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Research Article

Physico-Mechanical, Nutritional, and Sensorial Properties of Gluten-Free Chips with Almond Powder Dried Using Different Drying Methods

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Abstract: In this study, newly formulated gluten-free chips with almond powder were produced. Almond powders were obtained using 3 different drying methods: oven drying, freeze drying, and microwave drying. This study aimed to determine the effect of drying almond powders used in gluten-free chip production using different drying methods and then adding different ratios (10% and 30%) of these powders to the chips on the physicochemical, textural, mineral, and sensory properties of the chips. The physical, textural, mineral, and sensory analyses were then carried out. The moisture content values of the chips with almond powder were < 6.32% and the water activity values were < 0.300. Adding almond powder increased the total fat and protein content of the chip samples. The protein content of the gluten-free chips increased by 34.69-257.14% compared to the control sample and the highest protein content (1.75%) was determined in the samples containing 30% of the almond powder obtained using the microwave drying method. The hardness of the gluten-free chips decreased by increasing the almond powder. The addition of the almond powder to the chip formulation generally increased the B, Cu, Mn, and Zn contents of the gluten-free chips. All chip samples enriched with almond powder showed similar overall acceptability scores (5.00-6.89).

***Keywords*:** almond powder, oven drying, freeze drying, microwave drying, gluten-free chips

1. Introduction

Almond (*Prunus amygdalus* L.) is a stone fruit, and it belongs to the Rosaceae family. Almond seeds are rich in protein, mono and polyunsaturated fatty acids, vitamins, tocopherols, dietary fiber, and minerals in addition to phytosterols and polyphenols [1].

Almonds are used in the food industry in the form of whole or broken grains, flour, milk, and oil [2]. All these forms of almond and almond skin are used individually or together and appear as different products such as snack food, cake, muffins, chocolate, cookies, pasta biscuits, *etc*. [3].

Gluten is a dietary ingredient in various cereals. Some people who consume gluten-containing foods experience serious health issues, such as celiac disease which is one of the most prevalent conditions linked to eating gluten

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[4]. Almond by-products, which are used in a wide variety of areas in different industries, also have a critical role as an important protein source for patients with celiac disease and lactose intolerance or those who prefer a vegetarian lifestyle. Many functional products such as vegan nut cheese, milk, yogurt, ice cream, muffins, and cookies obtained from almonds have been developed for safe consumption by these people [5].

In recent years, the tendency of consumers to consume healthier snacks, fruits, and vegetables has been increasing. One type of common snack that has done well in the food market is chips [6]. Different methods such as deep-fat frying and drying are used to produce chips. One of the most popular methods is hot air drying. Freeze drying is preferred mostly for drying perishable foods, which is based on sublimating a frozen product to remove water. Another method is microwave drying, in which the drying time is reduced according to the dielectric heating technique which provides less energy consumption also this volumetric heating improves the drying rate.

In the literature, there is no study investigating the effect of different drying methods for producing the almond powder added to chips or on some of the quality properties of the almond chips. The main objective of this research was also to produce newly formulated gluten-free chips with almond powder. Therefore, the aim was to investigate the effect of drying almond powder using 3 different methods (oven drying, freeze drying, microwave drying) and adding the obtained powders to the chips at 10% and 30% on the physicochemical, textural, mineral, and sensory properties of gluten-free chips.

2. Materials and methods

2.1 *Materials*

Whole almonds were provided by a local producer. The corn and rice flour, corn starch, table salt, olive oil, and drinking water were purchased from a local market.

2.2 *Methods*

2.2.1 *Drying of almonds*

The almonds were washed and kept in water (20 °C) for 24 h. The almonds were then peeled and cut into small pieces using a blender. The crushed almonds were dried using three different pieces of equipment: an oven (Memmert UN110, Germany), a freeze dryer (Armfield FT 33, England), and a microwave oven (Beko16410S, Turkey). The oven drying (OD) experiments were performed at a constant temperature of 60 °C for 25 h. For freeze drying (FD), the crushed almonds are frozen at -20 °C in an air blast freezer (Frigoscandia, Sweden) for 3 hours, then freeze-dried for 8 h under vacuum (13.33 Pa absolute pressure), at a condenser temperature of -48 °C, and the heating plate temperature at 30 °C. The microwave drying (MD) treatments were achieved at 350 W microwave power for 15 min. The dried almonds were then ground using a grinder (Premier, PRG259, Turkey). The almond powder (AP) was then stored at 4 ℃ for further analysis.

2.2.2 *Preparation of gluten-free chips*

Samples were prepared by adding 10% and 30% of the almond powder (AP), which were obtained by three different drying methods, to the dough. The flow sheet of gluten-free chips (GFC) is shown in Figure 1. Firstly, the corn, rice flour, corn starch, salt, and AP (0, 10, and 30% substitution for corn flour) were weighed, placed in a bowl, and mixed. Then, olive oil and drinking water were added to the mixture and kneaded with a mixer (Beko2155, Turkey) homogenously for 5 min. The dough was covered and rested for 15 min for hydration. At the end of this time, small dough samples (≈ 10 g) were weighed and spread in a circle on the plate of the electric toaster (ArzumAR2009, Turkey) whose bottom and top plates can be heated and whose plates can be completely adhered to each other and baked at 180 °C for 4 min. The AP was not added to the control sample and was cooked under the same conditions as the other samples. The GFC was cooled to room temperature and stored in closed containers until analysis. In the control sample, there is no AP the other ingredients are: corn flour (100 g), corn starch (20 g), rice flour (30 g), olive oil (5 g), salt (2 g), and water (150 mL); in the sample, which is the gluten-free chips with 10% AP, contains 10 g almond flour, corn flour (90 g), corn starch (20 g), rice flour (30 g), olive oil (5 g), salt (2 g), and water (150 mL); in the sample, which is the GFC with 30% AP (30 g) was mixed with corn flour (70 g), corn starch (20 g), rice flour (30 g), olive oil (5 g), salt (2 g), and water (150 mL).

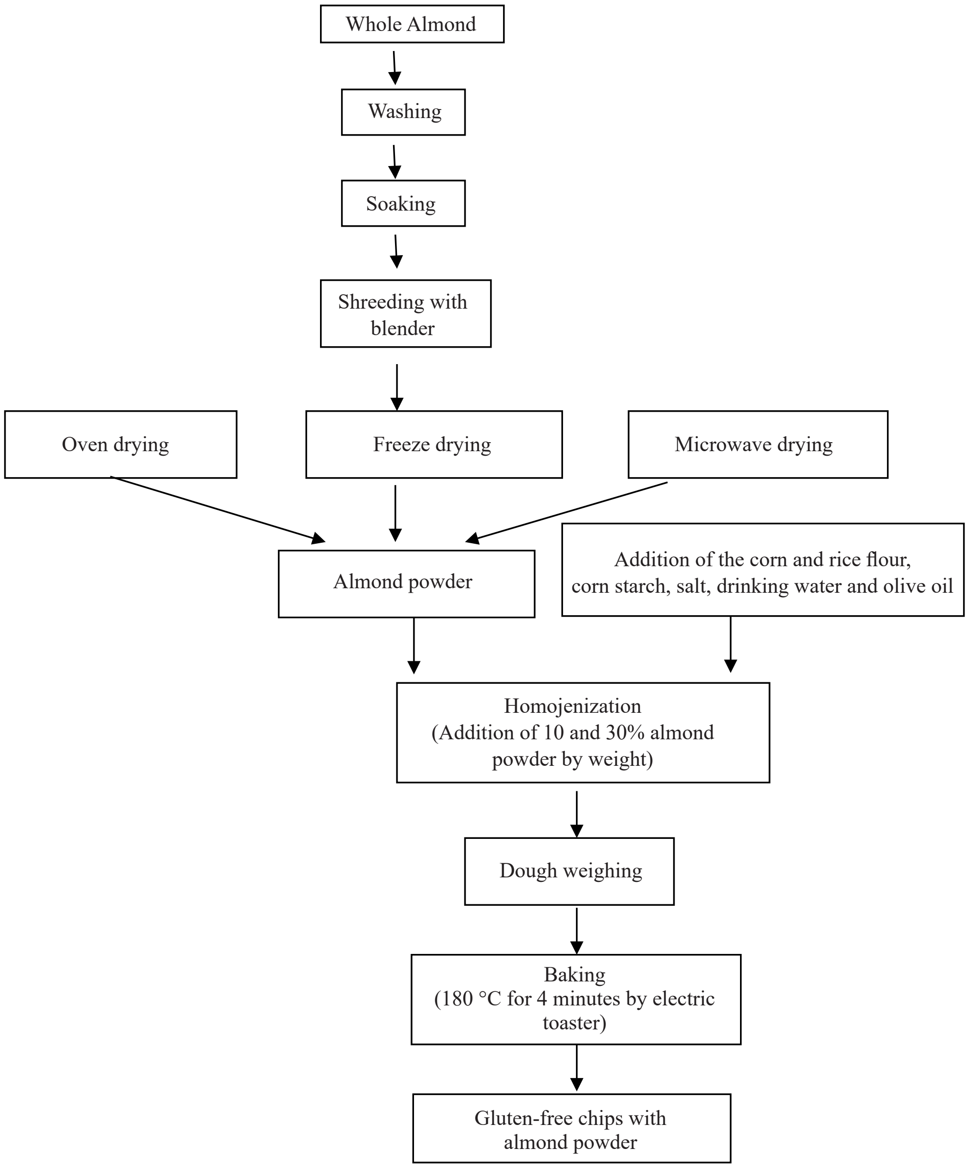

Figure 1. Flow sheet of the gluten-free chips

2.2.3 *Proximate analysis*

The moisture (44-19.01) and total fat (920-39 C) contents were determined according to American Association of Cereal Chemists methods [7]. The crude protein content was determined using the Kjeldahl method (46-13) [8]. A factor of 6.25 was used for converting the total nitrogen to crude protein.

2.2.4 *Evaluation of the total fat content*

The total fat content was determined with extraction using the Soxhlet method [9]. The total fat content was found to be as g fat/100 g dry sample.

2.2.5 *Textural analysis*

A Texture Analyzer (TA.XT Plus, UK) was used for the determination of the textural properties with six replications. The Kramer shear cell insert (HDP/KS-5) with a 50 kg load cell was selected and the 1 cm/min for pre and post-test speeds were adjusted. The breaking force (kg), the maximum force required to break the sample, was calculated using the time-force curve [10].

2.2.6 *Mineral analysis*

The mineral compositions of the GFC were determined according to a method by Zarcinas et al. [11]. Mineral concentrations were expressed as mg/100 g dry matter.

2.2.7 *Sensory analysis*

Panelists scored the color, flavor, odor, appearance, and overall acceptability on a 9-point hedonic scale from 1 = "Dislike Extremely" to 9 = "Like Extremely" [12].

2.2.8 *Statistical analysis*

A data analysis was performed using the statistical software SPSS 16.0 (SPSS Inc., U.S.A.). An Analysis of variance (ANOVA) at $P < 0.05$ was executed to analyze the differences among all samples.

Table 1. Proximate composition of the gluten-free chips

Sample	Moisture content (%, wet basis)	Water activity	Total fat (%)	Protein (%)
Control (0% AP)	7.00 ± 0.34^{f}	0.292 ± 0.002^{f}	1.84 ± 0.11^{a}	0.49 ± 0.02^{a}
10% OD	5.11 ± 0.17^{d}	0.262 ± 0.007^{d}	3.62 ± 0.10^{b}	0.84 ± 0.08^{c}
10% FD	6.32 ± 0.04^{e}	0.280 ± 0.010^{e}	7.93 ± 0.10^{d}	0.66 ± 0.05^{b}
10% MD	3.41 ± 0.07^{b}	0.246 ± 0.009^{c}	5.57 ± 0.10^{c}	0.90 ± 0.06^{d}
30% OD	4.53 ± 0.36^{c}	0.230 ± 0.008^{b}	9.11 ± 0.12^{f}	1.25 ± 0.04^{e}
30% FD	2.50 ± 0.09^{a}	0.222 ± 0.003^{ab}	8.98 ± 0.10^{e}	1.68 ± 0.07^{f}
30% MD	2.16 ± 0.16^{a}	0.215 ± 0.006^{a}	8.98 ± 0.10^{e}	1.75 ± 0.12^{g}

OD: Oven drying; FD: Freeze drying; MD: Microwave drying
Different letters (a-g) in the columns represent the statistical difference ($P < 0.05$)

3. Results and discussion

3.1 *Changes in proximate composition*

The moisture, water activity (a_w), total oil, and protein contents of the GFC are given in Table 1. Compared to the control, the moisture content (MC) and water activity (a_w) values of the GFC were found to be significantly different ($P < 0.05$). The MC of the AP dried using different methods was found between 1.76 and 2.23%. Unlike our study, stated that the MC of partially defeated almond powder was 5.7% [13]. It is thought that the difference in the method of obtaining AP may cause differences in MC. The a_w values of the AP samples ranged from 0.132 to 0.190. As the ratio of the AP dried with different methods increased, the MC and a_w values of the GFC statistically decreased ($P <$

0.05). The MC of the chips with AP was found between 2.16 and 6.32 % (wet basis). The control sample (0% AP) had a significantly higher moisture content (7%) than the other chips with AP. The a_w values of chips changed 0.215-0.292. The lowest moisture content value (2.16%) and a_w value (0.215) were found in the microwave-dried chips containing 30% AP. It was reported that the moisture content and water activity values of crispy fat-free chips produced from sweet potato dried by microwave vacuum drying method were 2.7 ± 0.6% (wet basis) and 0.262, respectively [14]. Similar values, between 0.88% and 5.45% of moisture content were reported by Yüksel et al. [15]. The MC (2.59-3.06%) and a_w (0.185-0.192) values of breadsticks with 5 and 10% red grape pomace reported by Rainero et al. [16] were compatible with our results. The MC of crackers with AP was found lower than the green gram flour crackers (5.76%) [17]. It may be due to the different cracker formulations and production processes.

The color values of the GFC are shown in Figure 2. For the L^*, a^*, and b^* values of the GFC, significant differences between the samples were found ($P < 0.05$). The L^* values of the GFC generally increased with increasing AP. The L^* values indicate lightness and a decrease in L^* values was possibly due to the light brown color of the AP. The a^* and b^* values of the GFC ranged between (3.81-9.98) and (28.79-35.11), respectively. The increase of the AP ratios from 10% to 30% increased the values of a^*, which represents the redness, of the samples significantly ($P < 0.05$). The highest b^* value (35.11 ± 1.46) which corresponds to the yellowness was achieved with the GFC prepared with 30% of the oven-dried AP. The AP contents did not affect the color. Qadri et al. [18] explained that Maillard reactions can cause a complex chemical reaction in the dough, caramelization, as well as surface color changes due to high temperature during cooking. The a^* (3.98-5.07) and b^* (30.84-36.88) values of deep-fried sorghum-based GFC reported by Kaplan et al. [19] were compatible with our results.

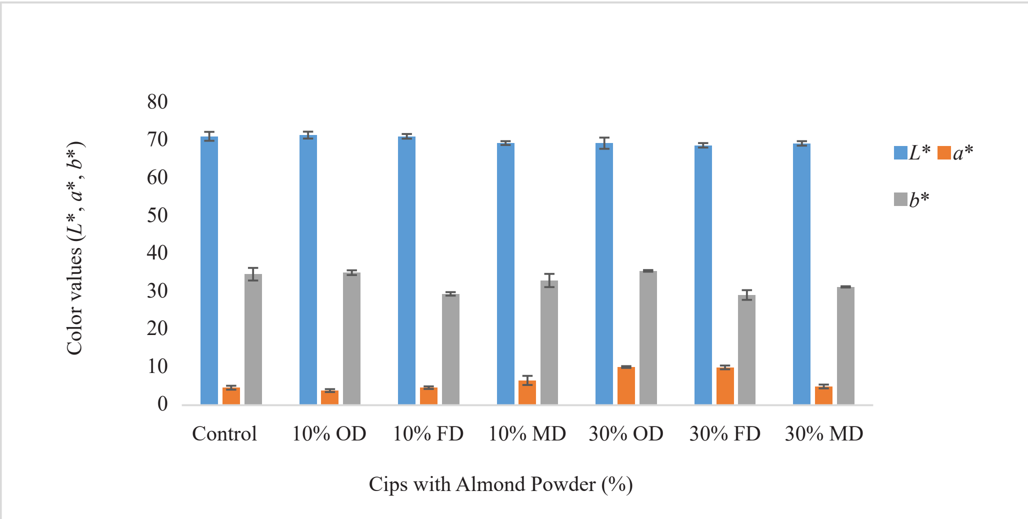

Figure 2. Color values of the gluten-free chips

The protein contents of the GFC were in the range of 0.49-1.75%. The protein level of the chips followed a clear linear trend with the control (0% AP) chip sample having the lowest protein content (0.49%) and the 30% containing samples having the highest contents (1.25-1.75%). The increase in the protein content of the GFC samples is due to the added AP as the 0% AP control sample contained the lowest protein content, which indicates that the AP can significantly increase the protein content in a GFC like product ($P < 0.05$). It was observed that the samples with the highest protein content for these two ratios of the chips dried with different drying methods and containing 10% and 30% AP were the GFC produced with the microwave-dried AP. The lowest protein contents were observed in the chips with the oven-dried AP. When the temperature rises, the formation of disulfide bonds and the promotion of the polymerization of the gluten protein may reduce the solubility of proteins [20]. In a study in which rosehip fruit was dried in the shade, at 50 °C and with 5 different microwave powers (100, 300, 500, 700, and 1,000 W), it was stated that the samples with the highest protein content were the rosehip fruits dried using the MD method [21].

3.2 *Changes in the total fat content*

The total fat content of the chip samples with AP was found in the range of 3.62-9.11% (Table 1). As expected, as the amount of AP increased, the level of total fat content increased proportionally in the GFC ($P < 0.05$). The difference between the total fat content of samples dried with FD, MD, and OD was found statistically significant ($P < 0.05$). The lowest total fat content (3.62%) was found in the OD chip containing 10% AP. When the literature was examined, chips with almond powder additives were not encountered. There are many studies on potato chips and unlike our study, most researchers found the total fat contents of potato chips between 29.25-39.25% [22] and 33-39% [23]. In our study, because the fat content of chips with AP was found to be considerably lower than in these studies is that the chips were produced without frying in oil. In addition, many researchers have noted that the fat content is related to the starch and dry matter content of the raw material [22, 24-25]. Microwave caused significant increases in the fat contents of the samples which were produced with 10% AP. Similar results were found in previous studies, for example, the fat content increased in the cakes produced with different amounts of corn flour [26].

3.3 *Changes in textural properties*

Hardness which is an important textural characteristic in GFC was measured and is shown in Figure 3. The hardness values of samples decreased with the increasing of almond powder significantly ($P < 0.05$). Maximum hardness content (9.52 kg) was determined for the FD chip containing 10% AP while minimum hardness level (3.73 kg) was obtained for the OD chip containing 30%. As the amount of AP increased, the highest decrease in hardness value was observed in chips dried by FD method. According to Zhang et al. [27], the fracturability of products could affect the presence of starch, sugar, etc. as well as the drying methods used. In addition, this can be because different moisture transfer mechanisms explained by the breaking force of the chip samples showed statistically significant differences ($P < 0.05$) in previous research by Halil et al. [28]. The increase in the AP decreased the hardness of the GFC in the same drying method groups ($P < 0.05$). Reversely, biscuits were produced with rice powder instead of wheat and this was also substituted with AP by 10, 20, and 30% and the results indicated that the AP increased the hardness value compared to the others. This was explained by the high dietary fiber content of the almond [29].

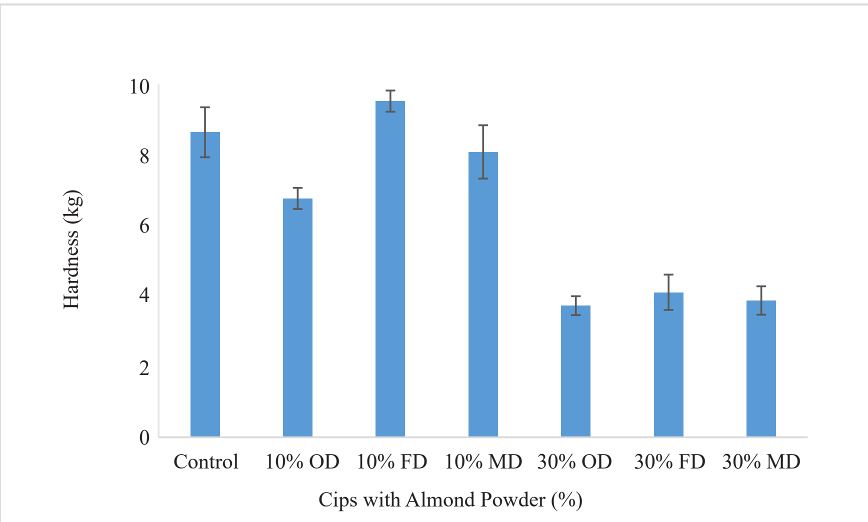

Figure 3. Hardness values of the gluten-free chips

3.4 *Changes in mineral composition*

The compositions of the minerals of the GFC are given in Table 2. The Cu contents of all the samples were found to range between 1.21 mg/kg-2.79 mg/kg. The Fe levels in the almond chips ranged between 5.46 mg/kg to 32.70 mg/kg. The Mn concentrations of the almond chips were found to be between 2.23 mg/kg and 3.40 mg/kg. The Zn contents of the samples ranged between 3.76 mg/kg and 7.85 mg/kg. The Na contents of almond chips ranged from 1,613.53 mg/kg to 2,186.66 mg/kg. The Al concentration in the GFC varied from 2.40 mg/kg to 19.45 mg/kg. Whereas, the Ca, K, Mg, P, Cd, Co, Cr, Mo, Ni, and Pb contents of all the samples were at lower levels (Table 2). Generally, the Cu, Mn, and Zn contents of the chips increased significantly ($P < 0.05$) when the AP addition was increased from 10% to 30%. Among the GFC, Na (1,613.53-2,186.66 mg/kg) had the highest mineral content. It was stated that the Ca content of the cookies containing different proportions of wheat, almond seed, and carrot flour blends varied between 192.17 mg/100 g-230.16 mg/100 g, the level of K varied between 941.22 mg/100 g to 984.26 mg/100 g, the content of Zn was between 5.75 mg/100 g to 6.56 mg/100 g, the concentration of Mg varied between 61.25 mg/100 g to 77.16 mg/100 g, and the amount of Na was between 48.44 mg/100 g to 56.12 mg/100 g [30].

Table 2. The compositions of minerals in the gluten-free chips

Sample	B (ppm)	Ca (%)	Cu (ppm)	Fe (ppm)	K (%)	Mg (%)	Mn (ppm)	P (%)	Zn (ppm)
Control (0% AP)	0.41 ± 0.02^{a}	0.01 ± 0.00^{a}	1.21 ± 0.07^{a}	7.72 ± 1.36^{b}	0.05 ± 0.00^{a}	0.01 ± 0.00^{a}	2.23 ± 0.26^{a}	0.07 ± 0.00^{a}	3.76 ± 0.13^{a}
10% OD	1.12 ± 0.43^{d}	0.01 ± 0.00^{a}	2.31 ± 0.42^{d}	10.69 ± 0.95^{c}	0.07 ± 0.00^{ab}	0.02 ± 0.00^{a}	3.01 ± 0.36^{b}	0.09 ± 0.00^{a}	5.74 ± 0.95^{bc}
10% FD	1.02 ± 0.00^{c}	0.01 ± 0.00^{a}	1.68 ± 0.05^{b}	8.51 ± 1.89^{b}	0.07 ± 0.00^{ab}	0.02 ± 0.00^{a}	2.06 ± 0.03^{a}	0.09 ± 0.00^{a}	6.12 ± 1.01^{c}
10% MD	0.50 ± 0.00^{b}	0.01 ± 0.00^{a}	1.91 ± 0.36^{c}	5.46 ± 0.63^{a}	0.07 ± 0.00^{ab}	0.02 ± 0.00^{a}	2.13 ± 0.05^{a}	0.09 ± 0.00^{a}	5.63 ± 0.94^{b}
30% OD	2.04 ± 0.23^{f}	0.03 ± 0.00^{a}	2.33 ± 0.32^{d}	10.89 ± 1.13	0.11 ± 0.00^{c}	0.04 ± 0.00^{a}	3.15 ± 0.04^{b}	0.12 ± 0.00^{a}	7.11 ± 0.14^{d}
30% FD	1.99 ± 0.31^{f}	0.03 ± 0.00^{a}	2.41 ± 0.22^{e}	8.73 ± 0.66^{b}	0.10 ± 0.00^{bc}	0.04 ± 0.00^{a}	3.19 ± 0.04^{b}	0.12 ± 0.01^{a}	7.85 ± 0.28^{e}
30% MD	1.44 ± 0.33^{e}	0.03 ± 0.00^{a}	2.79 ± 0.18^{f}	32.70 ± 2.41^{d}	0.09 ± 0.01^{bc}	0.03 ± 0.00^{a}	3.40 ± 0.37^{b}	0.10 ± 0.01^{a0}	7.09 ± 0.29^{d}

Sample	Cd (ppm)	Co (ppm)	Cr (ppm)	Mo (ppm)	Ni (ppm)	Pb (ppm)	Na (ppm)	Cr (ppm)	Al (ppm)
Control (0% AP)	-	0.07 ± 0.00^{a}	0.30 ± 0.00^{a}	0.08 ± 0.00^{b}	0.58 ± 0.05^{a}	0.09 ± 0.07^{a}	$1,613.53 \pm 4.62^{a}$	4.71 ± 0.56^{bc}	0.30 ± 0.00^{a}
10% OD	-	0.17 ± 0.00^{b}	0.45 ± 0.10^{abc}	0.08 ± 0.00^{b}	0.67 ± 0.03^{a}	0.75 ± 0.00^{d}	$1,740.09 \pm 14.88^{a}$	$7.99 \pm 0,78^{d}$	0.45 ± 0.10^{abc}
10% FD	-	0.12 ± 0.00^{ab}	0.30 ± 0.05^{a}	0.01 ± 0.00^{a}	0.62 ± 0.09^{a}	0.54 ± 0.06^{c}	$2,045.88 \pm 40.11^{a}$	5.06 ± 1.25^{c}	0.30 ± 0.05^{a}
10% MD	-	0.10 ± 0.00^{ab}	0.37 ± 0.01^{ab}	0.18 ± 0.00^{c}	0.86 ± 0.30^{b}	0.21 ± 0.00^{b}	$1,817.04 \pm 36.55^{a}$	2.40 ± 0.26^{a}	0.37 ± 0.01^{ab}
30% OD	0.02 ± 0.00^{a}	0.15 ± 0.00^{ab}	0.29 ± 0.01^{a}	0.03 ± 0.00^{a}	0.59 ± 0.09^{b}	0.58 ± 0.00^{c}	$1,833.30 \pm 61.48^{a}$	3.45 ± 0.48^{ab}	0.29 ± 0.01^{a}
30% FD	-	0.18 ± 0.00^{b}	0.49 ± 0.02^{bc}	0.11 ± 0.00^{b}	0.69 ± 0.11^{a}	0.20 ± 0.00^{b}	$2,186.66 \pm 86.43^{a}$	4.26 ± 0.73^{bc}	0.49 ± 0.02^{bc}
30% MD	0.02 ± 0.00^{a}	0.12 ± 0.00^{ab}	0.57 ± 0.06^{c}	-	0.83 ± 0.07^{b}	0.21 ± 0.03^{b}	$1,829.30 \pm 85.80^{a}$	19.45 ± 1.70^{e}	0.57 ± 0.06^{c}

OD: Oven drying; FD: Freeze drying; MD: Microwave drying. 10% and 30% indicate the amount of AP contained in the samples
Different letters (a-g) in the columns represent the statistical difference ($P < 0.05$)

3.5 *Change in the sensory evaluation*

Based on the sensory evaluation results, color, flavor, odor, appearance, and overall acceptability attributes did not show any differences when increasing the AP amount and the type of drying methods used ($P > 0.05$). A spider plot of the sensory analysis of the samples is given in Figure 4. Sensory attributes were found to be similar. The overall acceptability scores (5.00-6.89) of all samples were found to be almost equal. This showed that the 2 ratios (10% and 30%) of almond flours dried using different methods were highly appreciated and that a high ratio of 30% added to the formulation did not adversely affect the preference of the panelists. Unlike our study, Yılmaz [31] investigated the effect of hazelnut flour at the ratio of 20%, 30%, and 40% on the textural and sensory properties of the chips and it was reported that while the chips with 30% hazelnut flour were more liked, the control chips were less liked in general.

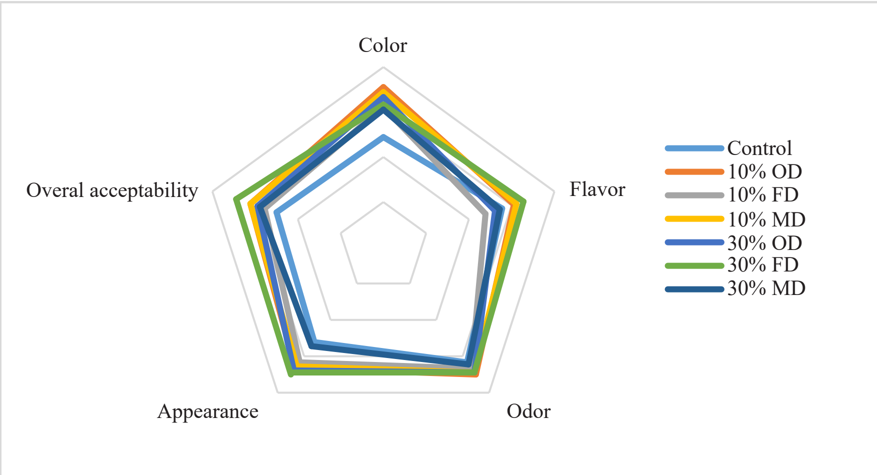

Figure 4. A spider plot of the sensory analysis of the gluten-free chips

4. Conclusions

When comparing the GFC samples containing the same amount of AP, it was observed that the MD method better preserved the protein content. Except for the FD group with a 10% formulation, the GFC enriched with AP resulted in lower hardness compared to the control. Furthermore, increasing the addition of AP generally led to higher levels of Cu, Mn, and Zn in the chips. Interestingly, all of the AP-added chips were highly regarded by the panelists, and it was found that the drying method and rate of the AP did not have any significant impact on the desirable sensory attributes of the chips.

Conflict of interest

The authors declare no competing financial interest.

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