC-AS. This effect may be due to the interaction between egg yolk proteins, which are mainly responsible for the emulsion structure, and AE-MCC-AS. The addition of AE-MCC-AS at up to 0.4% in the mayonnaise formulation may have empowered the shielding effect of the egg yolk proteins against the coalescence of lipid droplets. However, the decrease in the emulsion stability with the addition of 0.6% AE-MCC-AS showed the importance of the

Table 2. Results of some physicochemical characteristics of mayonnaise samples

		TREATMENTS					
	Time (Day)	**Control**	**BHT-M**	**α-tocopherol-M**	**0.2% AE-MCC-AS-M**	**0.4% AE-MCC-AS-M**	**0.6% AE-MCC-AS-M**
pH	**1**	$3.86±0.02^{Ca}$	$3.86±0.02^{Ba}$	$3.81±0.06^{Ba}$	$3.83±0.05^{Ba}$	$3.85±0.05^{Ba}$	$3.84±0.05^{Ba}$
	28	$4.02±0.02^{Aa}$	$4.01±0.03^{Aa}$	$3.99±0.03^{Aab}$	$3.94±0.01^{Ac}$	$3.95±0.01^{Abc}$	$3.95±0.02^{Abc}$
	56	$3.90±0.04^{Ba}$	$3.78±0.03^{Cbc}$	$3.81±0.04^{Bb}$	$3.71±0.05^{Cd}$	$3.71±0.02^{Cd}$	$3.74±0.03^{Ccd}$
L*	**1**	$80.24±1.44^{Aa}$	$80.35±0.13^{Aa}$	$79.36±0.67^{Ba}$	$79.38±0.14^{Aa}$	$80.08±0.59^{Aa}$	$77.40±0.48^{Ab}$
	28	$80.69±0.34^{Aa}$	$79.19±0.34^{Cb}$	$80.77±0.14^{Aa}$	$79.62±0.02^{Ab}$	$79.18±0.11^{Bb}$	$77.75±0.21^{Ac}$
	56	$80.15±0.30^{Aa}$	$79.99±0.11^{Ba}$	$79.69±0.49^{Ba}$	$78.75±0.35^{Bb}$	$78.27±0.68^{Cb}$	$76.51±0.15^{Bc}$
a*	**1**	$2.26±0.31^{Ac}$	$3.18±0.07^{Ab}$	$3.12±0.09^{Ab}$	$3.25±0.03^{Ab}$	$3.11±0.02^{Ab}$	$3.60±0.07^{Aa}$
	28	$1.23±0.05^{Be}$	$1.93±0.08^{Bc}$	$1.72±0.03^{Bd}$	$2.78±0.0.2^{Bb}$	$2.87±0.02^{Bb}$	$3.37±0.06^{Ba}$
	56	$0.92±0.10^{Ce}$	$1.40±0.09^{Cd}$	$1.03±0.13^{Ce}$	$2.37±0.02^{Cc}$	$2.70±0.03^{Cb}$	$3.45±0.02^{Aa}$
b*	**1**	$17.31±2.03^{Ab}$	$20.71±0.07^{Aa}$	$19.64±0.26^{Aa}$	$20.27±0.08^{Aa}$	$19.97±0.32^{Aa}$	$20.87±0.18^{Aa}$
	28	$17.26±0.12^{Ad}$	$17.74±1.13^{Bcd}$	$18.09±0.04^{Bbcd}$	$18.73±0.11^{Babc}$	$19.20±0.01^{Bab}$	$19.48±0.72^{Ba}$
	56	$16.48±0.21^{Ad}$	$17.65±0.17^{Bc}$	$16.70±0.12^{Cd}$	$18.01±0.24^{Cb}$	$18.13±0.06^{Cb}$	$19.50±0.10^{Ba}$
ES (%)	**1**	nd.	nd.	nd.	nd.	nd.	nd.
	28	nd.	nd.	nd.	nd.	nd.	nd.
	56	$87.51±2.38^{b}$	$90.76±0.95^{ab}$	$94.26±2.06^{b}$	$91.76±1.26^{ab}$	$92.26±2.63^{ab}$	$91.50±3.12^{ab}$

All data are presented as mean value ± standard deviation (three repetitions, n=3). Means in the same column with different capital letters are significantly different (by Tukey's test at P < 0.01). Means in the same row with different small letters are significantly different (by Tukey's test at P < 0.01). ES: Emulsion stability. nd: Not detected .

AE-MCC-AS ratio in emulsion stability. For this reason, in future studies, it is recommended to determine the most appropriate AE-MCC-AS ratio, which provides the best emulsion stability, using an optimization model. Xu *et al.* (2016) studied the effect of MCC on the physical stability of soybean protein hydrolysate stabilized curcumin emulsion through microfluidization. Similarly, they reported that the emulsion stability improved with the addition of MCC and claimed that the proper addition of polysaccharides and emulsifiers could improve emulsion properties.

The viscosity values of the mayonnaise samples are presented in Figure 1. At the beginning of storage, the highest viscosity was observed in the α-tocopherol-M, followed by BHT-M, control, 0.4% AE-MCC-AS-M, 0.2% AE-MCC-AS-M and 0.6% AE-MCC-AS-M, respectively. A significant (P < 0.01) declining trend was observed in the viscosity behavior of the mayonnaise samples during the storage of 56 days. At the end of storage, 0.4% AE-MCC-AS-M showed the most viscous structure, followed by α-tocopherol-M, BHT-M, 0.2% AE-MCC-AS-M, 0.6% AE-MCC-AS-M and the control, respectively. These findings were partially in good agreement with the firmness and consistency results of the mayonnaise samples (Figures 3a and 3b). Liu *et al.* (2007) reported that the viscosity of mayonnaise might partially reflect texture analysis parameters, but not all of them. The increase in the AE-MCC-AS ratio from 0.2 to 0.4% caused an increase in the viscosity of mayonnaise since adding AE-MCC-AS at the mentioned ratio may have contributed to the formation of a gel-like structure that trapped oil droplets. Therefore, the movement of oil droplets may have slowed down, which caused an increasing effect on the viscosity. However, the addition of AE-MCC-AS higher than 0.4% might cause a decreasing effect on the viscosity of mayonnaise. 0.6% AE-MCC-AS-M showed the lowest viscosity among the treatments of AE-MCC-AS. It can be seen as a reflection of the change in emulsion stability due to the increase in AE-MCC-AS concentration. Therefore, the AE-MCC-AS ratio played a crucial role in the formation of interfacial membranes and the prevention of partial coalescence of oil droplets. Similarly, Raikos *et al.* (2016), who studied the effect of beetroot supplementation on the physical stability, textural and sensory properties of mayonnaise, reported that the mean value of viscosity of mayonnaise supplement-

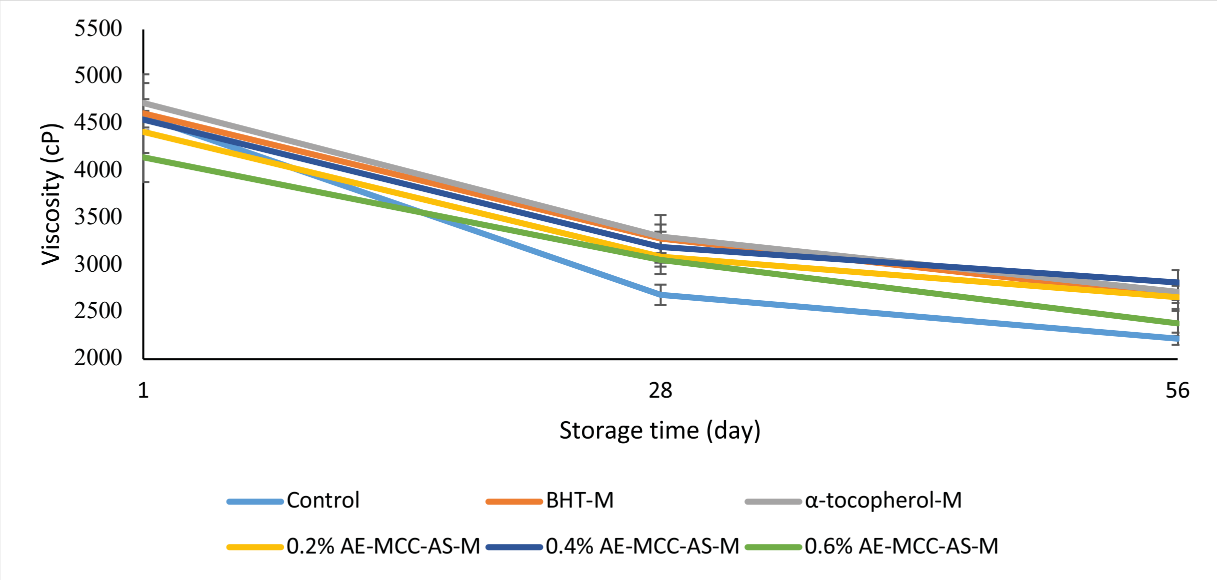

Figure 1. Viscosity results of the mayonnaise samples during storage at 25 °C (Mean ± SD; n=3). The data were analyzed using one-way ANOVA, and groups were compared with Tukey's multiple comparison test (P ≤ 0.01).

ed with beetroot was higher than the control (without antioxidant) and the commercial control. Kishk and Elsheshetawy (2013) studied the effect of ginger powder on the oxidative stability, rheological, and sensory characteristics of mayonnaise. In contrast to our results, the researchers reported that adding ginger powder at different concentrations (0, 0.5, 0.75 and 1.25%) to the mayonnaise formula showed no significant effect on the apparent viscosity. Xu *et al.* (2016) reported that the viscosity of soybean protein isolate stabilized curcumin emulsion increased with the addition of MCC.

The microstructure of the mayonnaise samples is shown in Figure 2. Larger oil droplets were observed in the micrographs of the control, 0.2% AE-MCC-AS-M and 0.6% AE-MCC-AS-M; while the smallest oil droplets were observed in the micrograph of α-tocopherol-M, followed by BHT-M and 0.4% AE-MCC-AS-M. These observations were consistent with the findings of the viscosity results on the 28th day of storage. Larger oil droplets lower the level of uniformity of the samples, while smaller oil droplets create a larger contact surface, which causes frictional forces opposing the free flow of the emulsion in a shear field (Golchoobi *et al.,* 2016). Ultimately, the decrease in oil droplet size caused an increase in viscosity. Chatterjee and Bhattacharjee (2015), who studied the effect of eugenol-lean clove extract on the physicochemical characteristics of mayonnaise, reported that the microstructure of mayonnaise containing eugenol-lean clove extract exhibited a more homogenous and compact microstructure compared to mayonnaise formulated with mustard. Furthermore, the researchers claimed that eugenol-lean clove extract positively affected the emulsification of the mayonnaise.

The saturated fatty acid composition of the mayonnaise samples is presented in Table 3. In addition to the saturated fatty acids (SFA) presented in Table 3, myristic acid (C14:0) and heptadecanoic acid (C17:0) were also determined; however, their concentration was lower than 0.1%. While the total SFA of mayonnaise was 9.88-10.79% at the beginning of storage, it increased to 11.35-12.18% at the end of storage. 0.4% AE-MCC-AS-M showed the highest SFA content, followed by α-tocopherol-M, control, 0.2% AE-MCC-AS-M, 0.6% AE-MCC-AS-M and BHT-M at the beginning of storage. The mean of the total SFA ratio increased in all treatments during storage. The increase in the total SFA is probably due to the degradation of monounsaturated fatty acids (MUFA) and polyunsaturated fatty acids (PUFA), which increases the ratio of the total SFA (Kunyaboon *et al.,* 2021). At the end of storage, the highest SFA ratio was observed in the control, followed by 0.4% AE-MCC-AS-M, BHT-M, 0.2% AE-MCC-AS-M, α-tocopherol-M, and 0.6% AE-MCC-AS-M. Among the SFA, palmitic acid (C16:0) and

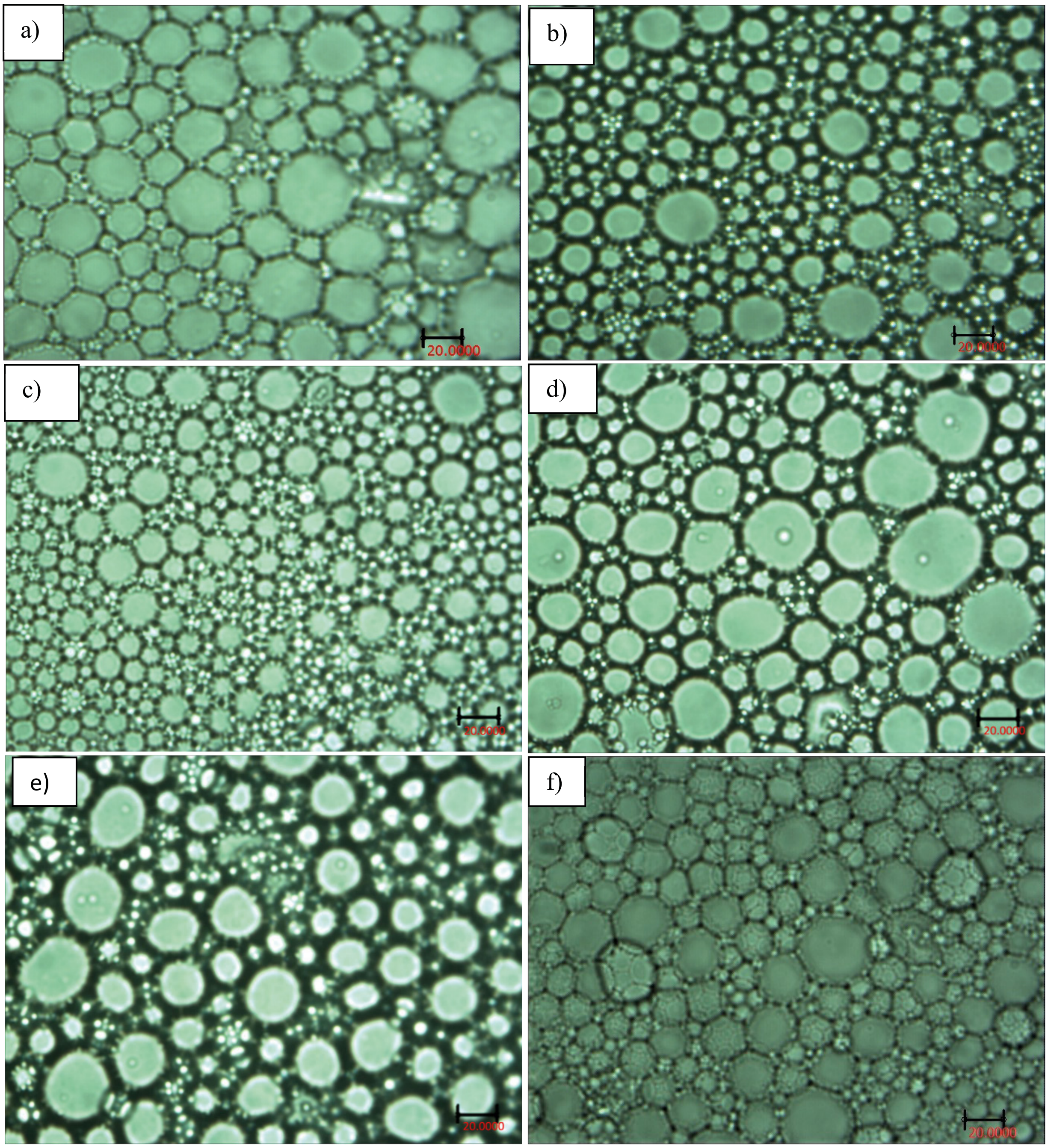

Figure 2. Micrographs of mayonnaise samples taken by optical microscope on the 28th day of storage. (a) Control; (b) BHT-M; (c) α-tocopherol-M; (d) 0.2% AE-MCC-AS-M; (e) 0.4% AE-MCC-AS-M; (f) 0.6% AE-MCC-AS-M

stearic acid (C18:0) had the highest ratio in all treatments. Similarly, Turan (2018) reported that the SFA content in hazelnut oil during 12 months of storage showed fluctuations and variability. However, the researcher reported that total SFA increased slightly at the end of storage compared to the beginning.

The MUFA and PUFA compositions of the mayonnaise samples are presented in Table 4. In addition to the unsaturated fatty acids presented in Table 4, heptadecenoic (C17:1), erucic acid (C22:1n9), nervonic acid (C24:1n9) and γ-Linolenic acid (C18:3n3) were also determined in all treatments, although their concentration was lower than 0.1%. While the total MUFA of mayonnaise was 25.84-26.25% at the beginning of storage, it decreased to 25.03-25.80% at the end of

Table 3. Saturated fatty acid composition of mayonnaise samples

		Treatments					
Fatty acid	**Time (Day)**	**Control**	**BHT-M**	**α-tocopherol-M**	**0.2% AE-MCC-AS-M**	**0.4% AE-MCC-AS-M**	**0.6% AE-MCC-AS-M**
C16:0	1	6.70 ± 0.24^{Ba}	6.63 ± 0.52^{Aa}	6.77 ± 0.21^{Aa}	7.13 ± 0.01^{Aa}	6.39 ± 0.15^{Aa}	6.33 ± 0.01^{Ba}
	28	7.27 ± 0.13^{ABab}	7.37 ± 0.06^{Aa}	6.83 ± 0.42^{Aab}	6.70 ± 0.00^{Aab}	6.92 ± 0.11^{Aab}	6.61 ± 0.03^{Bb}
	56	7.45 ± 0.14^{Aa}	7.59 ± 0.26^{Aa}	7.39 ± 0.42^{Aa}	7.49 ± 0.44^{Aa}	7.86 ± 0.19^{Aa}	7.15 ± 0.13^{Aa}
C18:0	1	3.39 ± 0.23^{Aa}	2.72 ± 1.00^{Aa}	3.32 ± 0.02^{Aa}	2.54 ± 0.38^{Aa}	3.75 ± 0.00^{Aa}	3.31 ± 0.33^{Aa}
	28	3.59 ± 0.04^{Aa}	2.93 ± 1.21^{Aa}	3.75 ± 0.20^{Aa}	3.31 ± 0.42^{Aa}	3.48 ± 0.04^{Aa}	3.61 ± 0.08^{Aa}
	56	3.95 ± 0.34^{Aa}	3.40 ± 0.01^{Aa}	3.66 ± 0.21^{Aa}	3.53 ± 0.00^{Aa}	3.62 ± 0.13^{Aa}	3.76 ± 0.20^{Aa}
C20:0	1	0.12 ± 0.02^{Ac}	0.22 ± 0.01^{Aab}	0.18 ± 0.02^{Ab}	0.20 ± 0.01^{Bab}	0.25 ± 0.00^{Aa}	0.22 ± 0.01^{Aab}
	28	0.17 ± 0.00^{Aa}	0.20 ± 0.00^{Aa}	0.19 ± 0.01^{Aa}	0.23 ± 0.01^{Aa}	0.21 ± 0.04^{Aa}	0.20 ± 0.01^{Aa}
	56	0.21 ± 0.06^{A}	0.13 ± 0.04^{A}	0.17 ± 0.01^{A}	0.18 ± 0.01^{B}	0.14 ± 0.05^{A}	0.16 ± 0.05^{A}
C24:0	1	0.16 ± 0.04^{Aab}	0.20 ± 0.03^{Aa}	0.11 ± 0.01^{Bb}	0.10 ± 0.01^{Bb}	0.21 ± 0.00^{Aa}	0.15 ± 0.01^{Aab}
	28	0.12 ± 0.00^{Ac}	0.19 ± 0.03^{Aab}	0.24 ± 0.00^{Aa}	0.18 ± 0.01^{Ab}	0.21 ± 0.00^{Aab}	0.16 ± 0.01^{Abc}
	56	0.17 ± 0.06^{Aa}	0.15 ± 0.08^{Aa}	0.25 ± 0.03^{Aa}	0.12 ± 0.02^{Ba}	0.12 ± 0.08^{Aa}	0.18 ± 0.01^{Aa}
Total SFA	1	10.46 ± 0.48^{Aa}	9.88 ± 1.53^{Aa}	10.48 ± 0.21^{Aa}	10.06 ± 0.42^{Aa}	10.79 ± 0.15^{Aa}	10.00 ± 0.41^{Ba}
	28	11.25 ± 0.09^{Aa}	10.80 ± 1.30^{Aa}	11.11 ± 0.70^{Aa}	10.52 ± 0.45^{Aa}	10.92 ± 0.03^{Aa}	10.67 ± 0.09^{ABa}
	56	12.18 ± 1.03^{Aa}	11.38 ± 0.23^{Aa}	11.57 ± 0.23^{Aa}	11.43 ± 0.46^{Aa}	11.85 ± 0.55^{Aa}	11.35 ± 0.27^{Aa}

All data are presented as mean value ± standard deviation (three repetitions, n=3). Means in the same column with different capital letters are significantly different (by Tukey's test at $P < 0.01$). Means in the same row with different small letters are significantly different (by Tukey's test at $P < 0.01$). SFA: Saturated fatty acid.

Table 4. Unsaturated fatty acid composition of mayonnaise samples

		Treatments					
Fatty acid	**Time (Day)**	**Control**	**BHT-M**	**α-tocopherol-M**	**0.2% AE-MCC-AS-M**	**0.4% AE-MCC-AS-M**	**0.6% AE-MCC-AS-M**
C16:1	1	0.10 ± 0.01^{Aab}	0.10 ± 0.00^{Aab}	0.09 ± 0.01^{Ab}	0.10 ± 0.00^{Aab}	0.11 ± 0.00^{Aa}	0.10 ± 0.00^{Aab}
	28	0.10 ± 0.01^{Aa}	0.10 ± 0.00^{Aa}	0.09 ± 0.02^{Aa}	0.10 ± 0.00^{Aa}	0.09 ± 0.00^{Ba}	0.09 ± 0.00^{Aa}
	56	0.10 ± 0.01^{Aa}	0.10 ± 0.00^{Aa}	0.09 ± 0.00^{Aa}	0.11 ± 0.01^{Aa}	0.10 ± 0.01^{ABa}	0.10 ± 0.01^{Aa}
C18:1n9c	1	25.59 ± 0.01^{Aa}	25.86 ± 0.21^{Aa}	25.55 ± 0.24^{Aa}	25.94 ± 0.06^{Aa}	25.71 ± 0.01^{Aa}	25.80 ± 0.24^{Aa}
	28	25.30 ± 0.27^{Aa}	25.22 ± 0.56^{Aa}	25.38 ± 0.24^{Aa}	25.65 ± 0.36^{Aa}	25.68 ± 0.15^{Aa}	25.68 ± 0.33^{Aa}
	56	24.75 ± 0.35^{Aa}	25.24 ± 0.21^{Aa}	25.21 ± 1.04^{Aa}	25.53 ± 0.03^{Aa}	25.38 ± 0.18^{Aa}	25.31 ± 0.41^{Aa}
C20:1n9	1	0.14 ± 0.01^{Aa}	0.13 ± 0.00^{Aa}	0.13 ± 0.00^{Aa}	0.13 ± 0.02^{Aa}	0.15 ± 0.00^{Aa}	0.14 ± 0.02^{Aa}
	28	0.12 ± 0.00^{Aa}	0.14 ± 0.00^{Aa}	0.12 ± 0.02^{Aa}	0.13 ± 0.01^{Aa}	0.11 ± 0.00^{Aa}	0.14 ± 0.01^{Aa}
	56	0.12 ± 0.00^{Aa}	0.14 ± 0.00^{Aa}	0.13 ± 0.01^{Aa}	0.12 ± 0.02^{Aa}	0.12 ± 0.02^{Aa}	0.13 ± 0.01^{Aa}
Total MUFA	1	25.90 ± 0.04^{Aa}	26.16 ± 0.20^{Aa}	25.84 ± 0.22^{Aa}	26.25 ± 0.06^{Aa}	26.09 ± 0.07^{Aa}	26.12 ± 0.26^{Aa}
	28	25.42 ± 0.27^{Aa}	25.51 ± 0.57^{Aa}	25.66 ± 0.22^{Aa}	26.04 ± 0.23^{Aa}	25.91 ± 0.23^{Aa}	25.98 ± 0.32^{Aa}
	56	25.03 ± 0.33^{Aa}	25.47 ± 0.32^{Aa}	25.50 ± 1.05^{Aa}	25.80 ± 0.05^{Aa}	25.65 ± 0.21^{Aa}	25.59 ± 0.42^{Aa}
C18:2n6c	1	62.55 ± 0.24^{Aa}	63.23 ± 1.31^{Aa}	62.94 ± 0.09^{Aa}	62.96 ± 0.22^{Aa}	62.41 ± 0.18^{Aa}	62.53 ± 0.40^{Aa}
	28	62.53 ± 0.41^{Aa}	62.98 ± 0.76^{Aa}	62.58 ± 0.37^{Aa}	62.65 ± 0.16^{Aa}	62.35 ± 0.00^{Aa}	62.25 ± 0.57^{Aa}
	56	61.57 ± 0.74^{Aa}	62.54 ± 0.23^{Aa}	61.99 ± 0.74^{Aa}	62.25 ± 0.19^{Aa}	61.94 ± 0.13^{Aa}	62.23 ± 0.33^{Aa}
C20:2	1	0.71 ± 0.01^{Aa}	0.65 ± 0.01^{Aa}	0.68 ± 0.11^{Aa}	0.67 ± 0.13^{Aa}	0.62 ± 0.02^{Aa}	0.61 ± 0.03^{Aa}
	28	0.51 ± 0.02^{Bab}	0.64 ± 0.04^{Aa}	0.59 ± 0.11^{Aa}	0.69 ± 0.01^{Aa}	0.31 ± 0.00^{Ab}	0.70 ± 0.01^{Aa}
	56	0.63 ± 0.06^{ABa}	0.54 ± 0.16^{Aa}	0.68 ± 0.01^{Aa}	0.42 ± 0.16^{Aa}	0.51 ± 0.18^{Aa}	0.54 ± 0.11^{Aa}
Total PUFA	1	63.33 ± 0.26^{Aa}	63.95 ± 1.32^{Aa}	63.69 ± 0.02^{Aa}	63.69 ± 0.36^{Aa}	63.07 ± 0.13^{Aa}	63.24 ± 0.46^{Aa}
	28	63.09 ± 0.39^{Aa}	63.68 ± 0.73^{Aa}	63.24 ± 0.68^{Aa}	63.40 ± 0.16^{Aa}	62.73 ± 0.02^{Aa}	62.99 ± 0.59^{Aa}
	56	62.26 ± 0.69^{Aa}	63.15 ± 0.09^{Aa}	62.74 ± 0.73^{Aa}	62.73 ± 0.35^{Aa}	62.50 ± 0.33^{Aa}	62.84 ± 0.43^{Aa}

All data are presented as mean value ± standard deviation (three repetitions, n=3). Means in the same column with different capital letters are significantly different (by Tukey's test at $P < 0.01$).
Means in the same row with different small letters are significantly different (by Tukey's test at $P < 0.01$). MUFA: Monounsaturated fatty acid. PUFA: Polyunsaturated fatty acid.

storage. The total MUFA ratios showed a decreasing trend in all treatments during the storage period. Although there was no significant difference among the treatments during storage, the lowest total MUFA was observed in the control, and the highest MUFA was observed in 0.2% AE-MCC-AS-M. Turan (2018) reported a similar declining trend in the MUFA content of hazelnut oil at the end of storage. Total PUFA was 63.07-63.95% at the beginning of storage, and it decreased to 62.26-63.15% at the end of storage. Similar to total MUFA, a declining trend was observed in total PUFA during storage. The lowest total PUFA was observed in the control, followed by 0.4% AE-MCC-AS-M, 0.2% AE-MCC-AS-M, α-tocopherol-M, 0.6% AE-MCC-AS-M, and BHT-M. While oleic acid (C18:1n9c) had the highest ratio among the MUFA, linoleic acid (C18:2n6c) was the dominant fatty acid among the PUFAs. This phenomenon could be originated from the sunflower oil used in the production of mayonnaise.

It is worth noting that the total MUFA and PUFA of mayonnaise showed a declining trend in all treatments with a higher decrease in the control; whereas the total SFA showed an increasing trend with a higher increase in the control during storage. The result of the oxidation analysis (peroxide value, TBARs value and induction time) that had been determined in our previous study (Ünver and Çelik, 2021) corroborated with these findings for the fatty acid composition. During oxidation, free radicals can easily react with long-chain unsaturated fatty acids, which cause off-flavors and taste in food products (Uçar, 2020). Exposure to temperature, air trapped in the headspace of the jars, and iron cations released from egg yolk during the storage of mayonnaise can cause rapid deterioration of long-chain unsaturated fatty acids. Therefore, the use of synthetic and natural antioxidants in mayonnaise can retard or inhibit oil oxidation. Furthermore, packaging mayonnaise under vacuum or changing the air in the headspace with nitrogen is beneficial to retard the oxidation reaction in mayonnaise.

3.2. Effect of AE-MCC-AS on the textural characteristics of mayonnaise

The textural characteristics were determined as firmness, consistency, and cohesiveness on the basis of force-time curves. Firmness, which indicates the strength of the emulsion, is the maximum force or peak of the force-time curve, and the recorded area of the positive region of the force-time curve represents the consistency in the back extrusion method. As shown in Figure 3, α-tocopherol-M showed the highest firmness, followed by the control, BHT-M, 0.2% AE-MCC-AS-M, 0.4% AE-MCC-AS-M and 0.6% AE-MCC-AS-M at the beginning of storage, and the difference between the firmness values of the treatments was found to be statistically significant ($P < 0.01$). The mean value for firmness showed a significant ($P < 0.01$) declining trend during the storage in all treatments. At the end of storage, α-tocopherol-M showed the highest firmness, followed by 0.4% AE-MCC-AS-M, BHT-M, 0.2% AE-MCC-AS-M, 0.6% AE-MCC-AS-M and the control. The same declining trend and order were observed in the consistency values of the mayonnaise samples. Cohesiveness (g) is the maximum negative force of the force-time curve obtained during the return of the probe. In other words, cohesiveness indicates the level of deforming before breaking when extended (Rojas *et al.*, 2019). At the beginning of storage, 0.4% AE-MCC-AS-M exhibited the most cohesive structure; while α-tocopherol-M exhibited the least cohesive structure, and the difference between the cohesiveness values of the treatments was found to be statistically significant ($P < 0.01$). The mean of cohesiveness showed a significant ($P < 0.01$) upward trend during storage in all treatments. At the end of storage, the highest cohesiveness was observed in the control, followed by 0.2% AE-MCC-AS-M, 0.4% AE-MCC-AS-M, BHT-M, 0.6% AE-MCC-AS-M and α-tocopherol-M, and the difference between the treatments was found to be statistically significant ($P < 0.05$). Raikos *et al.* (2016) reported that hardness, work done, adhesive force and adhesiveness of mayonnaise supplemented with beetroot were higher than the control sample (without antioxidant) and the commercial control.

4. CONCLUSIONS

The addition of AE-MCC-AS contributed to the emulsion stability, viscosity and some textural characteristics of mayonnaise compared to the control. Furthermore, the findings of fatty acid composition in this study supported the results of the oxidation analysis that had been determined in our previous study (Ünver and Çelik, 2021). In conclusion, the

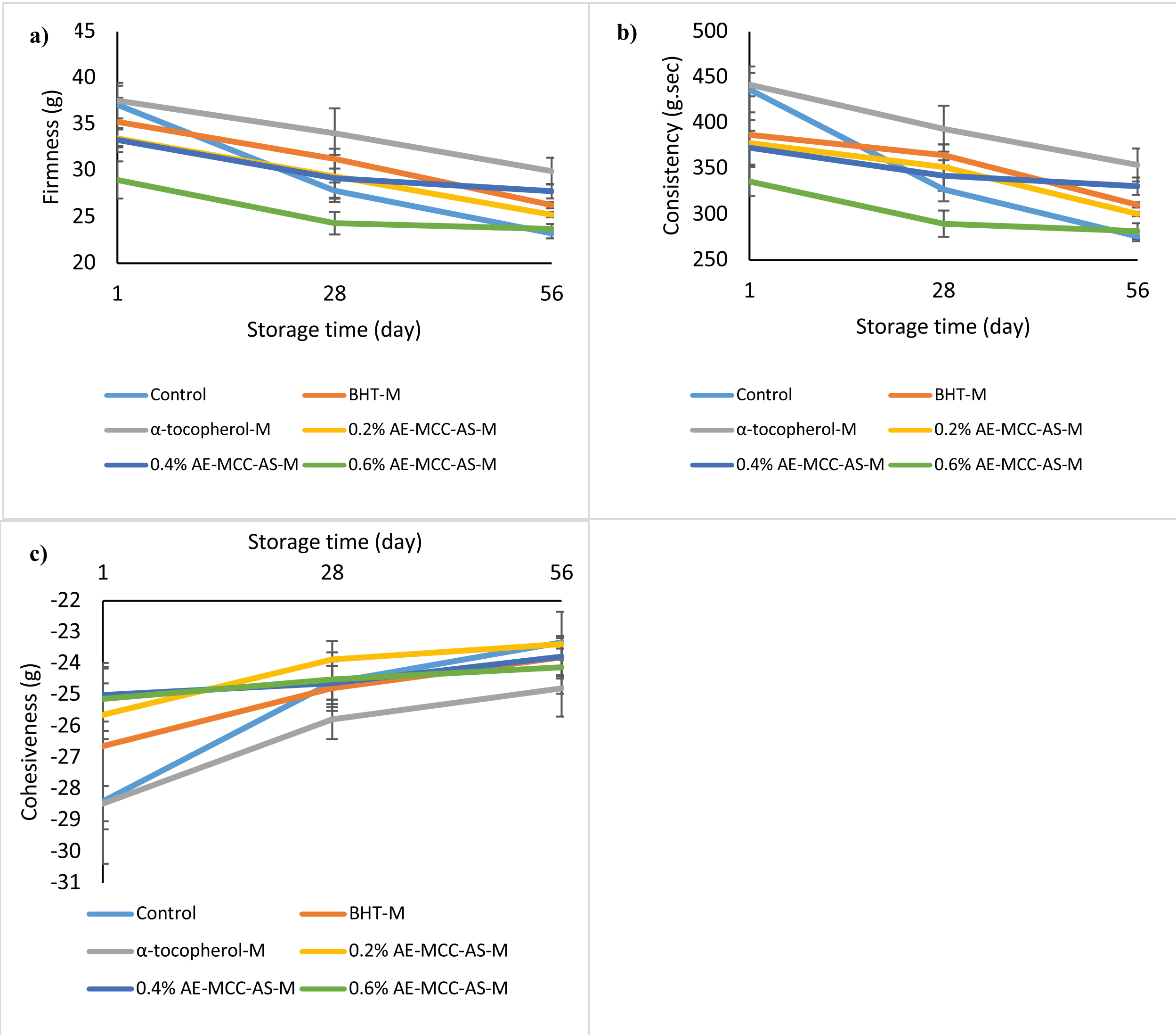

Figure 3. Results of firmness (a), consistency (b) and cohesiveness (c) of the mayonnaise samples during storage at 25 °C (Mean ± SD; n=3). The data were analyzed using one-way ANOVA, and groups were compared with Tukey's multiple comparison test (P ≤ 0.01).

study revealed that 0.4% AE-MCC-AS-M showed the highest emulsion stability, viscosity, firmness, and consistency among the samples that contained AE-MCC-AS. Furthermore, this study revealed that the AE-MCC-AS ratio was an important factor in the color characteristics of mayonnaise. Therefore, we suggest determining the effect AE-MCC-AS ratio on the physical, textural and emulsion characteristics of mayonnaise in detail with an optimization study.

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CONFLICT OF INTEREST

The authors have declared no conflicts of interest for this article.

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