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VALORIZATION OF ARTICHOKE LEAF POWDER IN EXTRUDED SNACKS: PRODUCT QUALITY AND IN VITRO STARCH DIGESTIBILITY

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ABSTRACT
Artichoke waste is a rich source of fibers and bioactive phenolic substances. The study aimed to investigate the effect of artichoke leaf powder (ALP) addition on physical properties and in vitro starch digestibility of wheat flour (WF) - based extrudates. Feeds were prepared to have extrudates with ALP:WF ratios of 0:100, 3:97, 6:94, and 9:91. Increasing ALP ratio reduced sectional and volume expansion indexes but increased bulk density and hardness values. The water absorption index decreased for the highest ALP: WF ratio (9:91), while the water solubility index was not affected by ALP addition. Rapidly and slowly digestible glucose fractions were not significantly affected by ALP addition. The overall acceptability of products was only affected at the 9:91 ALP: WF ratio. The findings showed that ALP could be valorized as a food ingredient. The information gained could guide future studies that will focus on developing nutritious ready-to-expanded snacks enriched with high fiber ingredients.
Keywords: Artichoke, extrusion, dietary fiber, available glucose

ENGİNAR YAPRAĞI TOZUNUN EKSTRÜDE ATIŞTIRMALIKLARDA KULLANILMASI: ÜRÜN KALİTESİ VE IN VITRO NİŞASTA SİNDİRİLEBİLİRLİĞİ

ÖZ
Enginar üretimi esnasında ortaya çıkan atıklar zengin lif ve biyoaktif fenolik madde kaynağıdır. Bu çalışma, enginar yaprağı tozu (ALP) ilavesinin, buğday unu (WF) bazlı ekstrüdatların fiziksel özelliklerine ve *in vitro* nişasta sindirilebilirliğine etkisini araştırmayı amaçlamaktadır. Çalışmada, ALP:WF oranları sırasıyla 0:100, 3:97, 6:94 ve 9:91 olacak şekilde ekstrüdatlar üretilmiştir. ALP oranının artırılması, genleşme indekslerini azaltmış, ancak yığın yoğunluğu ve sertlik değerlerini artırmıştır. Su emme indeksi en yüksek ALP:WF oranında (9:91) azalırken, suda çözünürlük indeksi ALP ilavesinden etkilenmemiştir. Hızlı ve yavaş sindirilebilen glikoz fraksiyonları ALP ilavesinden önemli ölçüde etkilenmemiştir. Ürünlerin genel kabul edilebilirliği yalnızca 9:91 ALP:WF oranında etkilenmiş olup bulgular, ALP'nin ekstrüdatlarda bir gıda bileşeni olarak değerlendirilebileceğini

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göstermiştir. Elde edilen bilgiler, yüksek lif içeriği ile zenginleştirilmiş, besleyici atıştırmalıkların geliştirilmesine yönelik gelecekteki çalışmalara rehberlik edebilir.
Anahtar kelimeler: Enginar, ekstrüzyon, diyet lifi, mevcut glikoz

INTRODUCTION

The extrusion is a high-temperature, short-time technology that combines several food processing operations such as mixing, shearing, heating, and forming in a single piece of equipment. The process combines mechanical, thermal, and chemical effects continuously. Its versatility makes it possible to produce different foods such as pasta, ready-to-eat cereals, and pet foods by simply changing the ingredient, extrusion conditions, and the die. The extrusion process is high throughput, energy-efficient, environmentally friendly, and low-cost technology. Therefore, it is convenient for developing value-added cereal-based products by incorporating by-products with nutritional benefits into the food stream for consumer appeal (Wani, Kumar, 2016). However, additional ingredients mainly composed of high dietary fiber and protein have adverse effects on extrudates' expansion and textural properties, which could reduce their acceptance rates by consumers (Ačkar et al., 2018; Blandino et al., 2022).

Extruded products' structural and textural quality may alter nutrients' digestibility (Rathod, Annapure, 2017). It is possible to increase the availability of bioactive compounds, antioxidant activity, and total phenolic content in the extrudates during digestion by incorporating vegetable-based materials (Tonyali et al., 2015; Ortak et al., 2017; Guven et al., 2018; Tonyali et al., 2020). Besides, additional ingredients high in fiber and protein content may reduce the starch digestion rate (H. Lu et al., 2021). Therefore, it is essential to investigate the quality, nutritional and sensory attributes of cereal-based extrudates enriched with by-products to improve the nutritional quality and increase consumer interest. Globe artichoke (*Cynara scolymus L.*) has many health benefits since it is rich in inulin, fiber, minerals, and bioactive phenolic compounds (Lattanzio et al., 2009). A great portion (60%) of harvested arthichoke biomass, consisting of external flowers, bracts and stems, is discarded during manufacturing operations (Guven et al., 2018). Artichoke waste is surprisingly rich in fibers and bioactive phenolic compounds. Several studies showed that the extrusion process improved the in vitro bioaccessibility of functional compounds, including the bioactive compounds found in the artichoke leaf powder (ALP) (Tonyali et al., 2015; Ortak et al., 2017; Guven et al., 2018; Tonyali et al., 2020). Therefore, the present study investigated the effects of ALP addition on the physical and sensory properties and *in vitro* starch digestibility of wheat flour-based extrudates.

MATERIALS AND METHODS

Materials and feed preparation

Wheat flour (WF) (72.2 g carbohydrate, 2.4 g fiber, 13.1 g protein in 100 g) (Soke Milling Industry and Trade Inc., Türkiye) and artichoke (*Cynara scolymus L.*) leaves from local groceries (Ankara, Türkiye) were used in feed preparations. Pepsin (EC 3.4.23.1, P7125, Sigma-Aldrich, St. Louis, MO, US), pancreatin (P7545, Sigma-Aldrich, St. Louis, MO, US), amyloglucosidase (EC 3.2.1.3, A7095, Sigma-Aldrich, St. Louis, MO, US), and invertase (EC 3.2.1.26, I4504, Sigma-Aldrich, St. Louis, MO, US) enzymes were used for enzymatic digestion of products.

Green fleshy outer leaves of artichokes leaves were washed and dried at room temperature for two weeks (Guven et al., 2018). They were ground (pulverisette 16 mill, Fritsch, Idar-Oberstein, Germany) and sieved (1 mm, Fritsch, Idar-Oberstein, Germany). The artichoke leaf powder (ALP, moisture of 8.4 ± 1.4 %) was stored at room temperature in closed jars until the analysis. A halogen moisture analyzer at 160 °C (MIX-50, AND, Tokyo, Japan) was used to measure the moisture contents of both raw and processed samples.

Feeds were prepared to have extrudates with ALP: WF ratios of 0:100, 3:97, 6:94, and 9:91 (g ALP: g WF on dry basis). The final moisture contents of the feed mixtures were adjusted to 20 % by adding distilled water and mixed

(KitchenAid, Greenville, OH, US). Feed mixtures were stored at +4 °C overnight for equilibration and kept at room temperature for 2 hours before the extrusion process.

Extrusion

A laboratory-scale co-rotating twin-screw extruder (Feza Machine Co. Ltd., Istanbul, Turkey) with screw configurations given in Table 1 was used to obtain the extrudates (Guven et al., 2018; Tonyali et al., 2015, 2020). Die diameter was 3 mm, and barrel length to diameter ratio (L:D) was 25:1 (cm: cm). The feed flow rate was 55 ± 1 g/min, the screw speed was 250 rpm, and barrel temperature zones were set at 80 °C, 90 °C, 130 °C, and 150 °C (die: 128 °C). Samples were taken only when the actual barrel zone and die temperatures varied maximum ± 2 °C from the set temperatures. The moisture content of the samples was 11.5 ± 0.5 % after the extrusion process, and they were dried at 50 º for 5 h (E28, Binder, Tuttlingen, Germany) to a moisture content less than 10 % and stored in plastic bags until the analyses.

Table 1. Screw configurations of the extruder.

8 *D* Twin lead feed screws
7x30° Forward kneading elements
4 *D* Twin lead feed screws
4x60° Forward kneading elements
4x30° Reverse kneading elements
2*D* Twin lead feed screws
6x60° Forward kneading elements
4x30° Reverse kneading elements
1 *D* Single lead feed screws
7x90° Kneading elements
2 *D* Single lead feed screws
Die
Screw diameter (*D*) = 25 mm
One kneading element = 0.25 D

Physical properties of extrudates

Color:

Extrudates were ground (KSW 445 CB, Bomann, Kempen, Germany) and sieved (212 μm) (Caltinoglu et al., 2013). The color of compressed powder was determined as color coordinates in CIELAB color space (L^*, a^*, b^*) (CR 10, Konica Minolta, Osaka, Japan), which was calibrated against a standard white (L^*= 93.8, a^*= 0.0, b^*= 5.2) (Caltinoglu et al., 2013). In order to determine the effect of ALP addition on the color, the color change upon ALP addition was determined. The ΔE value, which shows the color difference between the control and ALP added samples, was calculated according to Eq.1 where L^*_0, a^*_0, b^*_0, and L^*, a^*, b^* are the color values of the control sample and samples with added ALP, respectively.

$$\Delta E=((L^*-L^*_0)^2+(a^*-a^*_0)^2+(b^*-b^*_0)^2)^{1/2} \qquad \text{(Eq.1)}$$

Scanning electron microscopy (SEM):

Images of the extrudates were captured in the Middle East Technical University (METU) Central Laboratory with a scanning electron microscope (QUANTA 400F Field Emission, Thermo Fisher, Oregon, US). Before scanning, samples were coated with 6 nm Au-Pd by sputter coater (Polaron, Quorum Technologies Ltd, East Sussex, UK) (Caltinoglu et al., 2013).

Bulk density:

The liquid displacement method was used to determine the bulk density as described previously (Caltinoglu et al., 2013). Extrudates with known weight were submerged into molten paraffin and cooled to let paraffin cover the sample. The covered pieces were weighed and dipped into water with a glass ball with a known weight in a degree cylinder. The rise in the water level was measured. Bulk density was determined by using the below equations:

$$m_{paraffin} = m_{total} - m_{extrudate} \qquad \text{(g)} \qquad \text{(Eq.2)}$$

$$V_{paraffin} = m_{paraffin} / \varrho_{paraffin} \qquad (\text{cm}^3) \qquad \text{(Eq.3)}$$

$$V_{extrudate} = \Delta V_{liquid} - V_{glassball} - V_{paraffin} \ (\text{cm}^3) \qquad \text{(Eq.4)}$$

$$\varrho_{bulkdensity} = m_{extrudate} / V_{extrudate} \qquad (\text{g/cm}^3) \qquad \text{(Eq.5)}$$

where $m_{extrudate}$ (g), $m_{paraffin}$ (g), m_{total} (g) are the weight of the extrudate without the paraffin, the weight of the paraffin covering the extrudate, the total weight of the extrudate with the paraffin, respectively; $V_{extrudate}$ (cm^3), $V_{paraffin}$ (cm^3), $V_{glassball}$ (cm^3), ΔV_{liquid} (cm^3) were the volume of the extrudate, the volume of the paraffin covering the extrudate, the volume of the glass ball, the volume of water raised, respectively; $\varrho_{bulkdensity}$ (g/cm^3) and $\varrho_{paraffin}$ (g/cm^3) are the density of extrudates and the density of paraffin covering the extrudates, respectively.

True density:
The true volume and true density values of extrudates were determined by a helium pycnometer (Ultrapycnometer 1000, Quantachrome, Boynton Beach, FL, US) at the Middle East Technical University Central Laboratory (Caltinoglu et al., 2013).

Sectional expansion index (SEI), volume expansion index (VEI) and porosity:
Diameters of randomly selected extrudate pieces were measured with a digital caliper (Caltinoglu et al., 2013). The sectional expansion index (SEI) and volume expansion index (VEI) were calculated as described elsewhere (Pai, Blake, Hamaker, Campanella, 2009) by the following formulas:

$$SEI = (D_e / D_d)^2 \quad \text{(Eq.6)}$$

$$VEI = \varrho_{soliddensity} / \varrho_{bulkdensity} \quad \text{(Eq.7)}$$

$$Porosity = 1 - (\varrho_{bulkdensity} / \varrho_{soliddensity}) \quad \text{(Eq.8)}$$

where D_e (mm) and D_d (mm) are the diameter of the extrudate and the diameter of die, respectively; $\varrho_{soliddensity}$ (g/cm^3) and $\varrho_{bulkdensity}$ (g/cm^3) are the true density and the bulk density values of extrudates, respectively.

Water absorption index (WAI) and water solubility index (WSI):
Water absorption index (WAI) and water solubility index (WSI) were calculated by the method described elsewhere (Caltinoglu et al., 2013). Extrudates were finely ground (KSW 445 CB, Bomann, Kempen, Germany) and sieved (212 μm). 1 g powdered sample was mixed with 6 mL of distilled water in a beaker, and the mixture was stirred at 30 ºC, at 1000 rpm for 30 min (Wisd WiseStir MS-20D, witeg Labortechnik GmbH, Wertheim, Germany). The mixture was transferred into a tube and centrifuged at 4000xg, at 24 ºC for 20 min (2-16PK, Sigma Laborzentrifugen, Osterode am Harz, Germany). The supernatant was separated from sediment and transferred into a glass tube with known weight, and the remainder was weighed. The glass tube containing the supernatant was dried at 110 ºC for 18 h and weighed. WAI and WSI were calculated by the following formulas:

$$WAI = m_{sediment} / m_{dryproduct} \quad \text{(Eq.9)}$$

$$WSI = (m_{dissolved} / m_{dryproduct}) \times 100 \quad \text{(Eq.10)}$$

where $m_{dryproduct}$ (g), $m_{sediment}$ (g) and $m_{dissolved}$ (g) are the dry weight of product initially weighed, the weight of sediment after the centrifugation process, the weight of dissolved solids in the supernatant, respectively.

Breaking stress:
A texture analyzer (TA.XT Plus, Stable Micro Systems, Surrey, UK) in compression mode was used to determine the breaking stress (BS) (Caltinoglu et al., 2013). Height and force calibrations were conducted before the analysis. A 4-cm-long piece of the sample was placed on a three-point bend rig with two adjustable supports. The distance between supports was fixed at 2 cm. A sharp testing blade (0.12 cm thick, 8 cm wide) was used as the analysis probe. The trigger force, test distance, and test speed values were 5.0 g, 10 mm, and 10.0 mm/s, respectively. The maximum stress was calculated with the equation given below (Sahin, Sumnu, 2006):

$$\sigma = (F.L) / (\pi.r^3) \quad \text{(Eq.11)}$$

where σ, F, L, and r are the maximum stress (Pa), snapping force (N), the distance between two supports (m), and the radius of extrudate (m).

Determination of nutritionally important glucose fractions by in vitro digestion
In vitro digestion
To determine glucose fractions, in vitro digestion protocols described elsewhere (Englyst et al., 1999; Parada et al., 2011) were used with some modifications (Tonyali et al., 2020). The enzyme mixture was prepared fresh on the day of analysis. In each of the six centrifuge tubes, 3 g of pancreatin was mixed with 20 mL water by vortex-mixing and stirred on a magnetic stirrer for 10 min. The mixture was centrifuged at 1500 x g for 10 min. From each tube, 15 mL of supernatant

was transferred into a beaker and mixed with 4 mL of amyloglucosidase and 6 mL of invertase to have a 100 mL enzyme mixture.

Ground (KSW 445 CB, Bomann, Kempen, Germany) and sieved (212 μm) samples (0.7 g) were mixed with 5 mL saturated (50 %) benzoic acid solution and 10 mL pepsin-guar gum solution (5 g pepsin/L and 5 g guar gum/L dissolved in 0.05 M HCl) in 50-ml-tubes. A blank tube (without sample) was used to correct the glucose coming from the enzyme solutions and additional chemicals. All tubes were vortex-mixed and placed in a water bath at 37 ºC for 30 min. After the incubation at 37 ºC, 5 mL of sodium acetate solution (0.5 M), 5 mL of the enzyme mixture, and five glass balls were added to each tube. The caps of tubes were closed and slightly shaken. The tubes were placed in a shaking water bath (160 rpm) at 37 ºC (t=0 min). After 20 min (t=20), 0.2 mL sample from each tube was transferred into another tube labeled as G_{20} and mixed with 4 mL of ethanol. The original tubes were immediately returned to the water bath, and at the end of 120 min (t=120), the same sampling procedure was repeated for each tube to obtain the G_{120} samples. At the end of 120 min, the original tubes in the water bath were vortex mixed and placed in a boiling water bath for 30 min. Then they were cooled down in an ice-water bath for 15 min, and 10 mL of potassium hydroxide (0.7 M) was added into each tube. The tubes were returned to the ice-water bath and incubated for 30 min. Then, 0.2 mL of the sample taken from each tube was mixed with 1 mL acetic acid solution (1 M) and 320 μL amyloglucosidase solution (40 μL diluted with 280 μL water). This mixture was first incubated in a water bath at 70 ºC for 30 min, and then it was placed in a water bath at boiling temperature for 10 min. The tubes were let to cool down to room temperature, and 12 mL of ethanol was added to obtain total glucose (TG) samples.

High-pressure liquid chromatography (HPLC):
The G_{20}, G_{120}, and TG sample solutions were centrifuged at 1500xg for 5 min. The supernatants were dried in a concentrator (Concentrator 5301, Eppendorf AG, Hamburg, Germany), dissolved in 1 mL of distilled water, and filtered through a 0.45 μm PTFE syringe filter. G_{20} (glucose released during the first 20 min), G_{120} (glucose released during the first 120 min) and TG (total glucose in the sample) values were determined by HPLC analysis at METU Molecular Biology and Biotechnology R&D Center by adapting the official method of the European Community (NF EN 12630:1999) (Tonyali et al., 2020).

Calculation of glucose fractions: RAG (rapidly available glucose), SAG (slowly available glucose), and UG (unavailable glucose) were calculated according to the equations given below (Tonyali et al., 2020):

$$RAG\ (g/100g) = (G_{20} / TG) \times 100 \qquad (Eq12)$$

$$SAG\ (g/100g) = ((G_{120} - G_{20}) / TG) \times 100 \qquad (Eq.13)$$

$$UG\ (g/100g) = ((TG - G_{120}) / TG) \times 100 \qquad (Eq.14)$$

Sensory evaluation
Ten semi-trained panelists among the METU Food Engineering Department members evaluated the produced extrudates. Definitions of the quality attributes and the score sheet were explained to the panelists before the panel. The panelists rinsed their mouths with water just before tasting each sample. Panelists evaluated the samples in terms of appearance, color, taste, and texture on a 9-point hedonic scale (1: dislike extremely to 9: like extremely). They were asked to compare four products for each category separately for only one attribute. Panelists also scored the overall preference. Statistical analysis
Analysis of variance (ANOVA) was used to determine whether there was a significant difference between the samples ($p \leq 0.05$). When there was a significant difference, Duncan's Multiple Range Test was applied to determine means which significantly differed from others ($p \leq 0.05$). Minitab 16 Statistical Software (Minitab Inc., Pennsylvania, USA) was used in statistical analysis. Each experiment was replicated at least three times except the *in vitro* digestion experiments, where the replication number was two.

RESULTS AND DISCUSSION

Physical properties

Color:

The L*, a*, b* values, and ΔE values were depicted in Table 2. As ALP:WF ratio increased L* value decreased. The products became darker in color because the greenish color of ALP is naturally darker than the white color of the wheat flour. The redness (a*) and yellowness (b*) of the products increased with increasing ALP:WF ratio. Artichoke heads show a wide color range since they contain anthocyanin pigments, hydroxycinnamic acids, and flavones (Schütz et al., 2004; Zhu et al., 2004; Schütz et al., 2006a; Schütz et al., 2006b; Lattanzio et al., 2009). The product with 9:91 ALP:WF ratio had the highest color difference (ΔE) due to the increasing pigment concentration with increasing ALP content.

Table 2. Color parameters of artichoke leaf powder (ALP) added wheat flour (WF) based extrudates.

ALP: WF (g:g)	L*	a*	b*	ΔE
0:100	73.3 ± 0.3[a]	4.4 ± 0.4[d]	19.1 ± 0.2[d]	-
3:97	67.9 ± 0.5[b]	4.8 ± 0.4[c]	21.8 ± 0.2[c]	20. 9 ± 0.5[c]
6:94	64.6 ± 0.8[c]	5.1 ± 0.1[b]	23.3 ± 0.1[b]	24.6 ± 0.8[b]
9:91	61.2 ± 0.6[d]	5.4 ± 0.1[a]	23.7 ± 0.1[a]	27.9 ± 0.1[a]

Results are mean ± SD (n = 10). Significantly different values in the same column are followed by different letters (a, b, c, d) ($P \leq 0.05$). L*: lightness; a*: redness; b*: yellowness; ΔE: color difference between the control and ALP added samples.

Scanning Electron Microscopy (SEM):

The internal microstructures of extrudates were examined by scanning electron microscopy (SEM). Microstructure (cell number, size, and wall thickness) is related to the extrudates' expansion and textural properties (Gui, Ryu, 2014). The decrease in the size and the increase in the number of air cells after ALP addition, especially for the extrudates with 9:91 ALP:WF ratio could be seen qualitatively in Figure 1. In a previous study, corn-based extrudates enriched with semi-defatted sesame cake, the number of air cells increased, and the air cells' size decreased (Nascimento et al., 2012). The researchers claimed that dietary fibers in the semi-defatted sesame cake behaved as nucleating agents and increased air cell number. The same hypothesis can be valid for the present study since ALP is a rich source of fibers that may act as nucleating agents. In apple-pomace added corn-based extrudates, the reduction in air cell size was attributed to the reduction in elastic recovery and extensibility due to the replacement of starch with apple pomace (Karkle et al., 2012). In the present study, the dilution of starch in ALP added extrudates could be responsible for reducing elasticity and extensibility, which in turn causes reduced cell size and the less expanded samples. The cell wall thickening effect of ALP can also be observed (Figure 1). Thicker cell walls are responsible for increased rigidity, resistance to rupture, and hardness of extrudates (Bisharat et al., 2013; Rolandelli et al., 2020).

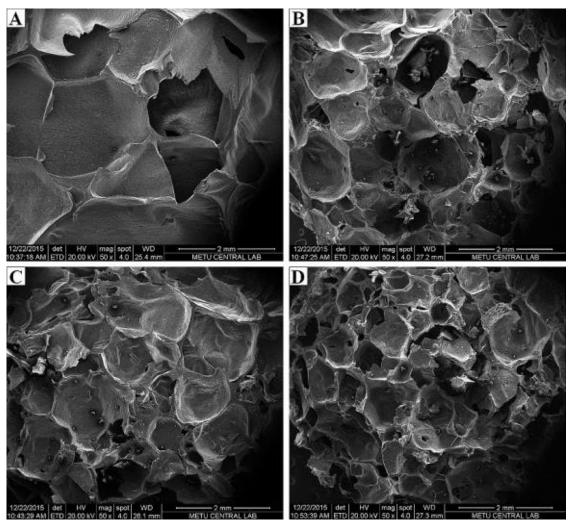

Figure 1: SEM micrographs of artichoke leaf powder (ALP) added wheat flour (WF) based extrudates. Extrudate with an ALP:WF (g:g) concentration of A) 0:100, B) 3:97, C) 6:94, D) 9:91.

Expansion properties:
The puffing degree of extrudates can be described by expansion ratio (expansion in the radial direction) and bulk density (expansion in all directions) (Falcone, Phillips, 1988). The porosity, another expansion property, is negatively correlated with bulk density (Yağcı, Göğüş, 2008). As ALP:WF ratio increased, bulk density increased, and porosity, SEI and VEI decreased (Table 3). At all ALP addition levels, extrudates had significantly different SEI and VEI values (Table 3). Bulk density and porosity were not significantly affected by ALP addition at 3:97 ALP:WF ratio; however, when ALP concentration increased further, bulk density increased and porosity decreased significantly (Table 3).

Table 3. Physical properties of artichoke leaf powder (ALP) added wheat flour (WF) based extrudates.

		ALP: WF (g:g)			
		0:100	3:97	6:94	9:91
Bulk Density†	(g/cm^3)	0.18 ± 0.00^{c}	0.21 ± 0.03^{bc}	0.24 ± 0.05^{b}	0.37 ± 0.10^{a}
SEI‡		14.11 ± 0.97^{a}	7.52 ± 0.05^{b}	6.01 ± 0.31^{c}	4.08 ± 1.22^{d}
VEI†		8.29 ± 0.34^{a}	7.32 ± 1.48^{b}	6.40 ± 1.75^{c}	4.23 ± 0.61^{d}
Porosity†		0.88 ± 0.01^{a}	0.86 ± 0.03^{ab}	0.84 ± 0.04^{b}	0.76 ± 0.03^{c}
WAI§	(g/g)	3.96 ± 0.03^{a}	3.87 ± 0.18^{ab}	3.70 ± 0.05^{ab}	3.63 ± 0.01^{b}
WSI§	%	24.05 ± 0.93^{a}	23.85 ± 2.39^{a}	26.08 ± 2.56^{a}	24.01 ± 0.99^{a}
Breaking Stress ‡	(MPa)	0.39 ± 0.08^{d}	0.95 ± 0.18^{c}	1.25 ± 0.20^{b}	2.17 ± 0.38^{a}

Abbreviations: ALP, artichoke leaf powder; WF, wheat flour; SEI, sectional expansion index; VEI, volume expansion index; WAI, water absorption index; WSI, water solubility index.
†Results are mean ± SD (n = 10).
‡ Results are mean ± SD (n = 50).
§ Results are mean ± SD (n = 6).
Significantly different values in each row are followed by different letters (a, b, c, d) ($P \leq 0.05$).

The primary polymer which plays an essential role in the expansion is starch, and the other components such as proteins, sugars, fats, and fibers act as diluents (Moraru, Kokini, 2003). In this study, ALP has negatively affected the expansion properties acting as a diluent. Artichoke bracts are mainly composed of dietary fibers (Villanueva-Suárez et al., 2019). Fibers may cause an overall reduction in expansion properties through different mechanisms (Robin et al., 2012). They interfere with bubble expansion, reduce the air cell size by causing premature rupture of gas cells and eventually lead to a reduction in the overall expansion (Lue et al., 1991; Chang et al., 1998; Moraru, Kokini, 2003; Yanniotis et al., 2007). Therefore, ALP may have reduced expansion and increased bulk density by interfering with bubble expansion, disrupting the continuous structure and restricting the available water.

Water absorption index (WAI) & water solubility index (WSI):
The water absorption index (WAI) indicates the volume occupied by the granule or starch polymer or the ability of starch to absorb water upon swelling in excess water (Sriburi, Hill, 2000; Zhu et al., 2010). In this study, there was no significant difference between WAI values of extrudates at 0:100, 3:97 or 6:94 ALP:WF ratios (Table 3). However, when ALP:WF ratio was further increased to 9:91, WAI was lower than that of extrudates with no ALP. In literature, for rice, barley, corn, and semolina based extrudates reduction in WAI was reported due to enrichment with pea grits, beetroot powder, tomato pomace, partially defatted hazelnut flour, apple pomace, and mushroom powder (Singh et al., 2007; Altan et al., 2008a; Yağcı, Göğüş, 2008; Karkle et al., 2012; Singh et al., 2016; Lu et al., 2020). Increasing fiber content was found to decrease the WAI of cornmeal extrudates in previous studies (Artz et

al., 1990; Jin et al., 1995); on the other hand, if the fiber has a higher water holding capacity than starch, it may lead to an increase in WAI (Yadav et al., 2015). WAI can be used as an indirect measure of the gelatinized starch granules (Zhu et al., 2010). The lower WAI value in extrudates with the highest ALP level (9:91 ALP:WF ratio) could be due to the dilution of starch, implying that ALP might have a slightly lower water holding capacity than the WF (Singh et al., 2007; Altan et al., 2008a; Yağcı, Göğüş, 2008; Singh et al., 2016). WSI measures free polysaccharides released from the starch after extrusion. It is an indication of starch degradation with combined effects of gelatinization, dextrinization, and the consequent solubilization (Gutkoski, El-Dash, 1999; Sriburi, Hill, 2000; Ding et al., 2005). In our study, the WSI values of samples were not significantly affected by ALP addition (Table 3). Differential scanning calorimetry analysis (data were not shown) showed that gelatinization was complete for all extruded samples. Previously, similar results were observed for mushroom enriched semolina-based extrudates and onion skin powder enriched wheat flour-based extrudates (X. Lu et al., 2020; Tonyali et al., 2020). We can conclude that fragmentation or gelatinization was not affected by ALP addition for all ALP levels.

Breaking stress:

Breaking stress (BS) can be used to measure the hardness of extrudates (Altan et al., 2008b; Stojceska et al., 2008; Robin et al., 2011; Delgado-Nieblas et al., 2019). According to the BS values given in Table 3, products' hardness increased significantly as ALP:WF ratio increased. These data were also supported by increased bulk density and decreased porosity data (Table 3). Generally, addition of by-products to extrudates increases product density and hardness (Korkerd et al., 2016).

Glucose fractions determined by in-vitro starch digestion

Thermal, mechanical, and, chemical processes applied to starch and its interaction with other ingredients in the food matrix contribute to forming a typical microstructure that can affect starch digestion and absorption of carbohydrates (Kaur, Singh, 2016; Lovegrove et al., 2017). According to the results given in Table 4, all the extruded samples had high rapidly available glucose (RAG) and low unavailable glucose (UG) values. In some studies, the addition of bran, inulin, guar, mushroom and additional fibers was found to reduce carbohydrate digestibility of extrudates (Brennan et al., 2008; Brennan et al., 2012; Schuchardt et al., 2016). However, in the present study, the used ALP:WF ratios did not cause any significant difference in the RAG and UG values (Table 4). The data in Table 4 were presented as RAG, SAG and UG "per 100 g total glucose" rather than "per 100 g of the samples". Therefore, the effect of dilution, due to replacement of WF by ALP, were excluded by normalizing the data with the total glucose found in the samples. In addition, according to the DSC results, all samples showed complete gelatinization (data not shown). Therefore, in this study, the used ALP:WF ratios were not high enough to limit the gelatinization and reduce the carbohydrate digestibility. Tonyali et al. (2020) also reported that onion skin powder addition did not affect the glucose release rate of wheat-based extrudates.

Sensory evaluation results

Extrudates were evaluated in terms of appearance, color, taste, texture and overall preference. Only the extrudates with the highest ALP:WF ratio (9:91) had significantly lower scores (Table 5). Among the other groups, there was not a significant difference in terms of evaluated attributes. Extrudates with lower breaking force and higher expansion degrees were reported to receive better sensory scores (Altan et al., 2008b; Ačkar et al., 2018). The poor expansion and hard structure of extrudates with 9:91 ALP:WF ratio may be responsible for the low sensory scores in the present study.

Table 4. Rapidly available glucose (RAG), slowly available glucose (SAG), and unavailable glucose (UG) fractions of artichoke leaf powder (ALP) added wheat flour (WF) based extrudates.

ALP:WF (g:g)	RAG	SAG (g glucose / 100 g TG)	UG
0:100	57.45 ± 11.1	6.45 ± 2.5	36.1 ± 20.3
3:97	74.74 ± 5.8	1.68 ± 6.8	23.58 ± 4.0
6:94	60.05 ± 10.08	1.41 ± 2.6	38.54 ± 19.2
9:91	58.86 ± 5.3	6.71 ± 2.9	34.43 ± 8.4

Results are mean ± SD (n = 2).

Table 5. Sensory evaluation results of artichoke leaf powder (ALP) added wheat flour (WF) based extrudates.

ALP:WF (g:g)	Appearance	Color	Taste	Texture	Overall Acceptance
0:100	7 ± 2 [a]	7 ± 2 [a]	7 ± 2 [a]	7 ± 2 [a]	7 ± 2 [a]
3:97	7 ± 1[a]	7 ± 1 [a]	7 ± 1 [a]	7 ± 1 [a]	7 ± 1 [a]
6:94	6 ± 2 [a]	6 ± 2 [a]	6 ± 2 [a]	6 ± 2 [a]	6 ± 1 [a]
9:91	4 ± 2 [b]	4 ± 2 [b]	4 ± 2 [b]	4 ± 3 [b]	4 ± 2 [b]

Results are mean ± SD (n = 10). Significantly different values in the same column are followed by different letters (a, b) ($P \leq 0.05$).

CONCLUSIONS

The study results showed that ALP addition caused changes in microstructures and quality attributes of wheat flour-based extrudates. As ALP concentration increased, the expansion and porosity decreased, while hardness increased. Except for the highest ALP level (9:91 ALP:WF), there was not a significant difference between the ALP added extrudates and control in terms of overall consumer preference. The *in vitro* starch digestion rate was also not affected by ALP addition at the studied ALP:WF ratios. The study showed that ALP could be added at low concentrations to expanded snacks. Future studies may focus on improving the quality attributes of ready-to-expanded snacks enriched with by-products by changing the process conditions.

AUTHOR CONTRIBUTIONS

Cagla Caltinoglu-Toraman: Investigation, Methodology; Ozge Guven: Writing - original draft, Investigation; Ilkay Sensoy: Conceptualization, Funding acquisition, Supervision, Writing - review & editing.

DECLARATION OF CONFLICT OF INTEREST

The authors declare that they have no known conflict of financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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INFORMED CONSENT

Participants of sensory panel were extensively briefed on the research, guaranteeing confidentiality. Participants had the freedom to withdraw from the study at any point without explanation, emphasizing their voluntary involvement and independence.

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