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Structural and sensory impact of various emulsifiers in cocoa hazelnut spread formulations

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Abstract: In this study, the effects of emulsifiers such as lecithin, AMPs, Palsgaard® Oil-Binder and GMS on cocoa hazelnut spread rheology were compared under the same process conditions and formulation. Emulsifiers were added to the formulation separately at rates of 0.3%–0.4%–0.5%. Hardness values in cocoa hazelnut spread were examined at 15-day intervals until the 60th day. In addition, viscosity, rheological analyses, color, spreadability, stability tests, and sensory analyses were performed. In the production of cocoa hazelnut spread, lecithin and AMP have less hardness and lower viscosity, greater fluent consistency, better spreadability, and lower "work of shear" values compared with other emulsifiers. The emulsifier type/ratio difference did not affect the color value statistically. It was determined that the use of Oil-Binder and GMS significantly protected the stability compared with other emulsifiers. During the 60-day storage period, lecithin preserved its hardness properties better than other emulsifiers. When sensory properties were examined, the use of lecithin and AMP in cocoa hazelnut spread samples scored high in brightness, spreadability, mouthfeel, and taste parameters. As a result, lecithin comes to the fore in the use of different types and ratios of emulsifiers in cocoa hazelnut spread production technology.

KEYWORDS
Cocoa hazelnut spread, emulsifier, lecithin, rheology

1 | INTRODUCTION

Spreadable chocolate is a homogeneous product that contains additives such as cocoa, sugar, skimmed milk powder, and emulsifier and gains a spreadable feature under room conditions by containing more than 40% fat. Hazelnut is one of the important components of spreadable chocolate. Cocoa hazelnut spreads are widely used both as a direct delicious food product and as filler in other foods such as cookies and cakes. The difference between spreadable chocolate from regular chocolate is the use of vegetable oils instead of cocoa butter (Böhme et al., 2016; Espert et al., 2020; Marra et al., 2023; Tarakçi & Yildirim, 2021).

Emulsifiers, which are important components used in chocolate production, have been used for a long time to improve the structural properties of chocolate or chocolate-derived products. These surfactants reduce the interfacial tension between the dispersed and continuous phases and play a role in regulating and modifying the rheological properties such as lowering its viscosity. The coating of cocoa powder and sugar with cocoa butter in chocolate occurs with the help of emulsifiers and the chocolate gains a good rheological property. Rheological properties directly affect the taste and aroma perception of chocolate products. For this reason, the type and content of the emulsifier used in the formulation are essential for the flow properties. Among the most commonly used emulsifiers to improve the rheological properties of chocolate or chocolate-derived products such as spread, AMP, GMS, and Oil-Binder can be used as an alternative to lecithin (Balcaen et al., 2021; Sözeri Atik et al., 2020; Toker et al., 2021).

Chocolate or chocolate products may always require the addition of one or more emulsifying additives, depending on their intended use, workability, and cost. Due to its affordable cost, sustainability, and unique properties, the main additive is lecithin. Lecithin is a naturally occurring substance present in a variety of foods, including plant seeds and egg yolks. The most commonly used emulsifier in the chocolate industry is soy lecithin derived from soybeans, and lecithins produced from sunflower, peanut, and corn seeds can also be used (Akcay, 2020; Norn, 2015b; Toker et al., 2021). In the food industry, lecithin refers to a mixture of phospholipids. It is a mixture of acetone-insoluble phospholipids containing compounds such as phosphatidylcholine (PC), phosphatidylethanolamine (PE), phosphatidylinositol (PI), phosphatidic acid (PA), and other substances (e.g., triglycerides, carbohydrates) (Bot et al., 2021; Malmos et al., 2018). These amphipathic (combination of hydrophobic and hydrophilic molecules) natural compounds are used for many purposes in food technology due to their versatile roles as emulsifiers, viscosity modifiers, antisplashing, and dispersing agents. When excess lecithin is added, that is, when the sugar crystals are sufficiently covered by the lecithin, the lecithin components align around each other to form a lamella, as the added lecithin simply does not dissolve in the oil phase. Thus, a second layer forms on top of the 'coated' crystals. However, as the fatty acid chains are now aligned around each other, the outside of the entire structure becomes more hydrophilic again. As a result, an increase in viscosity is observed (Caparosa & Hartel, 2020; Middendorf et al., 2015; Norn, 2015b).

The most important disadvantage of lecithin is that there may be compositional differences (PC, PE, etc.) arising from raw materials such as harvested soy, and these differences may cause quality and standardization problems. AMPs, also called synthetic lecithins, which have similar functions to lecithin, can exhibit a more stable composition and activity than lecithin. AMPs facilitate the processing of chocolate, especially at low shear forces, and can provide processing of chocolate at lower temperatures. The FDA has classified AMP in the category of nongenetically modified and nonallergic substances. In 2007, the use of AMP as an emulsifier in chocolate and vegetable oil coatings was approved by GRAS certificates up to 0.7% in the United States and 1% in the EU countries. According to research, the high addition of AMPs does not have a negative effect on the yield stress compared with lecithin, but it gradually reduces the viscosity (Malmos et al., 2018; Toker et al., 2024).

Oil-Binder products are a commercial blend specifically designed to reduce oil separation and oil formation in high-oil confectionery oil systems. If products such as cocoa hazelnut spread are not controlled due to their oil content, oil leakage may occur in the products. It is known that even in low concentrations, it extends the shelf life of the product compared with the time before it is lubricated, better tolerates the stress caused by storing confectionery products at different temperatures, and does not create a waxy mouthfeel.

GMS, which is widely used in the chocolate industry, is obtained by incomplete esterification of the hydroxyl groups of glycerol with stearic acid. It is known that these glycerol fatty acid esters are insufficient in reducing the yield value and plastic viscosity as they cause more friction as they cannot coat the sugar particles compared with their alternatives (Norn, 2015b; Toker et al., 2024).

One of the most well-known emulsifiers used in common food products such as cocoa hazelnut spread is PGPR. Some studies comparing the structural properties of PGPR with lecithin are included in the literature (Sözeri Atik et al., 2020). However, there are few studies comparing lecithin with PGPR, as well as AMP, GMS, and other commercial emulsifiers. This deficiency creates an opportunity to add innovation to the literature. In this study, it was aimed to examine and compare the structural and sensory properties of the emulsifiers used in the production of cocoa hazelnut spread by adding them in different ratios. In this respect, the study aims to fill an important gap in the literature and provide new information.

2 | MATERIALS AND METHODS

2.1 | Materials

Powdered sugar, sunflower oil, skimmed milk powder, demineralized whey powder, cocoa powder, hazelnut paste, and emulsifiers used in the study formulation were provided by Elvan Confectionery Corporation, Turkey.

TABLE 1 Usage rates of emulsifiers and sugar used in cocoa hazelnut spread (%).

Samples	Sugar	Soy lecithin	AMP	Oil-Binder*	GMS	Other fixed ingredients	Total
1	46.84	0.3				52.86	100
2	46.74	0.4				52.86	100
3	46.64	0.5				52.86	100
4	46.84		0.3			52.86	100
5	46.74		0.4			52.86	100
6	46.64		0.5			52.86	100
7	46.84			0.3		52.86	100
8	46.74			0.4		52.86	100
9	46.64			0.5		52.86	100
10	46.84				0.3	52.86	100
11	46.74				0.4	52.86	100
12	46.64				0.5	52.86	100
Other fixed ingredients and usage rates (%)							
Ethyl vanillin	0.01						
Aroma	0.15						
Milk powder without fat	1.8						
Alkalized cocoa powder	1.8						
Natural cocoa powder	2.8						
Hazelnut paste	5.7						
70% demineralized whey powder	13.8						
Vegetable oil (sunflower oil)	26.8						
Total	**52.86**						

[a]Oil-Binder is a commercial product by Palsgaard®.

2.2 | Methods

The cocoa hazelnut spread formulation and work plan are shown in Table 1. According to this formulation, four emulsifiers (lecithin, AMP, Palsgaard® Oil-Binder, GMS) were added separately at the rates of 0.3%–0.4%–0.5%. According to the change in these mixing ratios, the percentage ratios of the entire mixture were adjusted to the sugar ratio. The sugar value is in a small percentage as seen in the table. According to this study plan, there was an excessive increase in viscosity at experimental point 9 and this experimental point was excluded from the entire study plan. The control sample is a commercial emulsifier mixture used generally in the formulations.

Within the scope of the study, cocoa hazelnut spread samples were prepared in two replicate ball mills in the pilot facility. After adding powdered sugar, sunflower oil, skimmed milk powder, demineralized whey powder, cocoa powder, hazelnut paste, and emulsifier, the ball mill was run for mixing and refining. After the particle size was measured as 32–34 µm, aroma and ethyl vanillin were added and refining was continued until it reached 30 µm.

2.3 | Color determination

Samples were homogenized and placed in a transparent container to ensure uniform color measurement. Color determination of cocoa hazelnut spread samples were performed using Minolta Chroma Meter CR-400 (Minolta Camera, Osaka, Japan). Measurements are based on the CIE Lab Color measurement scale. In this measurement method, *L*: light transmittance value (0: no permeability and 100: fully permeable); a: redness (-a, greenery); b: a indicates yellowness (-b, blueness) value.

2.4 | Rheological analysis

Viscosity analysis: Samples were placed in the rheometer's measuring cup and analysis was carried out between 0.1 and 100 per second with a rheometer (Anton Paar, MCR-302, Austria) at 25°C using a gap of 1 mm on the 50 mm parallel plate probe. Shear stress values were measured under this condition (Acan et al., 2021b).

Frequency sweep analysis: Samples were loaded onto the rheometer (Anton Paar, MCR-302, Austria) equipped with a 50 mm parallel plate probe. The analysis was performed at 25°C, between 0.1 and 100 rad/s angular frequency and at 0.5% constant strain value within the linear viscoelastic region. Storage modulus G′ (Pa) and loss modulus G′′ (Pa) values were obtained (Tekin et al., 2020).

Stability analysis: Stabilities of the samples were determined with temperature cycles. At first, the samples are kept at 23°C for 5 min to achieve thermal stabilization at the beginning of each cycle, and after that, the samples are heated from 23°C to 45°C (ramp up) and cooled from 45°C to 23°C (ramp down). 10 cycles of this heating/cooling process were applied to the samples at 0.1% constant strain and 1 Hz constant frequency values. Using the obtained data, Δ value was calculated using the following equation:

$$\boldsymbol{\Delta} = \left| \left(G'_{,1\text{stcycle}} - G'_{,\text{lastcycle}}\right) \big/ G'_{,1\text{stcycle}} \right|,$$

where lower **Δ** values indicate higher stability of the sample against the temperature change (Tekin et al., 2020).

2.5 | Textural analysis

Samples were prepared by spreading them evenly on a flat surface. The textural properties of the samples were determined using a texture analyzer device equipped with the TA2/1000 Cone 30 mm D, 60° texture probe. The test speed was set as 3 mm/s, with a distance of 15 mm. The analysis was made in three replicates. From the obtained distance versus force curve, hardness values were obtained. Change in the hardness values was measured during storage of the samples at 28°C for 2 months. Spreadability of the samples was also determined by using a Texture Profile Analyzer (TA HD Plus, Stable Micro Systems, UK) to obtain the work of shear values. Spreadability can be defined as the necessary force for spreading food products using a knife. The force required for deformation can be used to determine the firmness of products. 45′ conical Perspex and 5 kg cell size were used. The pretest speed, test speed, and posttest speed values were 1, 3, and 10 mm/s, respectively (Acan et al., 2021b).

2.6 | Sensory analysis

The produced cocoa hazelnut spreads (color, brightness, spreadability, mouthfeel, and taste) were evaluated by 10 trained panelists who are experts in chocolate technology. The purpose of the study was explained to the panelists with an informative letter. Panelists signed an informed consent form if they agreed to the purpose of the study. All participants were informed before participating in the study and declared that they were not allergic to milk, hazelnuts, lactose, soy, and gluten. Samples were mixed homogeneously before analysis. Color was given a low score if it was light and a high score if it was dark, referring to the control sample. It was rated for color, brightness, spreadability, mouthfeel, and taste. A hedonic scale was used, scoring all assessments in the range of 1 of 5. Figure 4 shows the five-point hedonic scale from 0 to 5 and the range of scores with the level of acceptability (Frunză et al., 2023). Sensory evaluators were selected from master degree students taking a “sensory analysis” course. They were knowledgeable about the entire analysis process. During the sensory evaluation, each panelist was presented with a series of coded samples in random order to minimize bias. Each evaluator was provided with a total of 12 samples, with each sample weighing approximately 10 g. Panelists were instructed to cleanse their palates with water and unsalted crackers between samples to prevent carryover effects. Sensory evaluation was performed using standardized plastic containers with lids to prevent contamination and maintain sample integrity. To ensure a consistent environment, assessments were conducted in individual booths under controlled lighting and temperature conditions. The location of the sensory evaluation was a sensory analysis laboratory at Yildiz Technical University.

Institutional review board (IRB) statement: The study was reviewed and approved by the Yildiz Technical University IRB and informed consent was obtained from each subject prior to their participation in the study.

2.7 | Statistical analyses

Three-way analysis of variance (ANOVA) and Duncan test were performed using the SPSS 16.0 statistical package for Windows (SPSS Inc., USA).

3 | RESULTS

3.1 | Color properties of cocoa hazelnut spread

Color is an important parameter for all usage aims of such products such as direct consumption in breakfast, filling material in some products, etc. It was determined that different varieties/ratio emulsifiers added to the formulation in cocoa hazelnut spread production did not have a statistically significant effect on the color values of the cocoa hazelnut spread samples (Table 2).

TABLE 2 Spreadability, color, and η_{50} (Pa.s) results of cocoa hazelnut spreads.

Sample	Force (g)	Work of shear (g.s)	η50 (Pa)	*L**	*a**	*b**
1	740.42 ± 29.38aA	544.25 ± 14.72aA	9.15 ± 0.69a	34.17 ± 0.02aA	7.90 ± 0.05aA	12.31 ± 0.10aA
2	881.22 ± 112.63aA	719.13 ± 121.83aA	9.01 ± 2.34a	33.90 ± 0.08aA	7.97 ± 0.35aA	12.47 ± 0.30aA
3	743.86 ± 74.42aA	594.16 ± 65.73aA	10.63 ± 0.99a	33.80 ± 0.28aA	7.97 ± 0.26aA	12.48 ± 0.09aA
4	887.05 ± 32.16aA	783.18 ± 57.17aA	10.54 ± 2.18a	34.30 ± 0.26aA	8.00 ± 0.4aA	12.54 ± 0.08aA
5	975.7 ± 88.2aA	843.60 ± 81.73aA	9.15 ± 0.36a	33.88 ± 0.32aA	7.86 ± 0.31aA	12.13 ± 0.30aA
6	1080.39 ± 66.91aA	1042.35 ± 74.35aA	8.87 ± 0.16a	34.13 ± 0.42aA	7.97 ± 0.37aA	12.24 ± 0.38aA
7	2166.33 ± 58.41b	2165.26 ± 100.57b	13.88 ± 2.40ab	33.78 ± 0.29a	7.76 ± 0.22a	11.81 ± 0.34a
8	1982.01 ± 179.90b	1879.74 ± 308.74b	20.63 ± 2.26bc	33.91 ± 0.35a	7.90 ± 0.29a	12.30 ± 0.44a
10	2263.15 ± 400.98bA	2316.3 ± 420.96bA	20.27 ± 2.64bc	34.34 ± 0.12aA	7.67 ± 0.28aA	11.86 ± 0.34aA
11	2142.64 ± 51.21bA	2143.47 ± 109.11bA	20.77 ± 2.41bc	35.16 ± 0.24aA	7.56 ± 0.38aA	11.89 ± 0.34aA
12	2452.81 ± 199.57bA	2463.07 ± 256.91bA	23.86 ± 4.18bc	34.58 ± 0.24aA	7.59 ± 0.18aA	11.71 ± 0.25aA

Analysis could not be performed in sample 9 due to excessive viscosity increase.
According to the results of this analysis, ANOVA (Duncan) test was applied to better analyze the data ($p < 0.05$).
The letters a–b–c in the same column indicated with lowercase letters were used for the statistical comparison of samples with each other.
Capitalized letters A–B–C in the same column were used to statistically compare the analysis results of 1–2–3, 4–5–6, and 10–11–12 samples with each other. The tests were not performed for 7–8 because there were fewer than three groups.

3.2 | Spreadability and flow properties of cocoa hazelnut spread

Spreadability is one of the most important quality parameters of spreadable products. The results on spreadability are also given in Table 2. Spreadability refers to the ease with which a substance spreads between two surfaces. In the context of cocoa hazelnut spread, a low spreadability value indicates that the application requires low force, meaning it has a smoother and more fluent consistency. According to the force results in the spreadability tests, there were no statistically significant differences between lecithin and AMP and between Oil-Binder and GMS. Indeed, statistically significant lower force values were obtained with lecithin and AMP compared with Oil-Binder and GMS in terms of spreadability. This implies that by using lecithin and AMP, it is possible to produce cocoa hazelnut spread with less firmness and lower viscosity compared with other emulsifiers. This situation can also be observed in the viscosity values in Figure 1. For each of the four emulsifiers studied, there were no statistically significant differences in the use of different concentrations.

Similar results were obtained between the parameter of spreadability and the force values in terms of the "work of shear." There was no statistically significant difference in the "work of shear" values between lecithin and AMP, as well as between Oil-Binder and GMS. Overall, the cocoa hazelnut spread prepared with lecithin and AMP is more fluid, easier to spread, and has a lower "work of shear" value compared with Oil-Binder and GMS.

η50 (Pa) represents the viscosity of a liquid at a specific pressure level (50 Pascal). Dynamic viscosity is a property that measures the internal frictional resistance of a liquid and typically describes the fluidity of the liquid. Higher η50 (Pa) values indicate that the food is more viscous, while lower values suggest increased fluidity. According to the data in Table 2, there is no statistical difference between lecithin and AMP for η50 value. Similarly, there is no statistical difference between Oil-binder and GMS, except for the 0.3% Oil-binder concentration.

3.3 | Rheological properties of cocoa hazelnut spread

Flow behavior is important for the last product quality and process capability. The flow properties of chocolate-based products have a significant impact on the quality and stability of the final product due to their influence on parameters such as viscosity, consistency, and mouthfeel. In general, the flow properties of cocoa hazelnut spread products are affected by the fat and sugar content, type and concentration of emulsifier, and particle size distribution of the products.

Figure 1 shows shear rate versus viscosity plots of cocoa hazelnut spread samples, respectively. According to these graphs, it is seen that the viscosity values decrease as the shear rate increases. Similar behavior was observed in the previous studies (Acan et al., 2021a). It is seen that the emulsifier type and adding at different usage rates did not change the cocoa hazelnut spread flow behavior. It can be said that the use of lecithin and AMP in the cocoa hazelnut

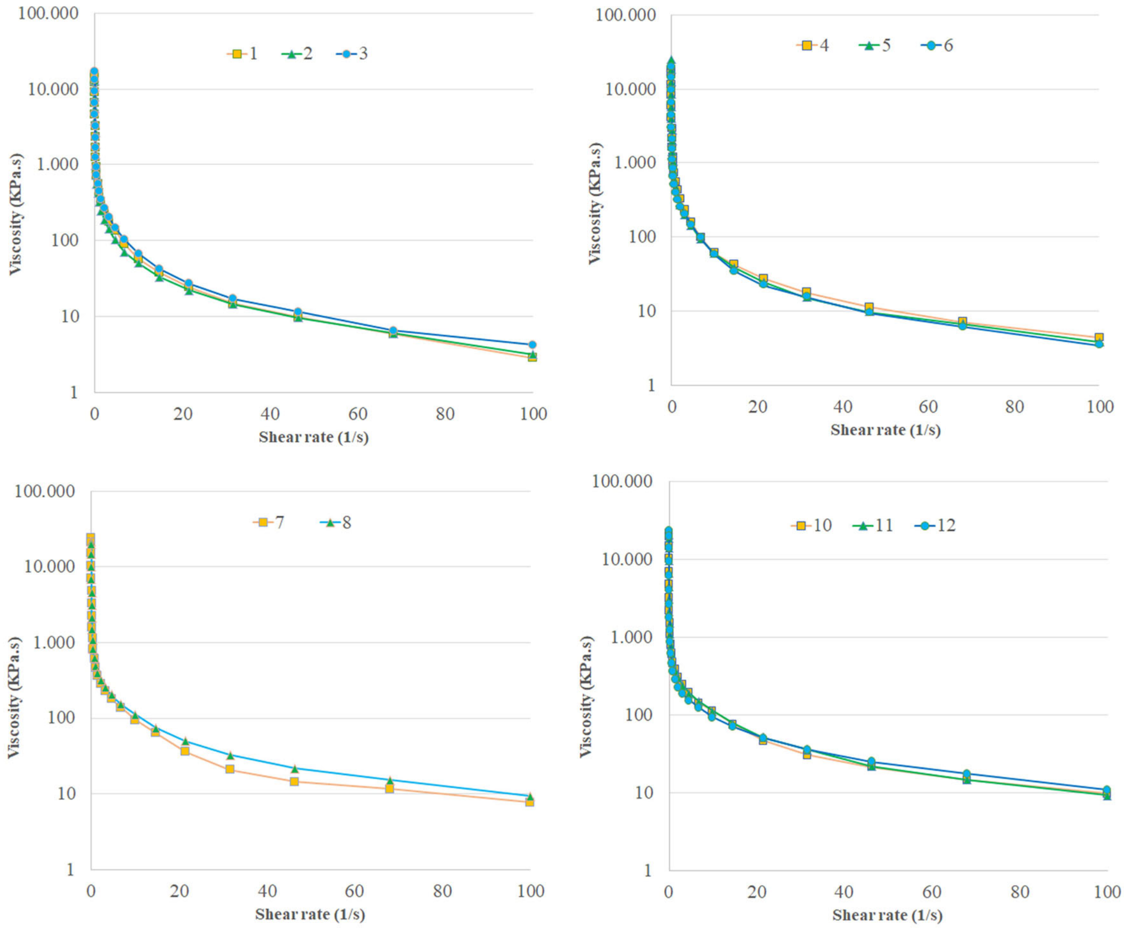

FIGURE 1 The effect of emulsifier use at different types/use ratios on the viscosity properties of cocoa hazelnut spread samples.

spread formulation reduces the viscosity relatively more than the use of Oil-Binder and GMS. The exact mechanism behind the viscosity-reducing effect of AMP is unknown, but it is likely that they act similarly to lecithin. The latter is considered related to the hydrophilic surfaces of carbohydrate and fat molecules. It is likely that AMP can aggregate closer to the particle surface due to its less bulky ammonium groups and thus does not form multilayers at a higher concentration than lecithin. This assumes that AMP is absorbed at a higher rate by the sugar particles. It is also claimed that AMP is more effective than lecithin in yield value (Hasenhuettl & Hartel, 2008; Norn, 2015a; Toker et al., 2024). However, there are insufficient data for all these assumptions.

Elastic modulus (storage modulus, *G'*) and viscous modulus (loss modulus, *G''*) values were also measured by a frequency sweep test applied in the linear viscoelastic regions of the samples in the range of 0–100 rad/s (Figure 2). The storage modulus *G'* (Pa) represents the elastic part of the viscoelastic behavior and describes the solid-state behavior of the sample. The loss modulus *G''* (Pa) characterizes the viscous part of the viscoelastic behavior, which can be seen, for example, as a liquid state behavior. Viscoelastic solids have a higher storage modulus than the loss modulus. This is due to chemical bonds or physical–chemical interactions within the sample. As the angular frequency increases, the *G'* value decreases and a tendency to show low resistance to the applied forces occurs, as in all examples such as the control sample. *G''* practically defines how much the filling resists changing its shape. In other words, it shows the feature of not returning to its original state when the force applied to the filling is removed. A chocolate spread with a high G'' value means that its spreadability value is low and it needs to be applied in thick layers for spreadability. In addition, a low *G''* value means low resistance to fluidity. *G'* values were higher than *G''* values, indicating the solid character of the cocoa hazelnut spread samples. Similar results were reported in previous studies (Acan et al., 2021a).

3.4 | Stability of cocoa hazelnut spread

The food products are exposed to different temperature variations during the storage period as in the market or as in homes due to temperature differences in daytime

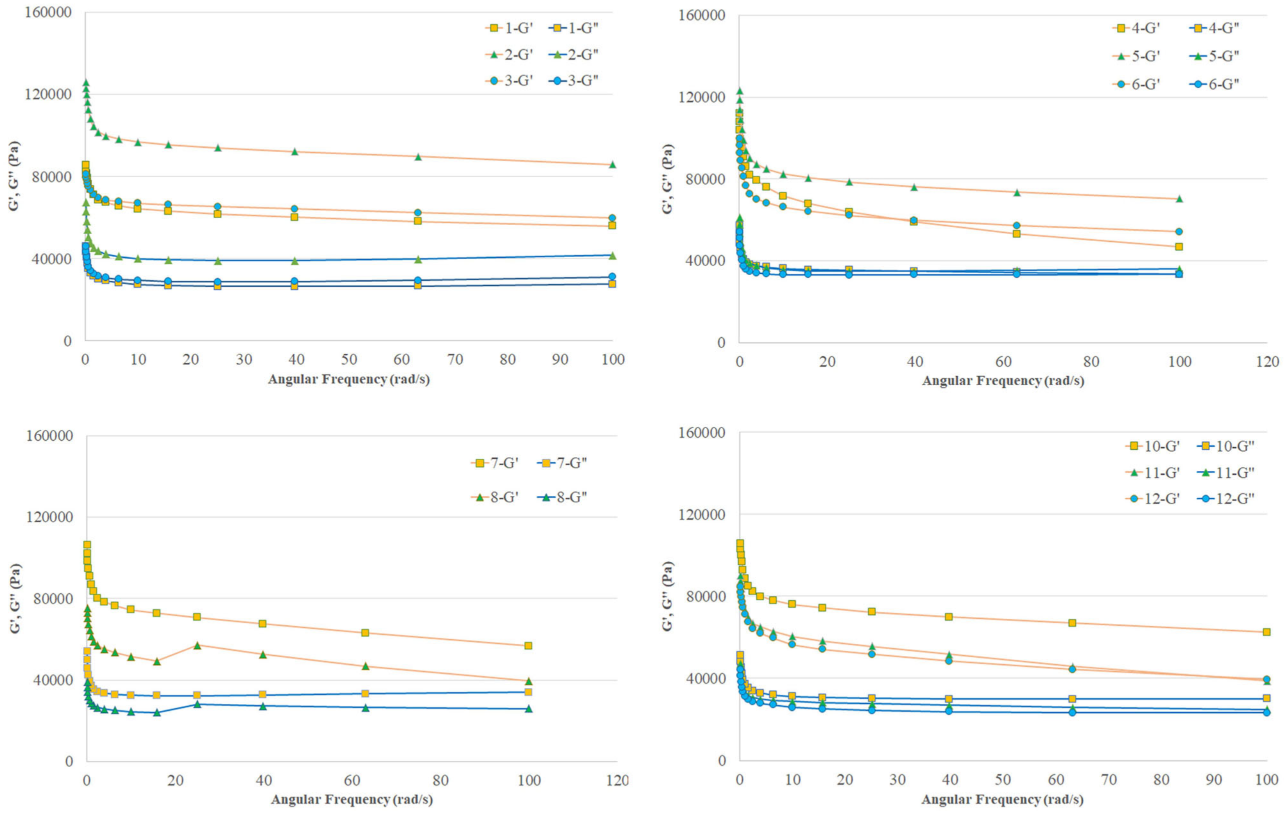

FIGURE 2 The effect of using emulsifiers in different types/use ratios on the rheological properties of cocoa hazelnut spread samples.

and season in a year. These variations can result in quality problems in products. Considering spread products, such temperature fluctuations during storage cause the melting of fat and separation of this melted fat from the matrix and then gathering of fat on the surface of the sample. This phenomenon negatively affects the quality properties of the samples. Rheometers can be used to simulate this temperature fluctuation and provide important and valuable data in a short time. In this test, the sample is exposed to temperature cycles and the change in the *G'* values depending on the cycle is measured. This test was satisfactorily applied in oil-in-water emulsions (Tekin et al., 2020).

Figure 3 shows the changes in *G'* values in high temperature (23°C–45°C) cycle tests of cocoa hazelnut spread samples containing emulsifiers at different types/use ratios. Significant changes in the maximum point of *G'* at each cycle are indicative of emulsion instability during thermally induced cycles.

The Δ values of the samples containing 0.3%, 0.4%, and 0.5% lecithin were found as 0.55, 0.16, and 0.23, respectively. The 0.4% lecithin concentration provided better stability than the other concentrations.. When the samples containing 0.3%, 0.4%, and 0.5% concentration AMP were calculated, Δ values were found to be 0.08, 0.57, and 0.23, respectively. The 0.3% concentration provided better stabilization for AMP. The Δ values of the samples containing 0.3% and 0.4% Oil-Binder and 0.3%, 0.4%, and 0.5% concentrations of GMS were all zero. Oil-Binder and GMS seem to provide very good stabilization at these concentrations. It was determined that the samples containing Oil-Binder and GMS showed better stability compared with the samples containing AMP and lecithin. In summary, emulsifier type and concentration significantly affected the stability of cocoa hazelnut spread samples. The results showed that the optimization of the emulsifier type and concentration is crucial for the production of the desired quality spread during the storage period. Oil separation from the spreads can be prevented by optimizing the type and amount of emulsifier to be used in the spreads.

3.5 | Effect of storage time on the hardness value of the spreads

The hardness parameter is essential in terms of sensory properties during consumption. In this respect, measuring the hardness parameter is an important indicator to evaluate the qualitative changes of chocolates with different formulations. It is known that the hardness of chocolate is related to the type and amount of oil used, emulsifier type and usage rate, sugar type, and amount, as well as parameters such as grain size distribution, tempering conditions,

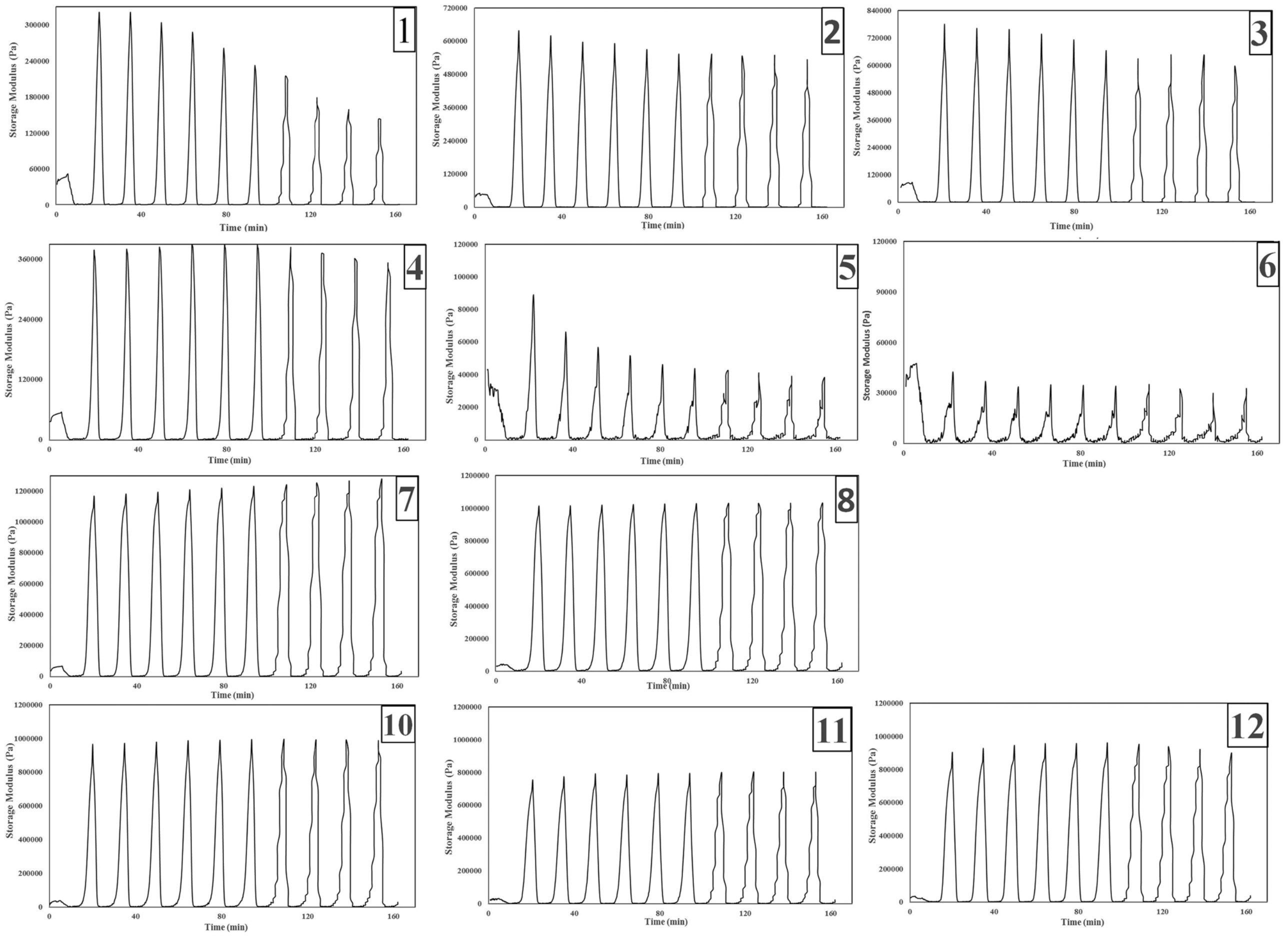

FIGURE 3 The effect of using emulsifiers in different types/use ratios on the stability of cocoa hazelnut spread samples.

and conching temperature depending on the processing processes. The hardness value has an inverse relationship due to the interaction between the particles depending on the particle size (Toker et al., 2021). The effect of partial changes in emulsifier type/use ratio and sugar content on the hardness of chocolate using the fixed product formulation was examined in Table 3. The changes in the hardness value of the cocoa hazelnut spreads produced at each experimental point up to 60 days at 15-day intervals were examined.

When the changes in the hardness value according to the emulsifier types and concentrations are examined, a statistically significant increase and distinction is observed only at 0.5% concentration of lecithin for day 0. A statistically significant increase was observed in the hardness value only at 0.3% Oil-Binder concentration on the 15th day. Although there is no statistical difference between the different concentrations of lecithin and AMP on the 30th day, differences can be seen between the concentrations of Oil-Binder and GMS. Especially at 0.3% GMS concentration, the hardness increased statistically significantly. On the 45th day, similar to the 30th day, there was no statistical difference between the different concentrations of lecithin and AMP in terms of hardness value, while statistically significant differences could be observed in the concentrations of Oil-Binder and GMS. Especially at 0.4% GMS concentration, the hardness increased statistically significantly. On the 60th day, there was a statistical difference between lecithin and AMP, and no difference was found between GMS and Oil-Binder in terms of hardness value. When the hardness values were examined for 60 days according to the concentration differences, a statistically significant increase was observed for lecithin only at 0.3%–0.4% concentrations on the 30th day. No other difference was found between hardness values over 60 days. For AMP, a statistically significant increase is observed at 0.4%–0.5% concentrations in the 45th-day hardness values. Similarly, a statistically significant increase is observed at 0.3%–0.4% concentrations in the 45th-day hardness values for GMS. In summary, there is a statistically significant increase in hardness value on day 0 for lecithin only at 0.5% concentration, while no difference can be observed at other concentrations and storage days. For AMP, significant differences are observed in the hardness values on

TABLE 3 The effect of different emulsifier types/use ratios on the hardness value of cocoa hazelnut spread for 60 days.

Samples	Hardness (g)				
	0.day	15.day	30.day	45.day	60.day
1	320.5 ± 28.2abcAx	336.3 ± 64.0aAx	402.0 ± 2.8aBx	349.5 ± 13.4aAx	336.0 ± 8.49aAx
2	334.2 ± 19.4abcAx	407.5 ± 17.7aAx	424.0 ± 3.2aBx	442.0 ± 84.9aAx	335.0 ± 65.0aAx
3	420.5 ± 14.7cAy	377.0 ± 33.9aAxy	356.5 ± 10.6aAxy	343.0 ± 60.3aAxy	273.0 ± 26.8aAx
4	322.5 ± 45.9abAx	353.3 ± 61.6aAx	419.0 ± 45.3aAx	400.0 ± 38.2aAx	665.0 ± 52.3bAy
5	369.3 ± 78.2bcAx	356.0 ± 68.4aAx	458.3 ± 54.4aAxy	627.5 ± 37.5aBy	629.0 ± 42.4bAy
6	238.0 ± 9.9abcAx	297.0 ± 4.2aAx	408.0 ± 25.5aAxy	514.0 ± 50.9aABy	551.3 ± 85.0abAy
7	408.0 ± 19.8abcx	603.0 ± 50.9bx	1155.5 ± 159.1bcy	1140.0 ± 91.9by	1300.0 ± 52.2cy
8	135.6 ± 32.8abx	334.7 ± 49.0ax	982.0 ± 65.1by	1310.0 ± 125.4by	1385.0 ± 198.7cy
10	143.0 ± 29.5abAx	264.0 ± 52.3aAx	1613.0 ± 49.5dAz	1704.3 ± 49.0cABz	1251.0 ± 73.5cAy
11	118.0 ± 24.0aAx	378.0 ± 33.9aAx	1228.0 ± 174.9bcAy	2099.5 ± 234.1dBz	1461.0 ± 53.7cAy
12	116.5 ± 20.5aAx	322.5 ± 17.7aAx	1359.5 ± 60.1cAy	1379.0 ± 32.5bAy	1394.0 ± 103.2cAy

Analysis could not be performed in sample 9 due to excessive viscosity increase.
According to the results of this analysis, three-way ANOVA (Duncan) test was applied in order to have a three-way interaction and to better analyze the data ($p < 0.05$).
The letters a–b–c–d in the same column indicated with lowercase letters were used for the statistical comparison of 11 samples with each other.
The letters A–B–C–D shown in capital letters in the same column were used for statistical comparison of three different concentrations of each emulsifier separately. The tests were not performed for 7–8 because there were fewer than three groups.
Lowercase letters x–y–z were used in the same column for statistical comparison of the change of analysis results of each sample according to time with each other.

the 60th day at 0.3% concentration and on the 45th day at 0.4%–0.5% concentration. For Oil-Binder and GMS, there was an increase in the hardness value at each concentration as of the 30th day. In this study, where the production method is the same, it is seen that the desired hardness can be obtained by changing the emulsifier type/ratio or by combining the emulsifiers.

3.6 | Sensory properties of cocoa hazelnut spread

According to the sensory analysis results, different emulsifiers added to the cocoa hazelnut spread formulation and different usage rates of these emulsifiers did not cause a significant change compared with the control sample. When panelists' evaluations are examined, color values are lower in the use of lecithin and AMP compared with the control sample, while color values at different usage rates of other emulsifiers are consistent with the control sample. As for the brightness value, no significant change was observed with different emulsifiers and different ratios of these emulsifiers compared with the control sample. Although there is no significant difference in the effects of emulsifiers on spreadability and mouthfeel values compared with the control sample, it is seen that the use of GMS reduces the spreadability and mouthfeel values. For taste value, it was observed that the use of lecithin and AMP emulsifiers in different proportions was consistent with the control sample, while the use of other emulsifiers in different proportions was stated by the panelists to reduce the taste values (Figure 4).

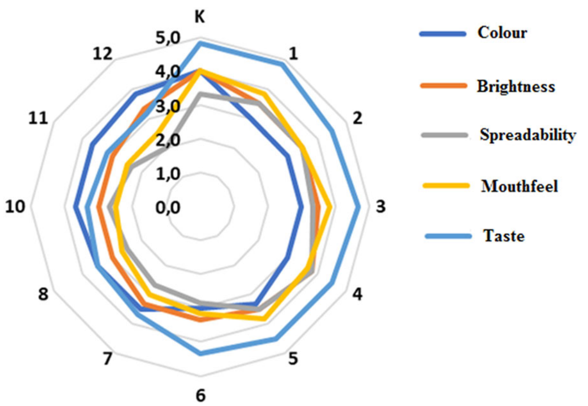

FIGURE 4 The effect of using emulsifiers in different types/use ratios on the sensory properties of chocolate (The range of scores with the level of acceptability which is 4.01–5.00 as highly acceptable; 3.01–4.00 as acceptable; 2.01–3.00 as moderately acceptable; 1.01–2.00 as slightly acceptable and 0–1.00 as not acceptable).

4 | CONCLUSION

Emulsifiers reduce the interfacial tension between the dispersed and continuous phases and play a role in regulating the flow character of chocolate by rheological lowering the viscosity of chocolate. In addition to lecithin, AMP, GMS, and Oil-Binder were compared in samples of cocoa hazelnut spread under the same process conditions and formulation. Emulsifier types and different usage rates did not affect the color values of cocoa hazelnut spread samples. It can be said that the use of lecithin and AMP in the chocolate formulation reduces the viscosity relatively more than the use of Oil-Binder and GMS. This means that by using lecithin and AMP, it is possible to produce cocoa hazelnut cream with less hardness and lower viscosity, more fluid, better spreadability, and lower "work of shear" value compared with other emulsifiers. It was determined that the use of Oil-Binder and GMS in cocoa hazelnut spread samples significantly preserved the stability compared with other emulsifiers. In this study, where the production method is the same, it has been seen that the desired hardness of cocoa hazelnut spread can be produced by changing the emulsifier type/ratio or by using combined emulsifiers. During the 60-day storage period, lecithin retained its hardness properties better than other emulsifiers. When sensory properties were examined, the use of lecithin and AMP in cocoa hazelnut spread samples scored high for shine, spreadability, mouthfeel, and taste parameters.

Furthermore, it is essential to explore the economic feasibility and scalability of employing different emulsifiers in large-scale food production settings. Although current research highlights the benefits of lecithin and AMP in cocoa hazelnut spread formulation, broader investigations into cost-effectiveness, supply chain reliability, and production efficiency are critical. Understanding how these emulsifiers integrate into existing manufacturing processes and their impact on overall production costs can provide valuable insights for industry decision-makers. Ultimately, advancing research in these areas would support the food industry in meeting evolving consumer demands while maintaining competitiveness in the global market.

AUTHOR CONTRIBUTIONS

Necattin Cihat Icyer: Writing—original draft; visualization; methodology; resources; data curation; conceptualization; investigation. **Duygu Ozmen**: Investigation; conceptualization; writing—original draft. **Dilek Sener**: Project administration; validation; writing—original draft; supervision. **Nagihan Kokyar**: Conceptualization; project administration; supervision. **Omer Said Toker**: Writing—original draft; conceptualization; investigation; writing—review and editing; validation; methodology.

CONFLICT OF INTEREST STATEMENT

The authors declared that they have no conflict of interest.

DATA AVAILABILITY STATEMENT

Data can be shared upon request.

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