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Research Article

Physicochemical Properties of Sponge Cake Fortified by Olive Stone Powder

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Olive stones are by-products in olive oil extraction and in table olive industries. Nonetheless, they contain beneficial nutritive elements such as fiber, phenolic compounds, and omega-3 and -6 fatty acids. In this research, olive stone powder (OSP) was used to substitute 0, 15, 25, and 35% of wheat flour in sponge cake recipe. The effects of this substitution were examined on the physiochemical and sensory properties of sponge cakes. The fiber content and the total phenolic compounds of the cake samples increased significantly from 0.67 to 8.60% and from 89.14 to 739.23 μg/ml, respectively, by increasing the OSP from 0 to 35%. With increased amounts of OSP, batter viscosity and consistency decreased (from 27430 to 11030 centipoise and from 8.67 to 13.42 g/s, respectively), while the specific volume of the cakes increased (from 2.08 to 6.21 cm^3/g). Parallel to the increased levels of substitution, the hardness and springiness of cakes decreased, whereas the gumminess and chewiness increased. The crumb structure of OSP-enriched cakes was more porous than that of the control. Color analysis indicated significant differences between the control and treated samples regarding L^*a^*, and b^* parameters. Cakes had colors that were darker than expected when treated with OSP ($p < 0.05$). According to sensory evaluations, no significant differences were observed between OSP cakes and the control sample in terms of taste, after taste, color, and odor ($p > 0.05$). In conclusion, substituting OSP for flour by 25% can yield acceptable dietary fiber content and antioxidant phenolic compounds while showing no undesirable changes in sensory properties.

1. Introduction

Olive or *Olea europapea* L., from the Oleaceae family, is cultivated in many regions of the world and is a very rich source of vitamins. It serves as a good source of phytochemicals [1]. Olive stones, or seeds, can be considered as important byproducts. They have strong lignified fibers as their primary structure. Their components include cellulose, hemicelluloses, and lignin, although there are trace elements of fat and protein in them too. The olive seed contains a considerable amount of oil (22–27% of its weight) that is richer in individual sterols and in total polyunsaturated fatty acids (PUFA) than the olive fruit itself [2]. Moreover, research has shown that olive stones are a rich source of phenolic compounds, mostly flavones and glycoside compounds such as salidroside, glucose nüzhenide, and nüzhenide-oleoside. Verbascoside is a major phenolic compound in its fruit flesh.

Since consumers are increasingly inclining towards healthy foods with low calories and fat, dietary fibers have become a priority in foods [3]. As a matter of fact, the right amount of dietary fiber can lower the risk of cardiovascular diseases, obesity, cancer, diabetes, and gallstones [4]. Apart from their positive health benefits, their unique functional properties can improve the texture, consistency, and stability in food production and storage [5].

The dietary fiber of many agronomic by-products has been undervalued because of their seemingly useless nature [6]. Several works have also been carried out on using fibers from different sources in the production of bakery products such as orange waste, carrot pomace, potato peels, and green pea peels in cakes [5], apple pomace in cake [7], watermelon rind and sharlyn melon peel powder in cakes [8], banana peel in butter cake [9], carrot pomace powder in gluten-free cakes [10], and oat, pea, apple, and lemon fibers in cakes [3].

Since olive stones are a valuable source of micronutrients, powdering and adding them to flour can bring on dietary fibers and phenolic compounds as antioxidants. However, to the best of our knowledge, there have been no studies on the application of this biomass in food products so far. The aim of this study is to examine the efficiency of OSP as replacement of wheat flour at levels of 15, 25, and 35% in order to increase its nutritional values. The physical and textural properties of the enriched batters and cakes are also investigated.

2. Materials and Methods

2.1. Materials. Olive stones (Manzanilla cultivar) were provided by the department of agriculture of Fars Province, Iran. After cleaning and washing, the stones were dried in an oven (Binder, Germany) at 50°C to an ultimate moisture of 6% (w.b) before being ground in a laboratory mill (IKA-A11 Basic, Germany) and sieved to a 100 μm particle size. The cake ingredients were wheat cake flour, sugar, corn oil, fresh whole eggs, and baking powder (Golha, Tehran, Iran). Chemical materials were purchased from Merck, Germany.

2.2. Olive Stone Characterization. Olive stone powder (OSP) was analyzed for moisture, ash, fat, protein, carbohydrate, and crude fiber content according to AACC methods [11]. Total phenol content was determined according to the method described by Ayadi et al. [12]. OSP (2 g) was mixed with 16 ml acidified methanol/HCl (1% v/v) for 24 h at 24°C and centrifuged at 4000 g for 15 min. Then, 20 μL of the supernatant was added to 1.6 mL distilled water, along with 100 μL of Folin–Ciocalteau reagent and 300 μL of 20% sodium carbonate. This was incubated for 24 h at room temperature. The absorbance of the solution was read at 765 nm in a spectrophotometer. The concentration of total phenolic compounds (TPC) was recorded as gallic acid equivalents (mg GAE/100 g dry weight). To measure the water binding capacity, one gram of OSP was mixed with 20 ml distilled water and was kept at room temperature for 18 h. It was then centrifuged at 3000 g for 20 min. The supernatant was discarded, and the tube was maintained in an inverted position for 25 min at 50°C. Water binding capacity (WBC) was expressed as g of water bound per gram of the dried sample. Oil binding capacity (OBC) was calculated according to [13]. For this purpose, 4 g of the sample was added to 20 ml corn oil and was stirred every 5 min for a total duration of 30 min. The solution was centrifuged at 1600 g for 25 min. The oil phase was discarded and the pellet was weighed (m_1). The OBC was expressed as g of oil bound per g of dried sample.

2.3. Batter and Cake Preparation. The dry material consisted of wheat flour 100 g, sucrose 72 g, and baking powder 1.34 g. These were mixed together before adding whole eggs 72 g, oil 57g, and water 25 g. A smooth, uniform batter was obtained by stirring. OSP was substituted for 15, 25, and 35% of total wheat flour, making three treatments. A blank sample did not contain OSP. Cake batters (50 g) were poured into aluminum pans and baked at 200°C for 17 min. The cakes were allowed to cool at room temperature for 30 min and were packaged in polyethylene bags before being tested.

2.4. Cake Batter Characterization. The density of the batter was determined by dividing a certain mass of the batter by its volume. Its specific gravity was calculated by dividing the mass of its volume by the mass of water. A rotational viscometer (Thermo Haake 7^L, Thermofisher, Germany) was equipped with a L4 spindle and was used for measuring the viscosity of each batter sample at a speed of 20 rpm at room temperature [14]. To determine the consistency of the batter samples, the method used by Pierce and Walker [15] was followed. The consistency was reported as g/s, and higher values indicated lower degrees of consistency.

2.5. Sponge Cake Characterization

2.5.1. Physicochemical Properties. Total phenolic compounds (TPCs) and crude fiber for each sample were determined the same way as the TPC [12] and crude fiber of OSP were [11]. The specific volume of cake samples was determined using the rapeseed displacement method. The weight loss (%) of cake samples was calculated by subtracting the initial batter weight from the cake weight immediately after baking. Crust and crumb moisture contents were determined according to AACC methods [16] using a 5 g sample of both cake crust and cake crumbs.

2.5.2. Textural Analysis. Texture profile analysis (TPA) of the samples (3 × 3 × 3 cm) were carried out on the midsection of the cakes, and the values were measured using a texture analyzer (Model LFRA-4500, Brookfield, USA) equipped with a cylindrical probe (38.1 mm diameter). The test was performed with two-bite compression tests at a speed of 0.5 mm/s and at a distance target of 10 mm. The textural properties were hardness, gumminess, cohesiveness, chewiness, and springiness of the cake samples which were recorded 1, 7, and 14 days after baking [17].

2.5.3. Microstructural Analysis. Cake samples were cut into 0.5 cm × 0.5 cm cubes and then freeze-dried. The dried cake samples were coated with gold palladium and microstructural images were obtained by scanning electron microscopy (Zeiss, Germany).

2.5.4. Color Measurement. The color parameters (L^*, a^*, and b^*) of cake samples were measured using a colorimeter (Model ZE6000, Nippon Denshoku Co., Japan). Hue angle (H), color difference (ΔE), saturation index (SI), and whiteness index (WI) were calculated using the following equations [17]:

$$H = \tan^{-1}\left(\frac{b}{a}\right), \quad (1)$$

$$\Delta E = \sqrt{\left[(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2\right]}, \quad (2)$$

$$\mathrm{SI} = \sqrt{a^2 + b^2}, \quad (3)$$

$$\mathrm{WI} = 100 - \sqrt{(100 - L)^2 + a^2 + b^2}. \quad (4)$$

2.5.5. Sensory Evaluation. Sensory evaluation of the baked sponge cakes was carried out by 20 untrained panelists using a five-point hedonic scale. The panelists received 4 samples from the midsection of each cake and were asked to rate their sensory properties (i.e., texture, aftertaste, color, flavor, chewing ability, odor, appearance, and overall acceptance) as (1) extreme dislike, (2) dislike, (3) neutral, (4) like, and (5) extreme like.

2.6. Statistical Analysis. All experiments were performed using three replications. One-way ANOVA was applied to discover significant differences between the treatments ($p \leq 0.05$). Duncan's multiple range test was employed to compare the mean values. All data was analyzed using SPSS v. 16 statistical analysis software.

3. Results and Discussions

3.1. Physicochemical Properties of OSP. The chemical composition of olive stone and its comparison with wheat flour are shown in Table 1. As can be seen, the OSP had significantly ($p < 0.05$) higher amounts of fiber, fat, and ash content compared with wheat flour, suggesting that the OSP can be a functional ingredient in sponge cake. Generally, these values were consistent with previous results by Rodríguez et al. [2] on the physiochemical properties of olive stone, although the slight differences between the values of these compounds can be attributed to the type of olive cultivar. The fiber content of the whole stone was higher than the seed husk, while phenolic compounds were greater in the seed [2]. The OBC and WBC of the OSP were 1.03 g water/g solid and 1.50 g oil/g solid, respectively (Table 1). The WBC of the powder was approximately comparable to that of the wheat flour (1.01 g water/g solid) and apple pomace (8.39 g water/g solid) as reported by Sudha et al. [7]. The low WBC of OSP could be explained by its chemical composition which is mainly composed of cellulose and lignin as insoluble dietary fibers. Indeed, a high concentration of soluble dietary fibers (e.g., hemicellulose and pectin) can bring on a high WBC. For instance, lemon fiber has the highest WBC among other fibers due to its highest soluble fiber content [3].

3.2. Cake Batter Properties. Cake batter characteristics changed in response to the addition of OSP to wheat flour (Table 2). According to this table, batter density significantly ($p < 0.05$) increased from 0.88 to 0.98 mg/ml by substituting OSP for 35% of wheat flour. This could be accompanied by less air incorporation into the batter, whereas an appropriate density should be associated with a good aeration of the batter during mixing. Batters are likely to contain larger volumes of air if they have lower density values. The final volume of each cake is affected by this factor. It is also affected by the amount of gas loss during processing, by a possible collapse of the structure after baking and by starch gelatinization [18]. This behavior has already been reported by Sudha et al. [7] and Majzoobi et al. [19] after the incorporation of apple pomace flour and oat fiber to wheat flour batter. Lu et al. [20] found that higher batter densities with higher substitution percentages can be related to the fiber content of added green tea powder, which increased WBC and cake batter density. The chemical composition of the cake batter significantly affects the batter properties. By replacing wheat flour with OSP, the fiber, fat, carbohydrate, and ash contents increased (Table 2). Higher amounts of fibers and carbohydrates can increase the batter density. They cause less aeration in the batter by disrupting the structure of the batter and by releasing the trapped air or CO_2 from baking powder. However, an increase in lipid content resulted from adding OSP, and it reduced batter density by increasing the batter aeration [21]. According to Majzoobi et al. [10] in a research on carrot pomace powder, the mineral content of the powder appeared higher than that of the gluten-free flour. The researchers suggested that this might affect the electric charges of proteins and, accordingly, change their interactions with water and other proteins. These can alter the gas-holding capacity of the proteins, thereby leading to a reduced density of the batter, along with an increased density caused by higher fiber, protein, sugar, and ash content.

According to the results (Table 2), increasing the OSP level led to an increase in the specific gravity of the cake batter from 1.03 to 1.17. This could be explained by the higher specific gravity of olive stone compared with wheat due to its denser structure and its higher fiber content. Lu et al. [20] also found an increase in the specific gravity of cake batter when increasing the percentage of green tea powder in the batter.

There was a significant decrease in viscosity of cake batters parallel to an increase in the OSP level (Table 2). Olive stone powder has a lower WBC compared to wheat flour, and this could result in more unbound molecules of water in the cake batter, thereby explaining the lower degree of viscosity caused by olive stone powder. Moreover, by reducing the viscosity of the sponge cake batter, more amounts of air could become trapped within the batter, which could also be interpreted as a change in specific volume. However, the viscosity of samples containing 15% OSP was not significantly different from the control ($p > 0.05$). This could be due to the relative water absorption of the dietary fiber in the olive stone powder. In this regard, previous research claims that adding cereal bran to a type of raw batter can cause a significant decrease in the viscosity of raw batter in comparison with the control [22]. Contrary to our findings, another previous study showed that the

Table 1: Physicochemical properties of OSP and wheat flour[†].

	Moisture (%)	Fiber (%)	Fat (%)	Ash (%)	Protein (%)	Carbohydrate (%)	TPC (mg GAE/100g)	WBC (g water/g solid)	OBC (g fat/g solid)
OSP	6.01 ± 0.04^b	53.17 ± 1.60^a	7.60 ± 0.33^a	1.19 ± 0.06^a	5.14 ± 0.20^b	80.03 ± 1.85^a	0.37 ± 0.05	1.03 ± 0.12^b	1.50 ± 0.04
Wheat flour	13.18 ± 0.15^a	0.22 ± 0.09^b	1.89 ± 0.19^b	0.35 ± 0.07^b	8.21 ± 0.24^a	76.37 ± 1.08^b	—	1.41 ± 0.18^a	—

[†]Results presented are the means ± SD of 3 replications. Different superscripts along horizontal line indicate significant difference at probability level of 5%. TPC, total phenol content; WBC, water binding capacity; OBC, oil binding capacity.

Table 2: Physicochemical properties of cake batters and sponge cakes prepared with different levels of OSP[†].

	Control	15%	25%	35%
Cake batter				
Viscosity (cP)	$27430.00 \pm 471.59^{a*}$	26590.00 ± 310.00^a	25690.00 ± 686.36^b	11030.00 ± 226.05^c
Density (mg/ml)	0.88 ± 0.02^c	0.88 ± 0.01^c	0.93 ± 0.01^b	0.98 ± 0.01^a
Specific gravity	1.03 ± 0.03^c	1.10 ± 0.02^b	1.14 ± 0.02^{ab}	1.17 ± 0.03^a
Consistency ($g{\cdot}s^{-1)}$)	8.67 ± 0.06^c	12.47 ± 0.16^b	13.20 ± 0.14^a	13.42 ± 0.09^a
Sponge cake				
Specific volume (cm^3/g)	$2.08 \pm 0.06^{c*}$	3.98 ± 0.12^b	4.71 ± 0.18^b	6.21 ± 1.56^a
Weight loss	8.50 ± 0.02^b	9.24 ± 0.04^a	9.25 ± 0.02^a	9.25 ± 0.01^a
Crust moisture (%)	26.73 ± 0.50^a	26.56 ± 0.47^a	25.83 ± 0.65^{ab}	25.40 ± 0.62^b
Crumb moisture (%)	26.06 ± 0.15^a	27.00 ± 0.26^a	26.43 ± 0.35^b	26.06 ± 0.15^b
Fiber (%)	0.67 ± 0.05^d	4.16 ± 0.19^c	6.27 ± 0.50^b	8.60 ± 0.41^a
Fat (%)	18.48 ± 0.40^a	19.54 ± 0.67^a	19.76 ± 0.91^a	19.98 ± 1.18^a
TPC (mg GAE/100 g)	71.31 ± 3.28^d	341.70 ± 15.21^c	460.17 ± 13.42^b	591.38 ± 19.94^a

[†]Results presented are the means ± SD of 3 replications. Different superscripts along the horizontal line indicate significant difference at probability level of 5%.

viscosity of cake batter increased in response to higher levels of banana peel and carrot pomace [9, 10]. This could be attributed to the high WBC of the fiber in carrot pomace and banana peel. The lignin content of such fibers is low, whereas their cellulose and hemicellulose contents are high, leading to a higher WBC.

According to the results (Table 2), the consistency of cake batter samples significantly decreased as the substitution level increased ($p < 0.05$). The decrease in the batter consistency can be related to the low WBC of OSP compared with the WBC of wheat flour. A suitable level of batter consistency can assist in retaining the air bubbles that are created when the batter is mixed and CO_2 bubbles are produced from the baking powder. The tiny air bubbles are assumed to rise, reach the surface of the batter, and escape during initial heating, that is, if the batter consistency is too low. However, batters with high levels of consistency prevent the formation of air bubbles in the batter and, consequently, prevent the enlargement of the cake during the baking process. Thus, batters with either low or high levels of consistency result in reduced cake volume [23]. Majzoobi et al. [24] examined the addition of fermented bran to cake batter and reported an increase in batter consistency and density, a decrease in cake volume, a darker cake color, and a harder structure. Changes in batter and cake qualities in the case of bran-added samples might be due to their higher fiber and protein contents (hydrocolloids) which could absorb more water. However, Tan et al. [25] studied the replacement of eggs with ultrasound-treated whey protein in a cake formulation and reported that the batter consistency, hardness, and cake chewiness decreased, while the cake volume increased. These were in agreement with our study. Moreover, according to Lebesi and Tzia [22], batters containing cereal bran had lower consistency index values than the control batter, while DF-containing batters were structurally more consistent.

3.3. Sponge Cake Properties

3.3.1. Physicochemical Properties. Adding OSP to flour caused notable changes in the characteristics of the sponge cake (Table 2). The TPC of cakes containing 35% OSP reached 591.38 mg GAE/100 g, whereas the TPC of the control was 71.31 mg GAE/100 g. Similarly, the fiber content was 0.67% and 8.60% in cakes that contained 0% and 35% OSP, respectively. This clearly indicates that OSP can be an alternative source of TPC and dietary fiber in cakes. Accordingly, TPC and fiber increased in the cake samples as the OSP substitution increased from 15% to 35%. It should be noted, of course, that mixing other compounds such as oil in the batter can lead to some levels of oxidation and could reduce some of the phenolic compounds in the cake.

3.3.2. Specific Volume. A significant increase ($p < 0.05$) in the specific volume of cake occurred by an increase in the OSP level. The control sample had an average specific volume of 2.08 cm^3/g, but the value increased to 3.98, 4.71, and 6.21 cm^3/g when using OSP15, OSP25, and OSP35, respectively. However, there was no significant difference between the specific volumes of the 15% and 25% samples ($p > 0.05$). Aeration in cakes during the mixing of batter and baking can give specific volumes to cakes, as determined by the distribution of bubbles in the batter and by batter viscosity [26]. The nature and amount of dietary fiber are also known to affect the specific volume of cakes [3]. Many authors have reported a reduction of specific volume after adding dietary fibers to cakes [3, 7, 19, 20]. This probably happens because of a disruption in the gluten network which leads to the decrease in the gas retention capacity. However, in agreement with our study, Al-Sayed and Ahmed [8] reported that cake volume and specific volume increased significantly parallel to increasing levels of watermelon rind and sharlyn melon peel powder. Lebesi and Tzia [22] also reported that the addition of dietary fiber (from wheat, oat, barley, and maize) can increase cake volume, whereas adding cereal bran (from wheat, oat, and rice) to cakes has negative effects on the volume. It has been reported that there should be an optimum degree of consistency in the batter if cakes are to have high volumes. Cake batters with too low and too high consistency tend to result in low specific volumes due to the rapid rise of bubbles and the slow expansion of cakes, respectively [3]. In this study, the increase of OSP led to higher batter density. However, the batter consistency decreased because the OSP inherently has lower values of WBC compared with wheat flour/starch. This could contribute to the evaporation of water and the production of large pores in the cake matrix, thereby resulting in a higher specific volume. This parameter reportedly decreases when different fibers with high WBC are used [14, 27]. In a study by Aydogdu et al. [3], the lowest specific volume of cake was obtained when apple and lemon fibers, as two highly soluble fibers, were added to cake formulations. The above differences emphasize the importance of the fiber source. Gularte et al. [28] observed that the highest cake volume could be obtained by adding a blend of oat-inulin, despite the highest collapse after baking which was seen in cakes containing inulin. Oat fibers impart strength to the structural network of the cake texture when treated with heat. This strength acts against the collapse associated with inulin, thereby explaining the positive effects of the oat fiber-inulin blend. Moreover, differences in the cake volumes observed in the present study could be ascribed to the patterns of bubble distribution within the sponge cake (Figure 1). For instance, the control group of cake was characterized by a more stable aeration in the form of smaller bubbles. The distribution of these air bubbles were more uniform compared with cakes containing OSP.

3.3.3. Weight Loss. The weight loss of cakes during baking is directly related to water loss [3]. The effect of OSP on weight loss of cakes is demonstrated in Table 2. The results revealed no significant differences between cake samples containing OSP ($p > 0.05$). However, weight loss was significantly less in the control group, compared with samples containing OSP. This is probably because the presence of OSP, which has a lower WBC than wheat flour, is associated with the presence of unbound water in the cakes. Therefore, insufficient amounts of water are absorbed by the OSP in cakes since the WBC of OSP is lower than that of wheat flour. Accordingly, water is lost more easily during the baking process and so more weight is lost. In agreement with our study, Gómez et al. [26] found no significant difference between the weight loss of pea-flour layer cakes and the control, as the starch-concentrate in the former lost weight more than the latter did, probably because of a lower water-retaining capacity of pea flour compared to wheat flour. According to Collar et al. [29], weight loss in breads could be reduced by adding soluble cocoa fiber. Also, Aydogdu et al. [3] reported that cakes enriched with 10% lemon fiber can lose less weight because of the high water-holding capacity of lemon fiber compared with the control group of cakes in their study.

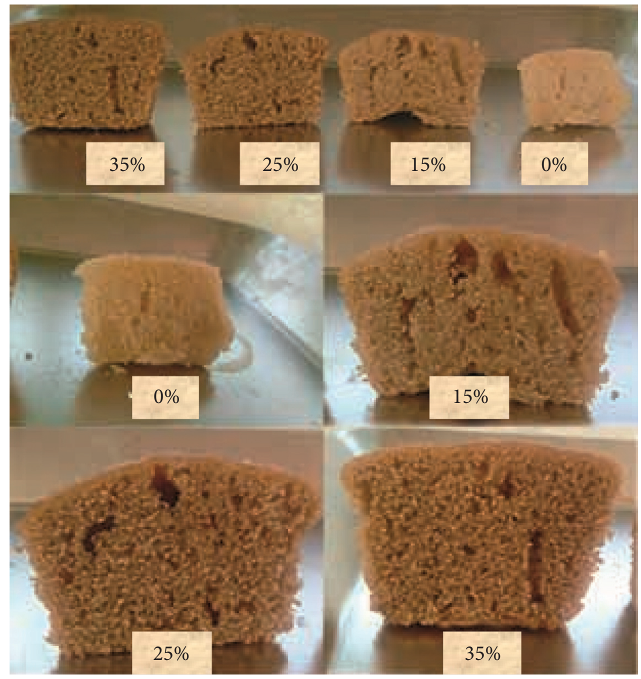

Figure 1: Cross section of sponge cakes containing 0% (control), 15, 25, and 35% OSP.

3.3.4. Crust Moisture. Using 15% OSP and more of it resulted in a significant decrease in the moisture contents of the crust and crumb of cakes ($p < 0.05$) (Table 2). However, no significant difference was observed between the control and the OSP15 treatment ($p > 0.05$). This might be due to the insufficient water absorption and water retention ability of OSP, leading to a greater moisture loss during baking. These results are in agreement with Al-Sayed and Ahmed [8] who reported a gradual decrease in protein and moisture contents of cakes when adding more amounts of watermelon rind and sharlyn melon peel powder to the batter. Contrary to our results, it has been reported that the addition of cheonnyuncho powder to sponge cake can increase its moisture content because of the increase in water absorption by the dietary fiber [6]. Luyts et al. [30] stated that the migration of moisture from crumb to crust can largely affect cake crumb firming at ambient temperatures. In this study, cake hardness decreased when higher amounts of olive seed powder were used, resulting in reduced levels of crust moisture in the final products.

3.3.5. Textural Properties. Table 3 shows the effects of OSP on the textural properties of cakes during 14 days of storage. The results revealed a significant decrease in hardness as the amount of OSP increased in formulation ($p < 0.05$). Generally, a harder texture is expected from a low specific volume of cake as in the control sample. The results are in agreement with a report by Lebesi and Tzia [22] who claimed that a softer texture can be found in all dietary fiber cakes ($p < 0.05$) compared with cereal bran cakes. They noted that crumb firmness can be indirectly related to the specific volume of cakes, with bigger cakes producing a less dense structure, thereby resulting in a softer crumb texture [22]. Aydogdu et al. [3] also found that enriching cakes with lemon fiber causes the lowest specific volume and the highest hardness value. Enough water cannot be absorbed by wheat flour when the type of dietary fiber that is added as a treatment has a high water binding capacity. This competition for water can weaken the ability of wheat flour in developing a gluten-protein network, thereby causing a rigid structure. In this study, the high lignin content of OSP and its lower WBC compared with starch resulted in decreased levels of water absorption and consistency of the batter, as well as an increased value of specific volume of the cake due to the evaporation of unbound water and the production of large pores and cavities in the cake during the baking process. These observations happened especially when there were increased levels of OSP powder in the formulations. The use of gums in cakes can enhance their water absorption and improve the viscoelastic properties of cakes. However, insoluble fibers with high lignin content and low WBC have diverse effects on the viscoelastic properties of bakery products. Moreover, the high amount of fat in OSP, compared with wheat flour, and the low oil binding capacity of OSP might also be responsible for decreasing cake hardness as the substitution level increases.

Elasticity is measured by springiness. It describes recovery, the extent of which is gauged between the first and second compressions. The springiness values of sponge cakes with OSP were in the range of 7.74 to 7.83 mm. By multiplying the values of gumminess and springiness, chewiness is calculated. It indicates the amount of energy required for dismantling a given food before swallowing. According to Adegunwa et al. [31], the chewiness and hardness of samples are strongly interrelated. The hardness of crumb texture and the amount of time for a food to be chewed are also described in this context. Gumminess is calculated by multiplying hardness and cohesiveness. The inner resistance of a food structure to force is termed 'cohesiveness'.

TPA values showed an increase in cake chewiness and gumminess parallel to increased levels of OSP. The values of chewiness ranged from 732.21 to 837.25 g mm, whereas those of gumminess ranged from 93.75 to 106.28 g. Generally, higher levels of OSP meant lower values of hardness and springiness but enhanced values of cohesiveness, gumminess, and chewiness. These findings confirm the previous results reported by Hosseini Ghaboos et al. [32] who showed that adding more amounts of button mushroom powder to the batter can result in cakes with lowered values of hardness, gumminess, and chewiness but an increased value of cohesiveness. Also, Salehi et al. [33] reported similar trends of change in those parameters when adding button mushroom powder to cake batter. A study by Gómez et al. [34] on the qualitative parameters of sponge cake made by a blend of wheat flour and chickpea powder found a reverse relationship between texture hardness and cake volume. They also reported lower springiness and higher stiffness, gumminess, and adhesiveness for sponge cakes containing high amounts of chickpea flour.

Moreover, according to Table 3, the first week of storage saw a significant increase in the hardness, chewiness, and gumminess of all cake samples, whereas the springiness and cohesiveness decreased ($p \leq 0.05$). After the first week, a slight reduction was observed in the mentioned parameters, with the exception of hardness ($p \leq 0.05$). This trend could be attributed to the staling of the gluten-starch network in cake samples. The chemical composition of OSP-enriched cake samples including the lower gluten, higher fat, and reduced sugar contents was the main cause of such variations.

3.3.6. Microstructural Analysis. Figure 1 shows the cross sections of the cakes containing different levels of OSP. In general, a high specific volume means that the structure of a baked product is more porous [3]. The images of cakes could be linked to porous structure in correlation with their specific volumes. As can be seen in Figure 1, the porosity of cake structure, the lack of uniformity and of homogeneity in the pores, and a darker color of cake crumb increased in response to higher levels of OSP. This can be a reason for the lower specific volume of the control cake in comparison with the specific volume of OSP-enriched cakes.

The microstructure analyses of the control sample and of the cake containing 35% OSP (Figure 2) show that the structure of the gluten-starch network is more uniform in the control sample. The same applies to the porosity, number, and size of the air cavities which are smaller in the control sample (at 50x magnification). These results validate and explain the hardness values of cakes. Greater aeration in cakes can lead to a lower hardness value and, accordingly, the hardness values of OSP-enriched cakes were lower than the hardness of the control cake. Similarly, Aydogdu et al. [3] stated that the addition of pea and oat fiber–mostly insoluble fiber–gave cakes a less rigid and more porous structure than the addition of lemon and apple fiber which have higher solubility. Moreover, the images indicated that part of the OSP particles are located in the gluten-starch network, while part of them are not and appear free in the image (at 500x magnification). The presence of dispersed particles of OSP significantly reduced the chewing ability of the product compared with the control sample, and the stone powders could be felt as coarse particles in the mouth. In this regard, Aydogdu et al. [3] stated that increasing the particle size of

Table 3: Textural properties of sponge cake made by different levels of OSP during 14 days of storage[†].

Sample	Hardness (g)			Springiness (mm)			Chewiness (g·mm)			Gumminess (g)			Cohesiveness		
	Day 1	Day 7	Day 14	Day 1	Day 7	Day 14	Day 1	Day 7	Day 14	Day 1	Day 7	Day 14	Day 1	Day 7	Day 14
0	202.96 ± 0.45^{Ba}	716.00 ± 2.08^{Aa}	717.66 ± 8.62^{Aa}	7.83 ± 0.02^{Aa}	6.97 ± 0.04^{Bb}	6.97 ± 0.04^{Ba}	779.37 ± 15.14^{Bb}	1492.16 ± 47.17^{Aa}	1478.33 ± 102.23^{Aa}	99.45 ± 2.25^{Bb}	214.06 ± 5.41^{Aa}	211.95 ± 13.28^{Aa}	0.49 ± 0.01^{Ab}	0.30 ± 0.01^{Bb}	0.29 ± 0.01^{Bb}
15%	195.33 ± 1.05^{Bb}	574.16 ± 11.36^{Ab}	578.33 ± 9.77^{Ab}	7.81 ± 0.02^{Aab}	6.86 ± 0.03^{Bc}	6.85 ± 0.04^{Bb}	732.21 ± 12.30^{Bc}	1293.86 ± 88.70^{Ab}	1264.33 ± 93.65^{Ab}	93.74 ± 1.45^{Bc}	188.66 ± 13.95^{Ab}	184.54 ± 14.76^{Ab}	0.48 ± 0.01^{Ab}	0.33 ± 0.02^{Bab}	0.32 ± 0.02^{Bab}
25%	190.06 ± 1.15^{Bc}	507.50 ± 7.85^{Ac}	507.33 ± 7.75^{Ac}	7.74 ± 0.03^{Ab}	6.82 ± 0.02^{Bc}	6.80 ± 0.00^{Bb}	736.26 ± 20.10^{Abc}	1214.95 ± 22.00^{Bbc}	1202.27 ± 70.76^{Bb}	95.03 ± 2.24^{Bbc}	178.14 ± 3.27^{Ab}	176.72 ± 10.54^{Ab}	0.50 ± 0.01^{Ab}	0.35 ± 0.01^{Ba}	0.35 ± 0.02^{Ba}
35%	186.43 ± 0.70^{Bd}	427.50 ± 8.67^{Ad}	473.16 ± 8.51^{Ad}	7.78 ± 0.05^{Aa}	7.86 ± 0.04^{Aa}	6.82 ± 0.03^{Bc}	837.25 ± 38.34^{Ba}	1137.84 ± 86.30^{Ac}	954.73 ± 41.77^{Bc}	106.28 ± 4.12^{Ba}	144.80 ± 11.80^{Ac}	142.01 ± 6.52^{Ac}	0.57 ± 0.02^{Aa}	0.30 ± 0.02^{Bb}	0.30 ± 0.01^{Bb}

[†]Results presented are the mean ± SD of 3 replications. Different lower case letters in columns and different uppercase letters in rows mean significant differences at a probability level of 5%.

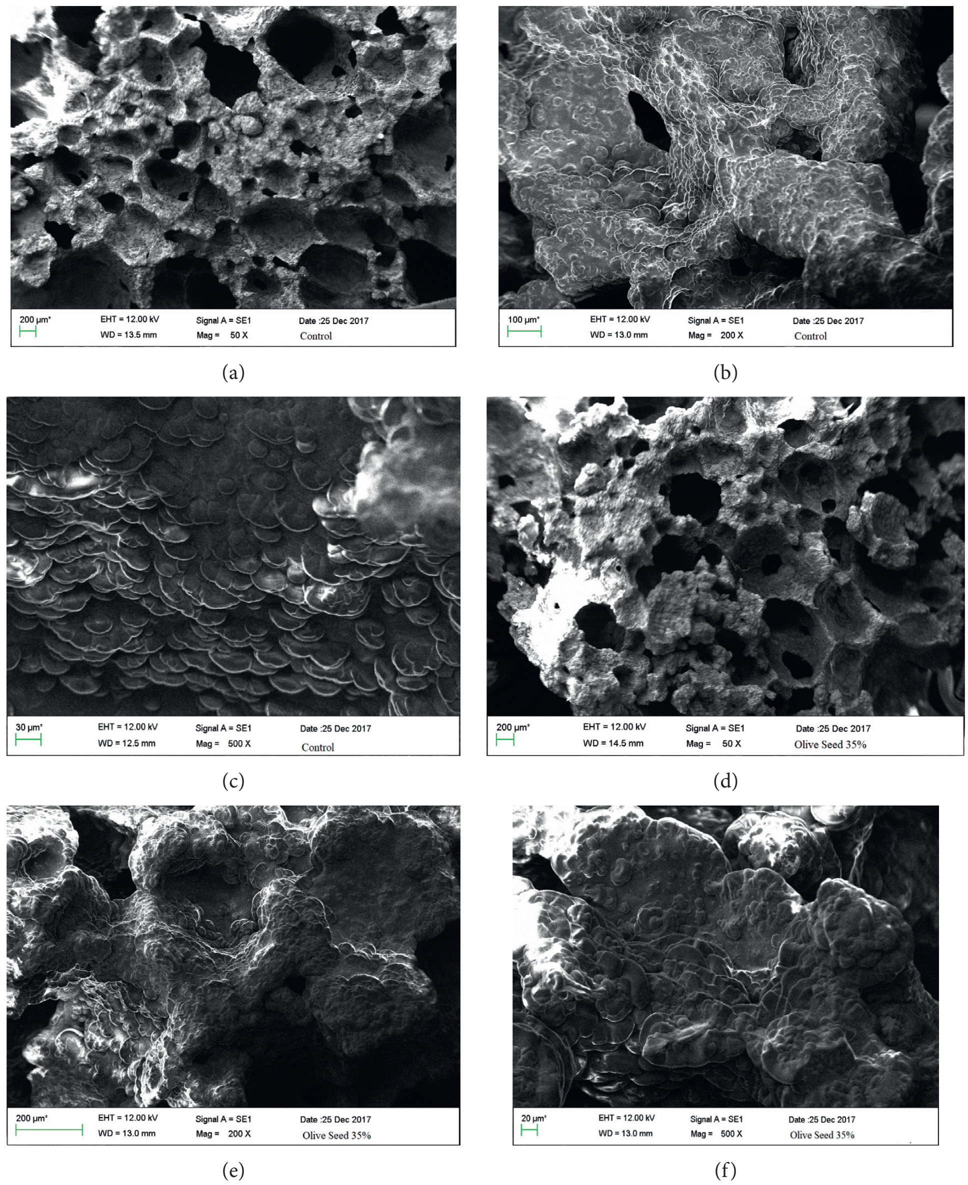

Figure 2: SEM images of sponge cakes containing 0% (control) (a, b, c) and 35% OSP (d, e, f) with different magnifications.

the fibers and increasing the amount of insoluble compounds such as lignin can make the gluten-starch matrix unable to situate these fiber particles in between the matrix, thereby resulting in textural changes and a loss of sensory properties.

3.3.7. Color Measurement. The effects of OSP flour addition on the cakes color are shown in Table 4. Significant differences were observed between the crust and crumb color of the control cake and the OSP-cakes ($p < 0.05$). The control cake gave higher L^*, a^*, and b^* color values compared with the fortified cake samples, indicating that a darker, greener, and less yellow crumb/crust was obtained as a result of OSP substitution. Olive stone dietary fibers are involved in color-forming reactions due to their water holding capacity and their effects on pH values. The water absorption capacity of OSP accelerates the water activity of the cake surface to a sufficient level that triggers the Maillard reaction, as evidenced by a darker cake crust. However, the temperature of the cake crumb during baking might not be sufficient for the Millard reaction and for caramelization. Thus, the crumb color is largely defined by ingredients. Darker pigments in OSP, compared to wheat flour, were the main cause that reduced the L^*, a^*, and b^* values of the cake samples. Another possible reason for a darker crumb color of OSP-enriched cakes could be the compact texture of the cake as caused by OSP. Ayadi et al. [12], Lu et al. [20], and Sudha et al. [7] reported that adding cheonnyuncho powder, green tea powder, and apple pomace to cake samples can lead to a reduction in L^* and a^* values but an increase in b^* values. Accordingly, Haghayegh and Zavehzad [35] stated that adding more than 10% whole stone of melon powder reduced moisture content and the L^* parameter in reduced-fat

Table 4: Color parameters of OSP and sponge cake prepared with different levels of OSP[†].

Sample	L^*	a^*	b^*	ΔE	H	SI	WI
Crumb							
0	76.90 ± 1.35^a	5.60 ± 0.70^a	78.60 ± 1.81^a	0^c	1.49 ± 0.01^b	78.80 ± 1.76^a	17.88 ± 2.07^b
15%	61.10 ± 1.97^b	3.10 ± 0.53^b	65.00 ± 2.85^b	21.05 ± 2.78^b	1.52 ± 0.00^a	65.07 ± 2.84^b	24.15 ± 2.17^a
25%	46.80 ± 0.78^c	-4.03 ± 0.25^c	52.00 ± 2.17^c	41.33 ± 1.73^a	1.49 ± 0.00^c	52.15 ± 2.16^c	25.48 ± 1.41^a
35%	45.20 ± 0.82^c	-4.10 ± 0.20^c	51.30 ± 0.62^c	42.97 ± 0.64^a	1.49 ± 0.00^c	51.46 ± 0.63^c	24.82 ± 0.91^a
Crust							
0	62.33 ± 2.52^a	8.73 ± 1.53^a	26.27 ± 4.72^a	0^c	1.24 ± 0.10^a	27.77 ± 4.08^a	53.13 ± 3.58^a
15%	54.23 ± 3.78^b	6.43 ± 1.08^b	8.00 ± 1.00^b	20.60 ± 4.13^b	0.91 ± 0.17^b	10.36 ± 1.60^b	53.07 ± 4.03^a
25%	52.20 ± 1.73^b	2.30 ± 1.44^c	3.77 ± 1.74^b	25.88 ± 2.14^a	1.05 ± 0.07^{ab}	4.42 ± 2.24^c	51.96 ± 1.88^a
35%	54.80 ± 2.64^b	1.90 ± 1.00^c	3.70 ± 1.00^b	25.24 ± 2.59^a	1.10 ± 0.19^{ab}	4.21 ± 1.16^c	54.59 ± 2.55^a
OSP	70.00 ± 2.65	-7.20 ± 0.26	63.70 ± 1.06	—	—	—	—

[†]Results presented are the mean ± SD of 3 replications. Different superscripts along horizontal line indicate significant difference at probability level of 5%.

Table 5: Sensory evaluation of sponge cake prepared with different levels of OSP[†].

Sample	Texture	Taste	Aftertaste	Color	Chewing ability	Odor	Appearance	Overall acceptance
0	4.80 ± 0.41^a	3.80 ± 0.89^a	4.05 ± 1.05^a	4.30 ± 0.97^a	4.40 ± 1.04^a	3.80 ± 0.89^a	4.55 ± 0.68^a	4.35 ± 0.67^a
15%	3.70 ± 1.12^b	3.45 ± 0.94^a	3.70 ± 1.12^a	3.85 ± 0.87^a	2.50 ± 1.00^b	4.00 ± 1.02^a	3.95 ± 0.60^b	3.45 ± 0.82^{bc}
25%	3.50 ± 1.10^b	4.05 ± 0.99^a	3.85 ± 1.08^a	3.70 ± 1.12^a	2.50 ± 0.68^b	4.30 ± 0.65^a	4.10 ± 0.55^b	3.35 ± 0.67^c
35%	3.90 ± 1.11^b	3.80 ± 1.19^a	3.90 ± 0.96^a	4.20 ± 0.95^a	2.80 ± 0.76^b	4.10 ± 0.85^a	4.35 ± 0.74^{ab}	3.80 ± 0.41^b

[†]Results presented are the mean ± SD of 3 replications. Different superscripts along the horizontal line indicate significant difference at probability level of 5%.

cakes. In fact, the loss of moisture makes a rough and wrinkled surface on the cake. Ultimately, it reduces the reflection of light and the L^* value.

According to Table 4, significant difference was observed between OSP-cakes regarding their ΔE ($p < 0.05$). The ΔE value of crumb and crust showed an increasing trend, as a result of OSP substitution. The hue angle, saturation index, and whiteness index of cakes containing 25% and 35% OSP were not significantly different ($p > 0.05$). The results indicated an increase in WI as the substitution level increased. On the contrary, SI decreased with increased OSP levels. However, the control and the 15% OSP cake were significantly different in this regard ($p < 0.05$) (Table 4). Kim et al. [6] stated that, with the increase of cheonnyuncho powder levels in the formulation, the L^* and a^* crumb color values decreased, but the b^* and ΔE values increased.

3.3.8. Sensory Evaluation. According to the sensory evaluation (Table 5), there were no significant differences between OSP-cakes and the control sample regarding their taste, aftertaste, color, and odor ($p > 0.05$). However, the samples containing OSP scored significantly less in terms of chewing ability, texture, and appearance parameters, although there was no significant difference between samples containing different levels of OSP in this regard ($p > 0.05$). Moreover, among the OSP cakes, the sample with 15% and 35% OSP received the highest and the lowest scores, respectively. The results revealed that, for the 35% OSP sample, the flavor and odor of the cake were less acceptable by the panelists. It seems that adding OSP at levels lower than 35% did not change the sensory properties of the final product, while it did increase nutritional properties. The chewiness values of all fortified cake samples were significantly lower than that of the control sample. It seems that the presence of lignin in the OSP was disliked by the panelists, especially at 35% OSP (Table 5). However, it seems probable that by reducing the particle size of OSP, the negative effects on some sensory properties will be alleviated. Similar observations were also found by Sudha et al. [7] and Ayadi et al. [12] in cakes fortified with apple pomace and cladodes fibers, respectively. According to their results, the control samples had maximum overall acceptability, whereas the samples containing more than 10% apple pomace and 5% cladodes fibers in cake formulations were found to be unacceptable to the panelists. Accordingly, An [36] studied the flavor, taste, texture, and overall consumer preference of muffins that had 3% and 6% bitter melon powder. These treatments did not cause any significant difference compared with the control. Moreover, based on their results, using less than 6% bitter melon powder could be appropriate for muffins.

Since replacing wheat flour with high percentages of OSP can significantly reduce sensory properties such as texture, color, and chewing ability, providing consumers with information on the nutritional advantages of having such cakes (e.g. fiber content, phenolic compounds and omega 3) can positively affect product acceptability despite their relatively low sensory properties.

4. Conclusion

The partial substitution of wheat flour with OSP at different levels (15, 25, and 35%) enhanced the nutritional properties of sponge cakes due to the high dietary fiber and antioxidant content of olive stone. The specific gravity and density of the batter increased significantly with higher OSP level, whereas the consistency and viscosity showed an opposite trend. The inclusion of OSP in the cake recipe darkened the cake color and decreased the hardness and springiness but increased its specific volume, cohesiveness, and chewiness. These effects were more pronounced when higher levels were used. Specific volume and hardness of cakes were validated by microstructural analysis. According to the images, cakes with 35% OSP were more porous because of the additional dietary fiber. Considering the chemical analysis of OSP, it can be expected that the main changes in the final product were mainly related to the reduction in the relative gluten content, along with an increase in fat and a decrease in sugars in the OSP-sponge cakes. The sensory evaluation revealed that the closest sample to the control cake was the one containing 15% OSP. Therefore, according to the results of textural analysis and of sensory evaluation, it can be said that higher levels of OSP replacement are not appropriate for the cake formula. Using 25% OSP did not cause significant changes in the sensory properties, while it did enhance the dietary fiber content and antioxidant phenolic compounds to an optimum level.

Data Availability

The data used to support the findings of this study are included within the article.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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