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Research Article

Evaluation of Physicochemical and Sensorial Quality of Nonconventional Olive-Enriched Snack with Biopolymer Barriers

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The freeze-dried snack enriched with olives was produced with different biopolymer supports in order to improve the texture and high microencapsulation of olive biomolecules in the matrix for the first time. The effects of biopolymers used to increase storage stability in terms of desired texture properties on existing texture and sensory profile were evaluated. The healthy olive-enriched snack formulated with modified potato starch, maltodextrin, sodium alginate, and gum arabic was obtained using the freeze-dry technique with 20.93% drying efficiency. The smallest pore diameter and homogeneous porosity were obtained in the snack containing sodium alginate. The addition of maltodextrin resulted in larger pores and greater porosity. Large pores and random pore distribution are striking in the snack recipe without biopolymer. Large porosity and voids caused increased brittleness in the control sample without biopolymer. While the hardness increased in the sample containing sodium alginate, the fracturability remained lower than the other polymer supports. The fracturability value determined in the sample without polymers was determined to not be able to protect the integrity of the product during packaging and storage. The highest rehydration ability (7.85%) was obtained in the sample containing sodium alginate. Maltodextrin gave higher fracturability (10.552 mm) and the lowest hardness value (12.00 N) compared to other polymer supports at the concentration used. Maltodextrin gave the lowest astringency value in olive-enriched snacks. The lowest glass transition temperature (80.0°C) was obtained in the maltodextrin-added snack. The addition of sodium alginate delayed the onset of oxidation (OT_s, 211°C). With the biopolymer supports used, functional and different taste snacks with nutritionally rich content were produced.

1. Introduction

The rise in the living standards of the consumers, the fact that they begin to question the effects of the foods they buy on health, and the increase in obesity and death rates due to unhealthy nutrition lead researchers to focus on the foods consumed, to search for ways to maintain a healthy life and prevent diseases. This orientation has enabled them to prefer natural vegetables, herbs, and fruits instead of products with medicinal effects such as drugs [1]. The fact that antioxidant substances taken from plants create a protective shield against the effects of oxygen and other harmful substances entering the body, which causes deformation of cells, increases the interest in natural products and the importance of functional food products [2]. Functional food concept is defined as foods that provide health benefits as well as meeting the nutritional needs of the organism. Phenolic compounds found in many fruits and vegetables have started to be widely used in various functional food development studies thanks to their antioxidant properties from natural substances containing [3].

Healthy functional product forms produced with fruit and vegetable sources rich in these biocomponents have led to an increased interest in today's ready-to-eat products. With the increasing awareness of healthy nutrition, healthy snacks that can replace meals in order to meet basic nutritional needs in activities such as travel, camping, and mountaineering will be of interest. The demand for these foods has the potential to create a market over time [4].

Olive is among the most important components of healthy diet trends. It is a rich source of bioactive components such as unsaturated fatty acids (oleic acid, palmitoleic acid, linoleic acid, and linolenic acid), as well as many phenolic compounds such as oleuropein, hydroxytrosol, trosol, caffeic acid, and rutin [5]. Protective effects of olive phenolics against cancer and neurodegenerative and cardiovascular diseases have been reported [6].

Microencapsulation technologies are a process applied to encapsulate micron-level molecules and components by entrapping them in the main or secondary support matrix [7]. Those technologies aim to prevent deformations of bioactive ingredients during consumption beyond improving the production and storage stability [5]. Freeze-drying is a microencapsulation technique used for entrapping of thermally sensitive bioactive components [8]. Process parameters and matrix composition are known to affect encapsulation efficiency, microstructure, and thermophysical properties [9, 10]. The method includes the basic steps of freezing and then drying the preprepared food [11]. The limiting factor is the expensive and lengthy processing requirement of the technology [12]. In the freeze-drying process, the foods are dried as a whole, sliced, or mashed, and the obtained dry products can be consumed whole or in powder form after grinding. The dried foods had low volume and low molecular weight which are easily packaged and transported [13]. In addition, with the increasing tendency towards natural substances in recent years, food powders processed by freeze-drying have been used as color and flavoring agents for foods [14]. High rehydration capacities, good color and flavor properties, and minimal nutrient losses are other advantages of this technology. Freeze-dried products can be stored and transported at room temperature without the need for a cold chain [15]. Offering a longer shelf life makes it advantageous over other drying methods.

Drying by ice sublimation can lead to increased porosity, precipitation in carbohydrate structures, and a rubbery structure during storage. The increase in the rubberiness causes the product to soften and the desired crispiness to be lost. It has been reported that processing at temperatures below the critical moisture value and glass transition temperature in dried products is an effective method to prevent the loss of crispiness during storage [16]. It has also been reported that reducing the glass transition temperature and critical humidity value increases the storage quality and life of the product. It will be possible to reduce product losses by designing processes to reduce glass transition temperature and critical humidity values. Increasing the glass transition points of freeze-dried fruit snacks with biopolymer supports prevents color and aroma losses as well as leads to structural improvements that have been reported in previous studies [17–19]. High molecular weight hydrophilic biopolymers are used in the food industry due to their functional properties such as stabilizing, gel forming, oil replacement, increasing encapsulation efficiency, adhesion, nutritional values, and probiotic effects, which act as thickeners, gelling agents, improving rheological and textural properties, and as foam and emulsion stabilizers [20]. These biopolymers function to inhibit the growth and expansion of ice and sugar crystals in frozen foods. Among the biopolymer supports consisting of plant, animal, and modified structures, sodium alginate, gum arabic, maltodextrin, and modified potato starch have a wide range of uses [21–24]. However, the effects of these additives during the freeze-dry process vary depending on the amount used, process parameters, and amorphous solid properties [25, 26].

The production of healthy snacks produced by freeze-drying has been the subject of many studies [27–35]. However, there is no report on freeze-dry snack enriched with olives. In this study, the possibilities of producing healthy, functional olive-based snacks were investigated by freeze-drying technology using biopolymer supports such as modified potato starch, gum arabic, sodium alginate, and maltodextrin. The olive-based product enriched with the high quality oil and phenolic components from olive is designed to allow long-lasting, functional, and timeless consumption. It is aimed at providing the desired crispness and increasing storage stability by preventing sensorial disadvantages such as loss of flavor and color components and sandiness caused by other drying methods.

2. Materials and Methods

2.1. Materials. Domat variety green olives (*Olea europaea* L.) in brine and tomatoes used as flavoring were purchased at a local market. Curd cheese (lor) containing high serum protein, obtained by pasteurization of whey, was purchased from the local market. Endemic mountain thyme was used as a seasoning. The diacetyl tartaric acid esterified modified potato starch (MPS, from local market), gum arabic (GA, Sigma-Aldrich Chemie GmbH, Eschenstr. 5, Germany), sodium alginate (SA, Alfa Chemistry, Ronkonkoma, NY 11779-7329, USA), and maltodekstrin (MD, Arshine food, China) were used as biopolymer. All chemicals used (Merck KGaA, Darmstadt, Germany) in the present study were of analytical grade.

2.2. Snack Preparation and Drying Process. In order to prepare olive snack, pitted domat olives (80%) and tomatoes (16.59%) at the rate determined by preliminary trials were pureed with a household blender (Beko, HB 5970, China). The olive-based puree, curd cheese (lor), thyme, and biopolymers were mixed using stand mixer (Arzum, AR1069, China) for 10 min. The biopolymers are equally selected to ensure the physical stability of the dried product. Five different recipes were prepared while the polymer-free sample was the control (Table 1). Olive-based snack premixes were frozen using cubic silicone molds (1×1 cm) at $-20 \pm 2^{\circ}$C for 24 h. The frozen snack cubes were freeze-dried at -43°C (freezing) and $+52^{\circ}$C (the final drying) at a flow rate of 6 CFM and a pressure of 0.2 MPa for 19 h using a freeze-dryer (Harvest Right, LLC, China). Finally, the freeze-dried olive snacks were stored in oxygen and water-tight doypack packages at $+20 \pm 2^{\circ}$C until to be used for laboratory tests (Figure 1).

2.3. Drying Efficiency and Physicochemical Aspects. The moisture content of both the fresh and freeze-dried olive snacks was determined. The snack premixes (weighing

Table 1: Code of snacks as a function of the matching recipe.

Premix	Biopolymers	g/100 g olive-based puree
Control	—	—
C+MPS	Modify potato starch	3.41
C+GA	Gum arabic	3.41
C+SA	Sodium alginate	3.41
C+MD	Maltodextrin	3.41

approximately 3 grams) were placed in meter cups and then placed inside a vacuum oven (Elektromag M420P) at 105°C and 600 mmHg vacuum until a constant weight described by ICC No. 110/1 (AOAC method 977.11) was reached [36]. The following equation was used for calculating the moisture content (MC):

$$\mathrm{MC} = \frac{(W_1 - W_2)}{(W_2 - W_3)} \times 100, \tag{1}$$

where W_1 is the initial weight of the weigh bucket and the sample, W_2 the final weight of the weigh bucket, and W_3 the sample and the weight of the weigh bucket that is expressed.

Since the shrinkage value, which is an important parameter in dried foods, cannot be measured accurately in olive-based snacks due to rehydration, determined by measuring three dimensions in uniform cubic-shaped frozen premix and freeze-dried snacks, the results were calculated in cubic centimeter according to the following equation:

$$V = a * b * c. \tag{2}$$

The dry samples were weighed and placed into a glass baker containing 150 mL of distilled water at room temperature for 6 h to measure of rehydration capacity (RC). The samples were placed on clean and dry filter paper to remove the water. The following equation was used for estimation of the rehydration capacity.

Rehydration capacity (RC) was determined described at [37]. The samples obtained after drying were weighed and put into tared centrifuge tubes, and 50 mL of distilled water was added. The rehydration process was continued for 24 hours, and at the end of the specified time, the samples were centrifuged (Electromag M815A) at 2500 rpm for 15 minutes. After the procedure, the tubes were weighed again and calculated according to the following formula:

$$\mathrm{RC} = \frac{m}{m0}. \tag{3}$$

The drying efficiency (DE) was calculated using equation (4) based on sample weights before and after drying [38].

$$\text{Drying efficieny } (\%) = [W_2 - W_1] \times 100. \tag{4}$$

2.4. Thermal Aspects. Thermal aspects were determined using a differential scanning calorimeter (DSC) (Hitachi High-Tech Sciences DSC7020, Japan) by measuring the onset ($\mathrm{Tg_o}$), midpoint ($\mathrm{Tg_m}$), endpoint ($\mathrm{Tg_e}$), and oxidation onset of the freeze-dried snacks. First, the DSC was calibrated using indium (Tonset = 155.74°C and ΔH = 28.69 J/g). Nearly 10 mg of the each pellet was placed into the aluminum DSC pans. The reference was an empty pan. The pans were closed hermetically. The heating process was performed in increments of 5°C/min from 30°C to 250°C.

2.5. Texture Profile and Morphological Aspects. The texture aspects of freeze-dried olive snacks were determined by measuring the hardness and fracturability parameters using a texture analyzer (TA-XT Plus, Stable Micro System, UK). The 10 ∗ 10 mm portions of freeze-dried olive snacks were compressed using a 36 mm diameter stainless steel cylindrical head with a test speed of 3 $\mathrm{mms^{-1}}$. The hardness value is the first force in Newton required to provide a certain deformation in the structure of the snack. Fracturability value is defined as the expression in millimeter of the deformation value caused by the force required to break the sample [39].

Microstructure properties of freeze-dry olive snacks were determined with micrograph images (×100-1000x) magnified at different rates. The micrograph images were obtained using scanning electron microscopy (SEM) (FEI Quanta 250 FEG, USA) by coating a very thin layer of gold on snack surfaces (thickness 0.1 cm).

2.6. Color Aspects. The color measurements were performed for the fresh and freeze-dried snack samples using the colorimeter device (LC100, Lovibond, Maharashtra, India). The color parameters evaluated included lightness (L^* value), redness (a^* value), and yellowness (b^* value). The white tile was used for calibrating the instrument as instructed by the manufacturer [40]. The other color attributes, such as chroma (saturation) and hue (h) angle, were evaluated using the following equations:

$$\begin{aligned} \text{Chroma} &= \sqrt{\left(a^2 + b^2\right)}, \\ \text{Hue angle} &= \tan^{-1} + \left(\frac{b}{a}\right). \end{aligned} \tag{5}$$

2.7. Sensorial Aspects. The sensorial aspects of the produced olive snacks were evaluated in the form of with trained panelists ($n = 85$), describing to the quantitative descriptive analysis (QDA) method and ISO 13299:2016 standard. Profile was characterized by appearance (smoothness, roughness, and color), odor (milk odor, fruit odor, and oil odor), taste (bitter, fruity taste, and oily taste), and texture (crispness, chewiness, grittiness, and permanence in the mouth). The intensity of those qualifications was rated on a hedonic scale from "0 = imperceptible" to "5 = very intense". The samples were coded (three digits) by labeling randomly. The samples were randomly presented to the panelists according to the experimental design established by applying the randomized block design (RCBD) [41].

2.8. Statistical Analysis. Results in this study were evaluated using Minitab 20 (Minitab Inc., State College, PA, USA) with mean values of standard deviation ($n = 2 \pm \mathrm{SD}$) of two separate data sets. Analysis of variance (ANOVA) and

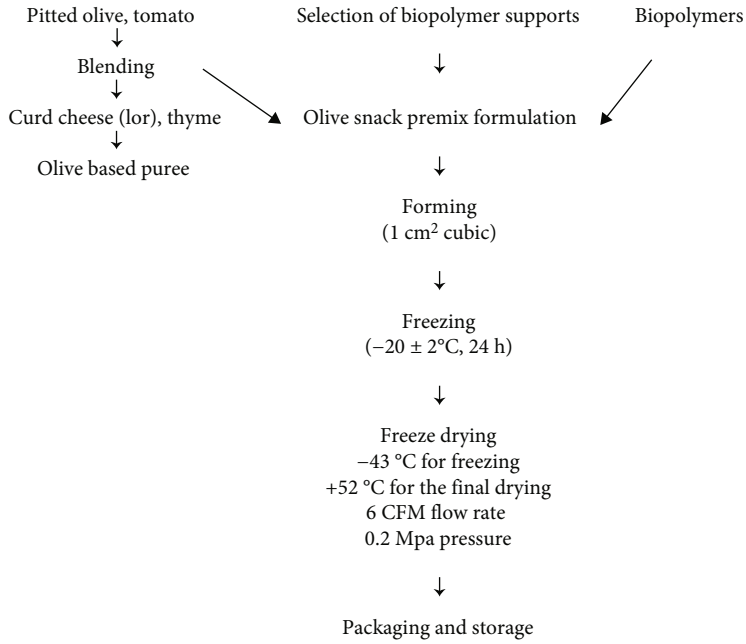


Figure 1: The process diagram used in the production of olive snacks.

Tukey test were used to determine significant differences in $p \leq .05$ for multiple variables. The relationship between the means was determined using linear correlation analysis [42].

3. Results and Discussion

3.1. Moisture Content. Moisture rates of fresh olive enriched snacks are between 70.33% and 68.19% (Table 2). The sample containing sodium alginate (SA) stood out with the least moisture content among the premixes (Table 3). The moisture contents of freeze-dried samples varied from 1.70% to 2.30%. No significant difference was found between the moisture content of freeze-dried olive snacks ($p > .05$). On the other hand, a significant difference ($p < .05$) was determined between C and other premixes while the difference in moisture contents of C+MPS and C premixes was not significant statistically ($p > .05$). Before freeze-drying, no statistically significant difference was detected between the other samples except the control (C) group ($p > .05$). The freeze-drying technology significantly reduced the moisture content of the all recipes ($p < .05$) (Table 3).

The main purpose of freeze-drying is to remove the maximum amount of water from the food while preserving the shape, aroma, and color of the product [43]. The moisture content of foods should be below 10% in order to be stored for a long time by preserving their physical and chemical properties which has been reported in previous studies [14]. Ciurzynska et al. [30] reported that the moisture content of freeze-dried multivegetable snack bars using sodium alginate and sodium lactate as hydrocollide is 0.78–1.52%, respectively, and 1.06%–1.33% in samples produced using xanthan gum and carob gum as gelling agents. Similarly, it has been reported that the moisture values of freeze-dry products produced using green and yellow bush beans, potatoes, carrots, and industrial apple pomace powder varied between 0.33% and 1.19% [44]. In freeze-dried snacks produced by adding pectin, dried apple, and blackcurrant pulp to a mixture of carrot, orange juice, ginger, and calcium lactate, moisture contents have been reported as 1.91%, 2.10%, and 2.55% [45]. As in the aforementioned studies, it was also determined in this study that the technology used caused a great decrease in moisture content despite the use of different hydrocolloids and fruit or vegetable bases.

3.2. Drying Efficiency. The profitability of a drying facility is associated with drying efficiency [34, 38]. Table 3 gives the drying efficiency results of the prepared mixtures. Olive snacks were freeze-dried with a drying efficiency of 29.42–32.90%. Among the biopolymer supports used, sodium alginate (SA) showed an unremarkable but slightly different increase effect on drying efficiency ($p > .05$) (Table 3). This is also marked by the fact that this sample has the greatest change in dry matter (Table 2). The moisture change caused by the difference between the amorphous matrices of the hydrocolloids used and the resulting microstructure properties affected not only the drying efficiency but also the texture properties of the product. However, it is obvious that different drying efficiencies can be obtained when different fiber contents and amorphous component ratios are combined.

3.3. Rehydration Capacity. As a result of the analysis, the rehydration capacities of the freeze-dried samples were between 5.58 and 7.85 (Table 3). All of the biopolymers added to the control group increased the rehydration capacity (Table 2). SA has the highest rehydration effect among other biopolymer supports. However, biopolymer support to snack mixes did not make a statistical difference in terms of rehydration capacity ($p > .05$). The rehydration of food is a complex phenomenon affected by many factors such as predrying processes, drying technology and conditions, food

Table 2: Physicochemical, color, and texture data of fresh and freeze-dried olive snacks.

	Snacks	MC	L^*	a^*	b^*	$h\circ$	C^*	T_g (°C)	OT_s (°C)	OT_m (°C)	OT_e (°C)	DE (%)	RC (%)	VR (%)	Fracturability (mm)	Hardness (N)
Premix	C+MPS	29.67^{ab}	53.70^{b}	9.80^{a}	20.50^{a}	64.5^{bc}	22.7^{a}	—	—	—	—	—	—	—		
	C+GA	30.93^{ab}	59.10^{a}	7.40^{a}	19.70^{a}	69.5^{a}	21.0^{a}									
	C+SA	31.81^{a}	58.10^{a}	8.90^{a}	20.90^{a}	67.0^{ab}	22.7^{a}									
	C+MD	30.88^{ab}	56.10^{ab}	9.20^{a}	19.30^{a}	64.5^{bc}	21.4^{a}									
	C	27.82^{b}	58.20^{a}	9.90^{a}	19.70^{a}	63.4^{c}	22.0^{a}									
Freeze-dried	C+MPS	2.30^{a}	55.50^{c}	12.80^{a}	27.70^{a}	65.1^{b}	30.5^{a}	$107^{o}C^{a}$	205^{c}	215^{a}	241^{a}	31.63^{a}	6.46^{a}	12.00^{ab}	9.478^{a}	51.34^{a}
	C+GA	1.70^{a}	60.40^{ab}	10.40^{a}	27.40^{a}	69.2^{a}	29.3^{a}	$91^{o}C^{b}$	209^{ab}	219^{a}	245^{a}	32.59^{a}	5.79^{a}	12.90^{a}	9.662^{a}	22.87^{b}
	C+SA	2.10^{a}	58.30^{bc}	11.30^{a}	25.70^{a}	66.3^{ab}	28.1^{a}	$82^{o}C^{cd}$	211^{a}	227^{a}	248^{a}	32.90^{a}	7.85^{a}	15.07^{a}	9.314^{a}	49.15^{a}
	C+MD	2.20^{a}	59.50^{b}	12.10^{a}	26.90^{a}	65.9^{ab}	29.5^{a}	$80^{o}C^{d}$	208^{abc}	218^{a}	239^{a}	32.33^{a}	6.40^{a}	6.58^{c}	10.552^{a}	12.00^{c}
	C	1.90^{a}	63.60^{a}	11.00^{a}	26.80^{a}	67.6^{ab}	28.9^{a}	$84^{o}C^{c}$	207^{bc}	222^{a}	240^{a}	29.42^{a}	5.58^{a}	8.88^{bc}	10.746^{a}	6.59^{d}

Note: the mean is based on duplicate analysis; for individual measured parameters, those various alphabets used to indicate different values within the same column are significantly different ($p \le .05$). C+MPS, C+GA, C+SA, C+MD, and C (control) are olive snacks.

Table 3: Statistical results of olive snacks.

Snacks	t	df	Sig. (2-tailed)	Mean	Lower	Upper	Negative ranks	Positive ranks	Ties	Std. deviation	Std. error mean
Premix L^*-FD L^*	-2.6720	4	0.056	-2.3320	-4.9347	0.09479	0^a	5^b	0^c	2.0253	0.90576
Premix a^*-FD a^*	-6.8420	4	0.002	-2.4800	-3.4864	-1.4735	0^a	5^b	0^c	0.8105	0.36249
Premix b^*-FD b^*	-12.924	4	0.000	-6.8800	-8.3580	-5.4019	0^a	5^b	0^c	1.1903	0.53235
Premix $h\circ$–FD h°	-1.1956	4	0.297	-1.0400	-3.4550	1.3750	2^a	3^b	0^c	1.9449	0.8698
Premix C^*-FD C^*	-13.722	4	0.000	-7.3000	-8.7770	-5.8229	0^a	5^b	0^c	1.1895	0.5319
Volume	13.731	4	0.000	0.6608	0.55758	0.76402	5^a	0^b	0^c	1.8638	0.04812
Premix MC-FD MC	-82.164	4	0.000	-4.1100	-5.0045	-3.2154	5^a	0^b	0^c	1.6153	0.41707
Premix V–FD V	7.340	4	0.002	0.66080	0.41083	0.91077	5^a	0^b	0^c	0.20132	0.09003
DE (%)							0^a	4^b	0^c		
RC							0^a	4^b	0^c		
OT_o (°C)							1^a	3^b	0^c		
OT_m (°C)							3^a	1^b	0^c		
OT_e (°C)							1^a	3^b	0^c		
T_g (°C)							2^a	2^b	0^c		

Note: the mean ± standard deviation is based on duplicate analysis; for individual measured parameters, those various alphabets used to indicate different values within the same column are significantly different ($p \le .05$). The glass transition (T_g), oxidation onset (Tg_o), midpoint (Tg_m), endpoint (Tg_e), drying efficiency (DE), rehydration capacity (RC), and moisture content (MC) of the premix and freeze-dried snacks are significantly different ($p \le .05$).

structure, composition, temperature, and retention time [46]. The most important feature sought is that when the product is hydrated, it can absorb the closest amount of water to the amount of water before the drying. However, the temperature of the water used during rehydration and the retention time of the product are important factors affecting the rehydration measurement. The rehydration capacity of freeze-dried pineapple, acerola, guava, mango, and papaya has been reported as 0.132, 0.420, 0.393, 0.129, and 0.113 (on dry matter) [47]. In another report, the rehydration capacity of onions dried in open air, solar dryer, cabinet dryer, vacuum dryer, and freeze-dryer has been measured as 5.07, 5.45, 5.50, 5.83, and 6.92%, respectively [38]. Lopez-Quigora et al. [48] determined the rehydration capacity of freeze-dried tomato samples reported as 52% for tomatoes rehydrated at 50°C and 37% for tomatoes rehydrated at 20°C. The drying process is defined as irreversible change [49]. The average rehydration capacity in industrial drying has stated approximately 3.5% in laboratory analyses [38].

3.4. Volume Reduction. The volumes of the premixes were determined before and after freeze-drying. Measured volumes range from 5.740 cm^3 to 6.163 cm^3 for fresh premixes and 5.050 cm^3 to 5.757 cm^3 for freeze-dried snacks. In total, volume shrinkage was determined between 6.58 and 15.07% (Table 2).

It was determined that after freeze-drying, all snacks decreased in volume (VR) (Table 4). The addition of MD led to less volume reduction, unlike other biopolymer supports. This recipe, in which the volume measurements were largely preserved in the control group without biopolymer, yielded positive results in terms of preserving the shape in olive snack production ($p < .05$). Other biopolymer supports caused a change much above the estimated shrinkage values (Table 4). MPS ($p < .05$) and GA and SA ($p > .05$) were found to increase VR (Table 4).

Volume change in freeze-dried products is much less than in other drying types. It has been reported that the low pressure applied in the process reduces the shrinkage and preserves the shape of the product [50]. Ciurzynska et al. [29] reported a volume reduction of 10.7%–13.01% in the snacks they produced after the freeze-drying process. Ciurzynska and Lenart [27] noticed that the volume reduction rates of freeze-dried gels containing low methoxyl pectin were 3–5%, and gels containing xanthan gum and guar gum resulted in higher shrinkage by 34–38%.

3.5. Color Aspects. It is known that among the sensory properties of foods, color acclaim is an important factor affecting consumer decision. The perception of quality food is often associated with the natural color and brightness of the product. It was determined that the L^* values were between 53.70 and 59.10, a^* values between 7.40 and 9.90, b^* values between 19.30 and 20.90, hue 63.4–67.0, and C^* values between 21.0 and 22.7 (Table 2) of the prepared premixes before freeze-drying. After freeze-drying, similar values were determined to vary between 55.50 and 63.60 for L^*, 10.40–12.80 for a^*, 25.70–27.70 for b^*, 65.1 9.2 hue angle and 28.1–30.5 for C^*, respectively.

The color values of the hydrocolloid-free samples after freeze-drying with other formulations containing hydrocolloid were compared in Table 3. L^* values decreased in mixtures containing modified potato starch (MPS), sodium alginate (SA), and maltodextrin (MD) after freeze-drying. Compared to the control group without hydrocolloid, only the change in the MPS-added group was significant

Table 4: Volume measurements before and after freeze-drying.

Snacks	Premix (cm^3)	Freeze-dried (cm^3)	Volume reduction (%)
C+MPS	5.855^a	5.135^a	12.00^b
C+GA	5.890^a	5.130^a	12.90^{ab}
C+SA	5.958^a	5.050^a	15.07^a
C+MD	6.163^a	5.757^a	6.58^c
Control (C)	5.740^a	5.230^a	8.88^c

($p < .05$). In the mixture with gum arabic added, the increase in L^* value after freeze-dry was similar to the change in the control group ($p > .05$). Biopolymer support decreased the a^* values of all mixtures before freeze-dry without any difference between them. However, this decrease was not statistically significant ($p > .05$). It was observed that MPS and SA addition increased the b^* value of pre-freeze-dry mixtures, while MD decreased the b^* value, while GA did not cause any change in the b^* value ($p > .05$). It was observed that all biopolymers added to the mixtures that were not freeze-dried increased the hue value, while this change was not significant in MPS- and MD-supported olive snacks compared to C ($p > .05$), but that increase was significant in mixtures supported by GA and SA ($p < .05$). Compared to the C group without hydrocolloid, MPS and SA biopolymers increased the C^* value, while GA and MD decreased ($p > .05$).

After drying, L^*, a^*, b^*, and C^* values of all mixtures increased, whereas hue values decreased. When the freeze-dried control group and the biopolymer-added samples were compared, contrary to the fresh samples, it was determined that the sample with the highest L^* value was the control group. When the L^* values of the freeze-dried control group and the biopolymer-added samples were compared, it was observed that the added biopolymers had a reducing effect on the L^* value by the freeze-drying process. This effect created a significant difference in the samples added MPS, SA, and MD, except for the sample with GA ($p < .05$). It was determined that the added MPS, SA, and MD increased the a^* value of the freeze-dried mixtures, while GA decreased the a^* value ($p > .05$). Support for MPS, GA, and MD increased the b^* value, while SA decreased it ($p > .05$). While GA added to freeze-dried samples increased the hue angle, other biopolymers had a reducing effect ($p > .05$). Except for the SA, all biopolymers decreased in the C^* value of freeze-dried olive snacks ($p > .05$).

Freeze-drying increased the L^* ($p > .05$), a^* ($p < .05$), b^* ($p < .05$), and C ($p < .05$) values of all mixtures. However, unlike other color parameters, there was no uniform change in hue angle, an increase was observed in the hue value of 3 samples, while a decrease was observed in the hue values of 2 samples ($p > .05$).

Halil et al. [51] reported a decrease in the L^* and a^* values of the chips with green olive added, which they produced using vacuum, microwave, and convection drying methods. Furthermore, they reported that while the b^* value remained constant by the microwave method, a decrease was observed in the b^* value of other products. The methods mentioned are high-temperature application, and it has been also reported that there is significant enzymatic browning during drying. Clearer L^* values have been reported after freeze-drying of apples, bananas, potatoes, and carrots compared to convective, vacuum, microwave, and osmotic systems [52]. Furthermore, it has been also reported that there was no browning in samples dried with all the freeze and osmotic drying methods. Rajkumar et al. [53] reported a statistically significant increase in L^*, a^*, b^*, and 5^* values of freeze-dried carrot slice compared to fresh carrot slices and a nonsignificant decrease in hue value. It has been reported that the L^*, a^*, and b^* value of freeze-dried apple cubes increased after drying, the C^* value remained the same, and the hue value decreased [11]. In freeze-dried orange-based snacks produced with the addition of gum arabic, modified potato starch, and maltodextrin, it has been reported that biopolymer supplementation increased L^* and hue values and decreased C^* values compared to the group without biopolymer [19]. Contrary to what has been reported in other studies, Pieniazek and Messina [54] have reported that a decrease in L^*, a^*, and b^* values associated with enzymatic browning occurred in freeze-dried peach samples stored at different temperatures. In the same study, it was reported that the whitish color of biopolymers caused an increase in the L^* value. Thanks to the remove of moisture by the sublimation, the increase in the C^* value reveals that the colors do not fade; on the contrary, they become alive. b^* values are thought to increase depending on the L^* value. Hue angles before and after drying were similar. In this case, it was determined that the color changing that can be perceived by the human eye after drying is very little.

3.6. Textural and Morphological Aspects. One of the most important factors affecting the consumer's perception of taste is the texture properties of the product. The properties expected from the texture vary according to each product. While hardness and fracturability are expected in a dried product, softness is expected in a boiled product. As a result of preliminary studies, it has been determined that freeze-dried olive-based products with high oil content have a sandy and fracturable structure. It is thought that it is caused by the barrier formed on the surface by the entrained oil along with the moisture release during the sublimation phase of olives with high oil content. In this study, biopolymers were added to find a solution to the fracturability and sandiness problem. The hardness and fracturability values of the samples after freeze-drying are shown in Table 2 as Newton and millimeter, respectively. It was determined that the highest hardness value belonged to the C+MPS sample (Figure 2). It was determined that the control group not supported with biopolymer had the lowest hardness value. MPS and SA had a high effect on the textural properties of the samples by increasing the hardness. Compared to the control sample, GA increased the hardness of the sample but that increase was less than supported with MPS and SA biopolymers ($p < .05$). MD increased the hardness of the product compared to the control group sample, but this ratio was found to be lower compared to other biopolymers used

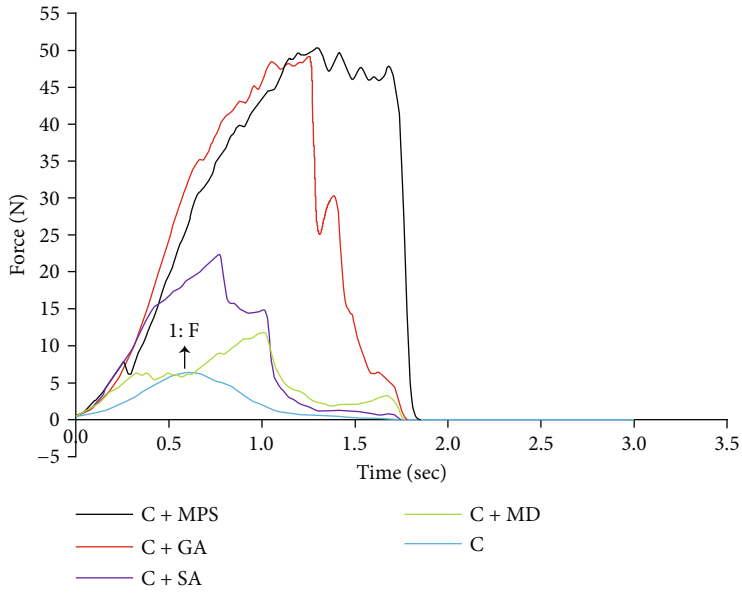


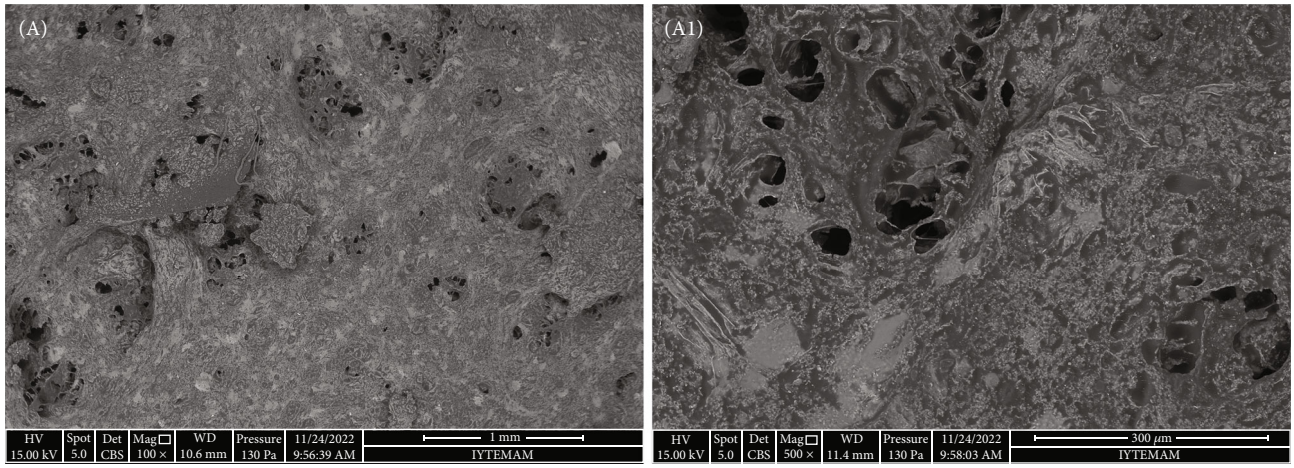
Figure 2: Texture analysis hardness parameter results of freeze-dried snacks.

($p < .05$). The fracturability values of the samples obtained within the scope of the study are between 9.478 and 10.746 mm. It was determined that the highest fracturability value belonged to the control (C) group although the fracturability values of the samples are close to each other. The lowest fracturability was obtained from the C+MPS sample. The usage of the SA, GA, and MD biopolymers decreased the fracturability compared to the biopolymer-free snack ($p < .05$). From an industrial point of view, low sandiness and fracturability with high hardness values are expected as an expression of the measurability of perceived crispiness. The hardness values of C+MPS and C+SA samples have no statistically significant difference ($p > .05$). However, hardness values of C+GA, C+MD, and C samples were statistically different from these results and from each other ($p < .05$). No statistically significant difference was found in terms of fracturability in all prepared recipes ($p < .05$). Although the differences between biopolymer supports in terms of fracturability were not statistically significant ($p > .05$), they became meaningful with the change in hardness value as previously reported. In that case, MPS and SA, which are biopolymers used due to increase the hardness value and decrease the fracturability value, will be the most suitable biopolymers for olive snack production.

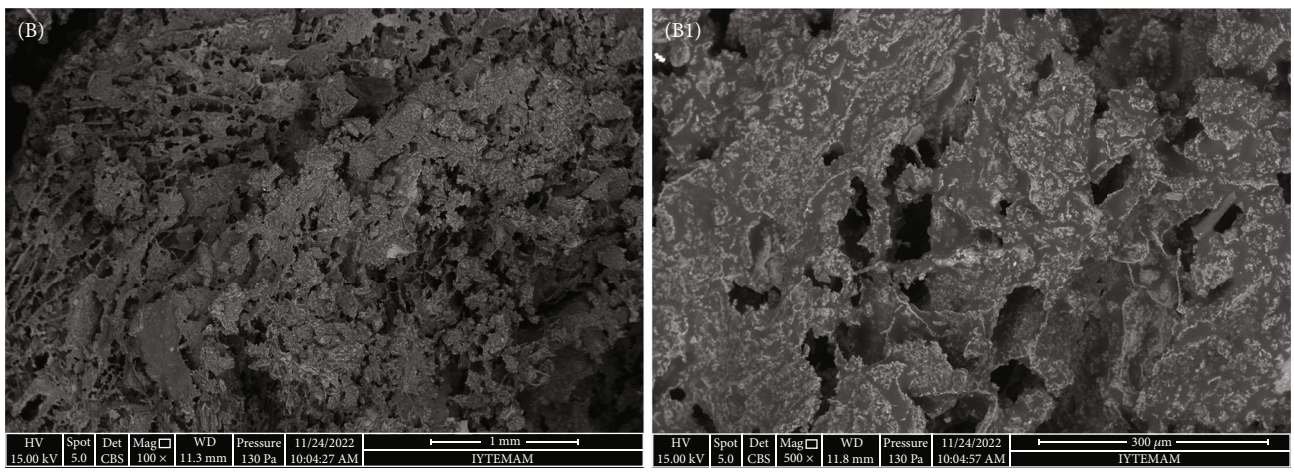
Scanning electron microscopy (SEM) was used to determine the macro- and microstructure of the samples containing different biopolymers and the control group without biopolymers. Micrographs are given in Figure 3 with ×100-×500 magnification. In the sample without biopolymer (C), long pores appear after sublimation of ice crystals growing in the direction of the cell (Figure 3(e_1)). Larger and irregular pores were formed as a result of the tearing of the cell walls by sublimation. With the addition of sodium alginate, the pores turned into finer slits and smaller shapes were formed (Figures 3(c) and 3(c_1)). It has been reported in previous studies that the use of high-concentration sodium alginate causes low porosity in freeze-dry products [19, 55]. Figures 3(d) and 3(d_1) highlight larger pores and greater porosity in micrographs of maltodextrin-containing samples than other biopolymer supports. In all micrographs, low pore size and high number of pores are seen with the generally used biopolymer supports. The effect of a fast and good rehydration process in freeze-dried samples is evident in the porosity distribution. Samples containing modified potato starch had the lowest porosity and the smallest pore diameter. In general, porosity and fragility increase in direct proportion for all biopolymer-supported recipes (Table 3).

3.7. Oxidation Stability and Glass Transition Temperature. Oxidation stability is an important criterion to evaluate the shelf life and quality of products. One of the values characterizing this measurement is the oxidation initial temperature (OT_s). The glass transition temperature is critical in drying technology because the glass transition temperature (T_g) also represents the collapse temperature of the food. In freeze-drying technology, the T_g information of foods has high importance to preserve the shape and volume of the food. Glass transition temperature (T_g), oxidation start temperature (OT_s), oxidation medium temperature (OT_m), and oxidation end temperature (OT_e) of the samples prepared within the scope of this study are shown in Table 2. Figure 4 to T_g and Figure 5 to OT values are demonstrated.

The glass transition temperatures of the samples prepared using biopolymer were compared with the values of the control group. Although the values are close to each other, MD and SA, which are biopolymers used, have a lowering effect on the glass transition temperature, while GA and MPS have a positive effect on the sample by increasing the glass transition temperature. When the data were analyzed statistically, the difference between the glass transition temperature of the control group and SA was not significant



(a)



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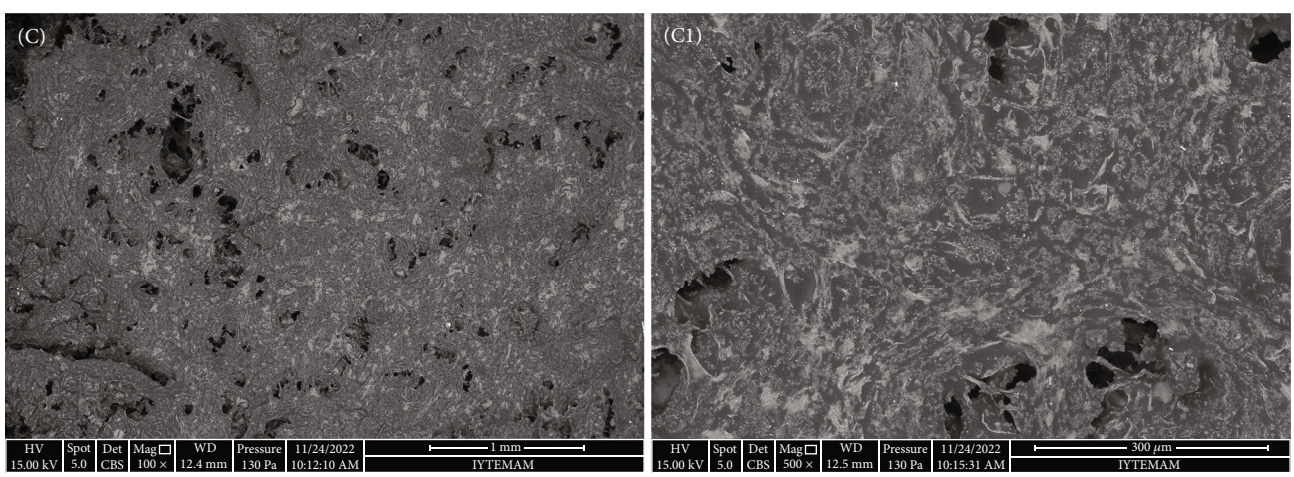

(c)

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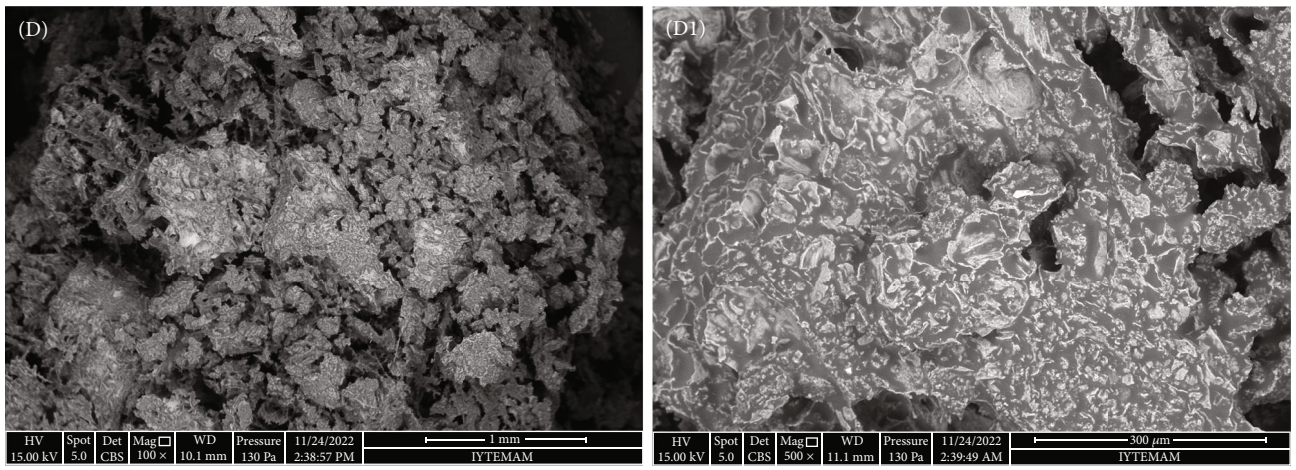


Figure 3: View of the cross-section of freeze-dried mixtures under scanning electron microscopy. (a) C+MPS 1 mm, (a_1) C+MPS 300 μm, (b) C+GA 1 mm, (b_1) C+GA 300 μm, (c) C+SA 1 mm, (c_1) C+SA 300 μm, (d) C+MD 1 mm, (d_1) C+MD 300 μm, (e) control 1 mm, and (e_1) control 300 μm.

($p > .05$), while the differences between the glass transition temperatures of the control group and MPS, GA, and MD were not found to be significant ($p < .05$). In terms of the results obtained, the collapse of olive-enriched snacks can be improved by using MPS and GA biopolymers to increase the glass transition temperature.

Although the oxidation start temperatures of the samples are close to each other, when compared with the control group, while MPS decreased the OT_s temperature, GA, SA, and MD increased the OT_s. No significant difference was found between the oxidation start temperatures of the control group and GA and MD ($p > .05$) (Table 3). However, the differences between the oxidation onset temperatures of the control group and MPS and SA were statistically significant ($p < .05$). The use of SA was found to be safer for olive-enriched snacks compared to all other biopolymers in terms of oxidation initiation. Similarly, an increase was observed in OT_m and OT_e values of the snacks with SA added compared to the control group in terms of oxidation middle and end temperatures; no significant changes were detected in these values of snacks with MPS, GA, and MD added ($p > .05$) (Table 3).

3.8. Sensory Acceptability. The sensory acceptability of the mixtures prepared according to prescription formulations after freeze-drying was evaluated by the panelists. The samples were coded with random numbers and presented to the panelists. The results of the sensory analysis are demonstrated as appearance, smell, taste, texture, and general taste in Figure 6. The highest fruit odor was in MPS sample and the least in GA sample; the highest oil smell was in the MD sample, in the sample containing the least GA; the highest milk odor was most pronounced in the MD sample and in the least GA sample. Taste characteristics were evaluated as fruity, oily, and bitter. MPS for fruit taste and GA for oily taste were the most prominent biopolymer supports. The sample in which all the aforementioned flavors are felt the least contains MD. While MPS increased the dominance of fruit flavor, it was observed that GA suppressed the odor and taste characteristics that should be perceived in the product. The bitter taste of the control sample was found to be more than the other samples. The slightly bitter taste of naturally fermented olives is due to the oleuropein it contains.

In olive-enriched snacks, MPN was the hydrocolloid that gave the best results in terms of slickness in appearance. It

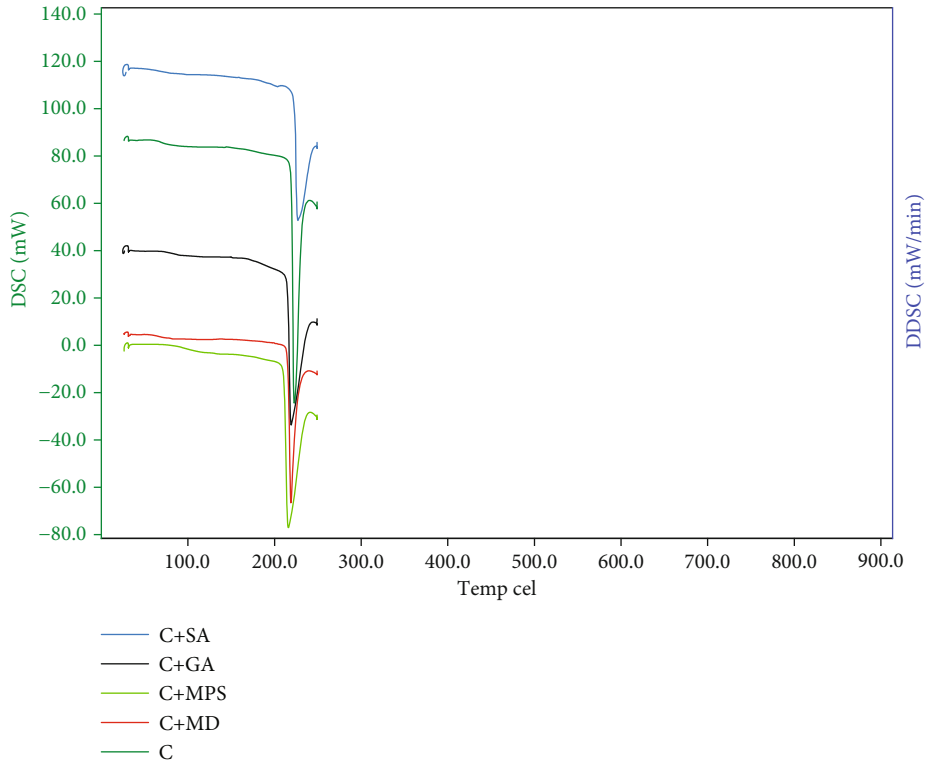


Figure 4: Glass transition temperatures of samples determined by DSC. "C+MPS" light green color, "C+GA" black color, "C+SA" blue color, "C+MD" red color, and "control (C)" dark green color.

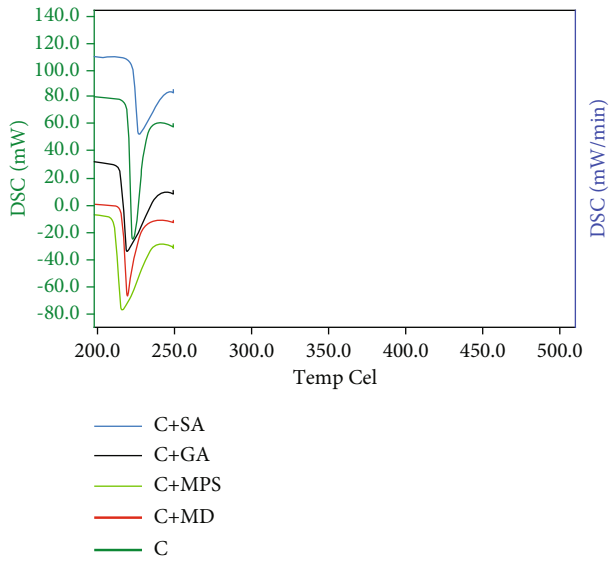


Figure 5: Oxidation temperatures of samples determined by DSC. "C+MPS" light green color, "C+GA" black color, "C+SA" blue color, "C+MD" red color, and "control (C)" dark green color.

was expected that the microstructure and texture improvement effect of hydrocolloid supports would increase slickness, which is the sensory expression. Accordingly, the control sample did not meet this expectation with its hydrocolloid free structure. According to the panelist performance, the sample containing MPS was characterized with the lowest roughness, while the roughness was found to be higher in the sample containing MD compared to the other samples. Color perception was expressed as less desirable in olive snacks containing SA compared to other samples. It has been stated that other biopolymer supports do not adversely affect color perception.

Texture acceptability was characterized by brittleness, chewiness, intraoral spread, and sandiness. While the snack containing MPS was appreciated in the brittleness evaluation, the samples containing MPS and SA were appreciated in terms of chewiness. Accordingly, the sandiness value was scored the lowest in the MPS-containing snacks. Intraoral dissemination was more prominent in the sample containing MD, while it was less felt in the sample containing MPS. Within the scope of this study, improving the texture structure is among the purposes of using biopolymer. Compared to the control sample, the use of biopolymer decreased the brittleness value and sandiness values and increased the chewiness value as expected.

While brittleness and chewiness values were negatively correlated, sandiness and roughness were characterized by linear variation ($p < .05$). The use of hydrocolloid (MPS the best rated) increased overall acceptability, while the hydrocolloid-free snack was rated with low hedonic.

The brittleness value that can be measured through sensory is seen as equivalent to the fracturability value as the hardness value that is negatively correlated that can be measured with a texturing device. Considering the results of this study, the samples with the highest and lowest brittleness values determined by the panelists and the samples with

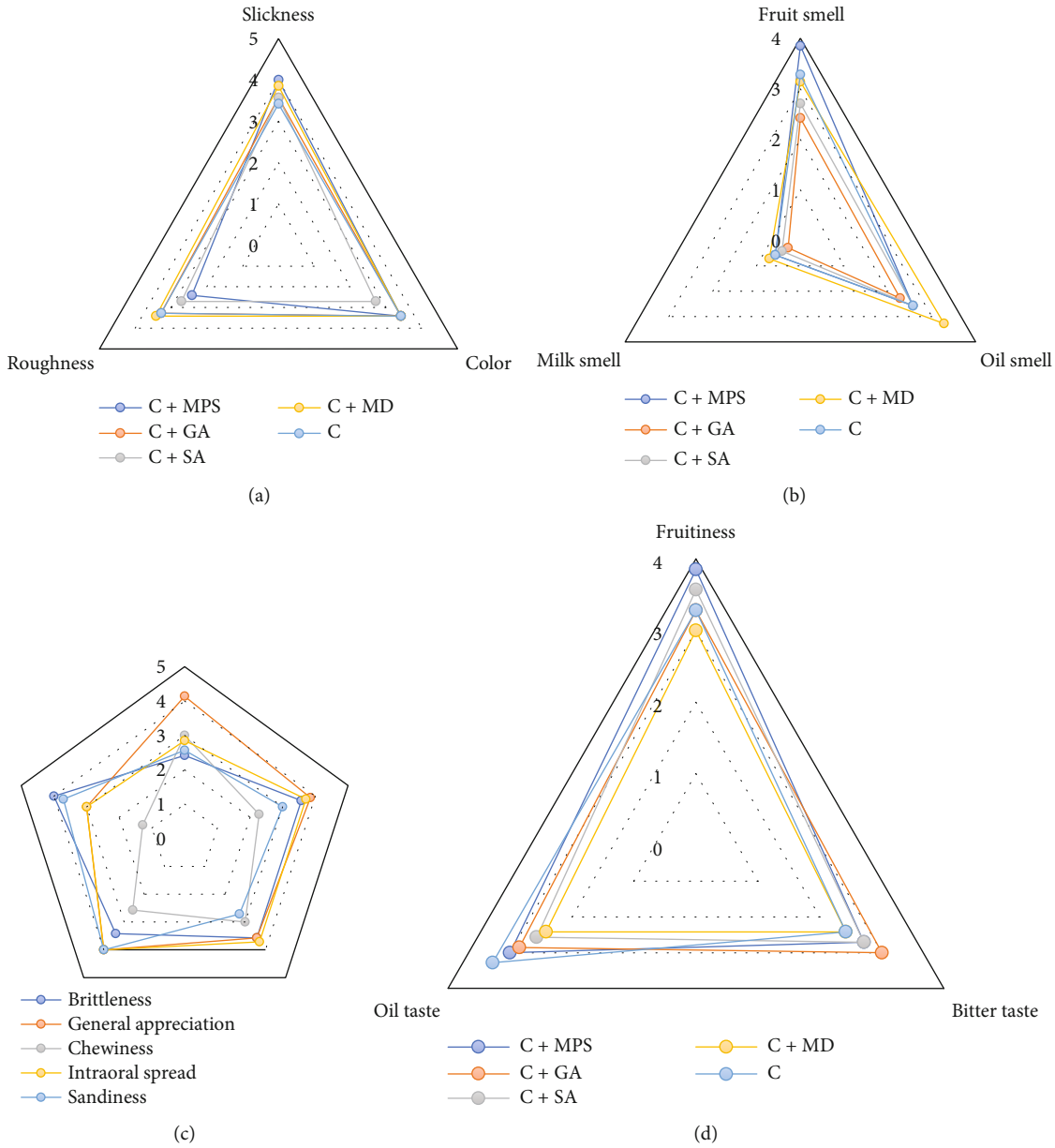
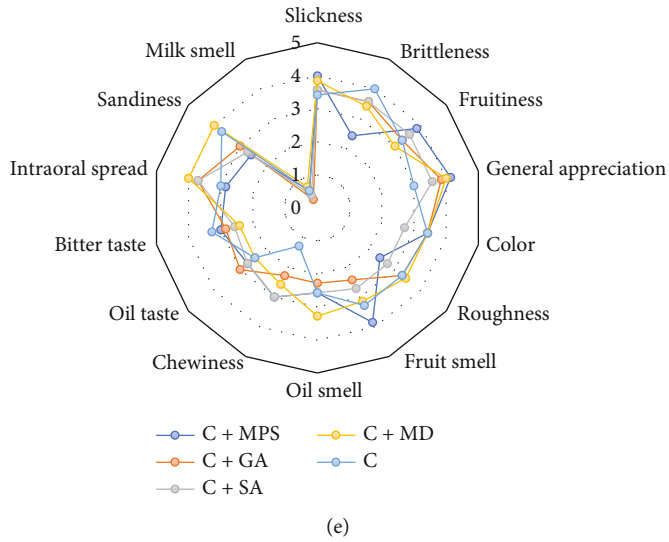


Figure 6: Continued.



(e)

Figure 6: Radar diagrams of the (a) appearance, (b) odor, (c) texture and hedonic, (d) taste, and (e) overall sensorial acceptability characteristics of olive snacks.

the highest and lowest brittleness values determined by the texturing device are the C and C+MPS snacks, respectively. The results are compatible with each other.

Olive snacks containing MPS gained a higher appreciation score compared to other samples due to their smoother shape, more crispness, more intense fruit flavor and odor, less roughness, and less sandiness. In this respect, it has been seen that the snack with MPS added was a product that could be acceptable by the consumer. The snack brittleness score of olive-enriched snack without hydrocolloid affected the general appreciation and remained on the lowest hedonic scale. It is thought that the sleekness and less oily taste and high bitter taste also affected the panelists.

4. Conclusion

The fact that people spend more time in business life in changing living conditions has led consumers to fast consumption products. Consumption products with preservatives do not satisfy nutritionally but also cause us to consume harmful substances that our body does not need. In this study, it was aimed at producing healthy fast consumption products. In addition, based on the olive taste score given in the sensory analysis results, it is thought that this product may be a good alternative for consumers who do not like olives. With this product, a new usage area is offered to the olive fruit and it provides high added value to the olive. Thanks to the freeze-drying technology, the water content in the product is well below the critical humidity level that will cause deterioration, making it suitable for storage at room temperature and the shelf life is extended without the need for any additives. In addition, packaging, storage, and transportation costs have been reduced and it is thought that food waste can be prevented. The rehydration capacity and drying efficiency of the product are within normal limits when looking at other studies, which shows that the product is suitable for industrial production. Finally, when the general desirability score is examined in the results of the sensory analysis, it is seen that the product will be loved and consumed by the consumer.

Data Availability

The authors declared that they can share the data when requested.

Conflicts of Interest

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

Authors' Contributions

Elif Savaş was responsible for project administration, funding acquisition, supervision, methodology, investigation, conceptualization, research, visualization, writing, and draft editing. Vera Demir was responsible for formal analysis and writing.

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