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Improvement of Functional and Nutritional Properties of Extruded Snacks with the Utilization of Red Dog Flour

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HIGHLIGHTS

- Extruded corn snacks (ECS) were developed with red dog flour (RDF), rich in ash, protein, dietary fiberand bioactive component.
- The best-optimized corn snack wasdetermined with a 20% RDF ratio.
- The addition of the RDF increased the nutritional and functional properties of ECS.
- Extrusion greatly reduced the phytic acid content of ECS containing RDF.

Abstract: Red dog flour (RDF), a milling by-product, is rich in nutritionally and functionally crucial components. Extrusion conditions for extruded corn snacks (ECS) with RDF were optimized using Response Surface Methodology (RSM) with Box-Behnken Design (moisture content: 13.5%, RDF ratio: 20%, screw speed: 468 rpm, and die temperature: 110°C). Then, functional, nutritional, and sensory properties of ECS containing an increasing ratio of RDF were determined. The addition of RDF improved ash (1,84 fold), fat (2,7 fold) protein (0,51 fold), dietary fiber (roughly 2,8 fold), and mineral content (Fe, K Mg, P, and Se) significantly compared to ECS without RDF. Extrusion condition considerably declined the total phenolic content (from 144.50 to 25,09 mg GAE/100g), Trolox equivalent of antioxidant capacity (from 1.13 to 0.41 mMol Trolox/g), and phytic acid content (from 2147 to 968.11 mg/100g) of ECS with RDF compared to raw materials. However, the increasing ratio of RDF had an increment in bioactive compounds (up to 2,38 fold mg GAE/100g, and 1,63 fold mMol Trolox/g) and phytic acid content (up to 0.36 fold). According to the sensory evaluation, 30% of ECS with RDF was the most preferable snack.

Keywords: red dog flour; extrusion; by-product; nutritional; dietary fiber; functional.

INTRODUCTION

Worldwide, ready-to-eat foods such as snack foods, breakfast cereals, cakes, crackers, and biscuits have growing demands daily. The global snack food market had an annual value of 51.59 billion USD in 2019 and is expected to extend by more than 4% by 2026 [1]. Several snack foods are offered to the market using different production techniques. In extrusion technology, one of the different techniques, many processes such as mixing/kneading, homogenization, stabilization, cooking, expansion, shaping, and partial drying can be performed in a short time (1-2 minutes) with a single device [2]. Corn-based snack foods, expanded using extrusion technology, loved and consumed by all age groups, are popular foods. However, the nutritional and functional properties of ECS made of corn grits are relatively poor as the bran and germ fractions are removed during the corn grit milling process. Conscious consumers tend to choose healthier foods, i.e., foods low in fat and energy density and high in fiber and other functional components.

Red dog flour (RDF), a by-product of the wheat flour milling process with 0.5-3.0% yield, comprises an aleurone layer, endosperm, fine bran, and germ particles. The chemical composition and nutritional value of RDF depend on the proportion of those fractions and vary by the type of wheat grain and the milling process. RDF is generally more affluent than refined white flour in protein (15-20%), fat (3-6%), ash (3-6%), and fiber (5-15%) and is mainly used for animal feeding [3, 4]. However, a limited number of studies have been carried out on different products containing RDF. Das Neves and coauthors[5]. used two types of RDF, with different carbohydrate and fibrous content, in the production of ethyl alcohol by subjecting them to the saccharification and fermentation processes. According to the study, the ethanol yield differed from the RDF type. Zhang and coauthors[6] studied the effects of the RDF on dough rheology and bread quality. The water holding capacity, dough development time, and gluten yield increased, but the kneading tolerance index, dough stability, and gluten index decreased with the RDF. Sarfaraz and coauthors [3] found that the protein content and antioxidant capacity of RDF were higher than coarse and fine bran. The aleuron layer, a precious anatomical part of wheat in terms of nutritional and functional, is concentrated in the RDF during the milling process. Erim Köse [7] reported that the addition of RDF to the formulation of kavut, a traditional product, increased the nutritional value of kavut.

This study aims 1) to give a new usage area for RDF in the functional food industry 2) to optimize ECS process condition by using RSM with Box-Behnken Design 3) to develop functional and nutritional ECS with an increasing ratio of RDF 4) to determine the chemical composition, functional, nutritional and sensory properties of the ECS with RDF.

MATERIAL AND METHODS

Materials

Corn grit and RDF were provided by Değirmenci Agriculture-Food Corn Flour Factory (Gaziantep) and Sosyete Flour A.Ş. (Karaman), respectively. All materials were stored at +4 °C until use.

Experimental designs and statistical analysis

In the first stage of the study, extrusion conditions for ECS with RDF were optimized utilizing Response Surface Methodology (RSM) with Box-Behnken Design. Optimization was established on the textural and physical characteristics of the products. In the second stage, the RDF content of the ECS was gradually increased (25, 30, 35, and 40%) for further nutritional and functional enrichment of the product.

Design-Expert (v7.0, Stat ease, Minneapolis, USA) program, consisting of Box Benken design, was utilized to interpret four independent variables with three levels: RDF ratio, die temperature, screw speed, and moisture content. Coded and actual levels of independent variables are exhibited in Table 1. Two interaction and second-order polynomial models were used to define the independent variables. Analysis of variance (ANOVA) for each response employed statistical significance of the terms in the regression equation. Minitab 17 (Minitab Inc, USA) was performed to define correlation coefficients between dependent variables from a Pearson correlation matrix. Distinctions between chemical and nutritional characteristics of ECS were analyzed by multiple range test of Duncan using SPSS 16.0.

Extrusion

RDF blends were prepared as dry bases based on replacement corn grit with 20, 40, and 60%. The blends were adjusted to 10-20% moisture content, left to rest at +4 °C for 24 hours and rested at room temperature for 1 hour before extrusion. Moreover, the moist mixtures were fed with a gravimetric feeder (Brabender Technologies, Germany) into a twin-screw extruder (Rondol Technology, England) at a constant rate of 2.5 kg/h. The barrel diameter was 21 mm, and the barrel length to diameter ratio (L/D) was 40:1. The barrel temperatures were stable at 50, 60, 70, 90, and 100 °C throughout all runs. RDF ratio (20-60%), die temperature (110-150 °C), screw speed (325-575 rpm), and moisture content (10-20%) were used as independent variables with three levels for Box Behnken design (Table 1). The levels of process variables were determined according to preliminary trials. The drying process were performed in the oven at 70 °C for 2-3 h.

Table 1. Box Benken design for extrusion process with coded and actual levels

Run	Coded levels				Actual levels			
	X1	X2	X3	X4	A (rpm)	B (%)	C (%)	D (°C)
1	-1	0	-1	0	325	15	20	130
2	1	-1	0	0	575	10	40	130
3	0	0	1	-1	450	15	60	110
4	-1	-1	0	0	325	10	40	130
5	0	0	0	0	450	15	40	130
6	0	1	1	0	450	20	60	130
7	0	0	0	0	450	15	40	130
8	0	-1	0	1	450	10	40	150
9	0	0	-1	1	450	15	20	150
10	1	0	-1	0	575	15	20	130
11	1	1	0	0	575	20	40	130
12	-1	0	0	-1	325	15	40	110
13	0	-1	-1	0	450	10	20	130
14	0	1	0	-1	450	20	40	110
15	0	-1	1	0	450	10	60	130
16	0	0	0	0	450	15	40	130
17	0	1	0	1	450	20	40	150
18	0	0	1	1	450	15	60	150
19	0	0	0	0	450	15	40	130
20	1	0	0	-1	575	15	40	110
21	0	0	-1	-1	450	15	20	110
22	-1	0	0	1	325	15	40	150
23	1	0	1	0	575	15	60	130
24	0	-1	0	-1	450	10	40	110
25	1	0	0	1	575	15	40	150
26	-1	0	1	0	375	15	60	130
27	0	0	0	0	450	15	40	130
28	-1	1	0	0	375	20	40	130
29	0	1	-1	0	450	20	20	130

A: screw speed (rpm), B: moisture content (%) C: RDF ratio (%) D: die temperature (°C)

Textural and physical properties

A TA-XT2i Texture Analyzer (Stable Micro Systems, Godalming, UK) employing a Kramer shear cell probe was utilized to measure the textural characteristics of snack samples. A software program recorded the curve was analyzed (Texture Exponent 32, version 2.03). The peak force is as an expression of hardness [8].The peak number and distance (mm) at which a product breaks were measured from the force-distance curve and considered crispiness and brittleness, respectively [9]. The expansion ratio was calculated by dividing the sample diameter by the circular die diameter. The true densities of snack samples were measured with a gas pycnometer (Accupyc 1340, USA). Measuring the dimension of snack samplings was defined the apparent density of snack samples. True and apparent density values were used to calculate porosity [10]. All samples were measured in triplicate.

Chemical analysis

Chemical analyses were determined for RDF, corn grit, and ECS samples. Moisture (44-15A), ash (08-01), protein (46-12), fat (30-25) analyses were carried out using common methods of AACC [11].

Functional and nutritional properties

Phytic acid analysis was conducted according to Haug and Lantzsch [12]. Samples were extracted with 0.2 N hydrochloric acid solution, then treated with a certain amount of iron III solution. The amount of iron remaining in the serum part was determined by spectrophotometric method. The amount of phytic acid was calculated as mg/100 g.

Folin-Ciocalteou approach [13]was employed to define total phenolic content. In brief, raw materials and ECS were milled in the blender to pass 375 µm. Extraction was conducted by tenfold acidified methanol (HCl/methanol/water, 1/80/10, v/v/v) vibrating at 200 rpm for 2 hours. After centrifugation (1000xg, 10 min), the purified extract (250 µL), 2N Folin-Ciocalteu reagent (250 µL), and distilled water (5.75mL) were incorporated and rested at ambient temperature for 8 min. The purified extract (250 µL), 2N Folin-Ciocalteu reagent (250 µL), and distilled water (5.75 mL) were incorporated and rested at ambient temperature for 8 min. Then 2.5 mL sodium carbonate solution (7%) and 5.00 mL distilled water were added and rested for another 2 hours. The absorbances of raw materials, ECS samples, and standard solutions were read at 750 nm to determine the total phenolic contents.

The method of Beta and coauthors [14] related to DPPH radical scavenging activity was utilized to define the antioxidant activity of raw materials and ECS. The same extracts were used for total phenolic contents. 3.9 ml DPPH solution and 100 µL extract were incorporated and rested in the darkroom for 30 min. The absorbances of raw materials, ECS samples, acidified methanol (blank), and DPPH (control) were read at 515 nm to determine the antioxidant activity.

The ABTS radical cation decolorization assay determined the free radical scavenging capacity of antioxidants extracted from the samples, according to Re and coauthors [15] with a partial modification of the method. The ABTS radical cation (ABTS+) was generated by responding seven mM ABTS with 12.5 mL 2.45 mM potassium persulfate and authorizing the blend to stand for 12–16 hr in the dark at ambient temperature. The ABTS+·solution was diluted with 0.1 M phosphate buffer (ph 7.4) to an absorbance of 0.7 (±0.02) at 734 nm. Raw materials and ECS samples were removed with 80% methanol at ambient temperature for 30 min at 70 rpm and purified by centrifugation (15000xg, 10 min). The purified extracts (10, 20, and 30 µL) and 3mL of ABTS+·solution were mixed and rested at darkroom temperature for 6 min and read the absorbance at 734 nm. The calibration curve of Trolox absorbance versus concentration (5–25mmol/L) was employed to define Trolox equivalent values of samples.

Raw materials and ECS samples were ground to pass via a 375 µm sieve screen for dietary fiber analysis. Insoluble (IDF) and total dietary fiber (TDF) from raw material and ECS samples were prepared based on AOAC, 960.43 [16]. The amount of soluble dietary fiber (SDF) of the samples was calculated by subtracting the amount of IDF from the TDF (AOAC, 2005). Briefly, 1.000 ± 0.005 g of milled sampling in replication was subjected to sequential enzymatic digestion by heat-stable 50 µL α-amylase (3000 U/mL, boiling water bath for 30 min), 100 µL protease (350 tyrosine U/ml, pH 7.5, 60 °C water bath for 30 min), and 200 µL amyloglucosidase (3300 U/mL, pH 4.5, 60 °C water bath for 30 min) to dismiss starch and protein. The residue rinsed with hot distilled water, 20 ml ethanol (95%), and 20 ml acetone (95%) were vacuum filtered and guided to IDF. The sample preparation and enzyme treatment procedure described above were also followed in TDF analysis. 225 mL ethanol (95%, 60 °C) was mixed and rested for 1 hour at room temperature. The residue washed with ethanol (78% and 95%), and acetone (95%) were vacuum filtered and referred to as TDF. All samples were dried at 105 °C overnight in an oven. Both IDF and TDF were calculated by subtracting ash and total protein amounts from sediment weight.

The mineral component contents (Fe, K Mg, P, and Se) of the raw materials and ECS samplings were defined by inductively-coupled plasma spectroscopy, ICP–OES (Vista series, Switzerland). Dry samples were digested employing a closed vessel microwave (MARS 5, CEM Corporation, USA) with concentrated nitric acid and sulfuric acid. Then, concentrations were determined by using ICP-OES [17] .

Sensory analysis

Ten semi-trained panel members performed sensory analysis assessed optimized ECS with 20 % RDF and selected four ECS samples containing 25, 30, 35, and 40 % RDF for color, taste, odor, texture (hardness, crispness, and brittleness), pore structure, and overall acceptability using the 7-point hedonic scale. ([1]color, taste, odor, crispiness porosity, and overall acceptability from 1 = dislike extremely to 7 = like extremely. [2]brittleness and hardness from 1 = like extremely to 7 = dislike extremely) [10].

RESULTS AND DISCUSSİON

Textural and physical properties

The texture (hardness, crispiness, brittleness) reflects the structural integrity of extruded products and plays a critical role in the acceptability of absolute products. Peak force, peak number, and distance values of snack samplings considered hardness, crispiness, and brittleness varied from 263.59-801.9 N, 0-38 (peak number) 456.14-1391.76 (Nxs), respectively. The results of the predicted models indicated that the screw speed did not have a substantial effect ($p>0.05$) on the textural characteristics of ECS with RDF. It was attributed to the screw speed not having a certain effect on textural properties. Other independent variables such as the raw material composition and screw configuration should be considered with the screw speed [18]. Moisture content had a substantial adverse linear impact on hardness but had an effective positive impact on brittleness and crispiness ($p<0.05$). In contrast, the RDF ratio had a considerable negative linear effect on brittleness but had a substantial positive impact on hardness ($p<0.05$) (Figure 1A). Similar findings were observed by Lobato and coauthors [19] who utilized the oat bran, rich in fiber, in extruded puffed and reported that enrichment of oat bran caused reduced expansion and increased hardness.Textural characteristics of the snack samplings were influenced by interaction terms of moisture content and RDF ratio, while the quadratic terms of moisture content were positively significant for hardness and negatively significant for crispiness. Also, Figure 1B represents that the increase in the RDF ratio and moisture content caused an increased hardness and decreased crispiness. There is a positive correlation between the RDF ratio and hardness of ECS with RDF ($R=0.751$, $p<0.001$), and is a negative correlation between the RDF ratio and crispiness and brittleness ($R=-0.728$,$p<0.001$ and $R=-0.775$, $p<0.001$). The water absorption of starch changes under extrusion conditions, and water can easily penetrate the starch. Starch, exhibiting plastic properties, loses water with heat, pressure, and shear force, increasing viscosity. A glassy structure occurs in 8-10% moisture content in the barrel. Extruded snack product has a hard and brittle texture [8]. As a result of the continuous increase in moisture content, the expansion of the products decreases, the air bubbles become thinner, thick cell walls are formed, brittleness, expansion ratio, and porosity decrease, and hardness and apparent density increase [20]. Die temperature had a notable adverse linear influence on hardness and crispiness but had an influential positive effect on brittleness ($p<0.05$). Crispiness and brittleness were affected by interaction terms of screw speed and die temperature (Table 2). Bisharat and coauthors[21] studied the effects of different extrusion conditions (moisture content 14-19%, screw speed 150-250 rpm, and die temperature 140-180 °C) on the thermal, textural physicochemical properties of ECS enriched with olive paste. They reported that the structure of products was rigid, and brittleness increased with olive paste concentration, screw speed, and moisture content.

The degree of expansion ratio is another important quality parameter to the acceptability of the final products. The expansion ratio altered from 1.30-3.40, while the apparent density changed with 0.13-0.68 g/cm^3 for the ECS with RDF. The porosity of the samples was between 0.53-0.90. There is a positive correlation between the porosity and expansion of ECSs ($R=0.664$, $p<0.001$). There were comparable results for expansion ratio and porosity in the literature for extrusion of high-quality cassava-tigernut composite flour [22] and for extrusion of fermented chickpea-based extrudates [10], respectively. The consequences of the predicted models showed that the linear impacts of screw speed on the expansion ratio of snack samplings were not meaningful ($p>0.05$).

Table 2. Models, lack of fits, R^2, R^2adj and R^2pred for the responses of the 20 % ECS with RDF*

Response	Model	F value	p value	Lack of fit	R^2	R^2 adj	R^2 pred
Hardness	456.11 - 26.17 x B + 141.18 x C+ 23.52 x D -102.77 x (B x C) +116.12 x (B^2)	54.39	<0.0001	0.776	0.92	0.91	0.86
Brittleness	1030.41 + 174.07 x B – 48.11 x D – 126.91 x (A x D) + 171.58 x (B x C)	54.11	<0.0001	0.197	0.93	0.91	0.86
Crispiness	20.21 + 2.49 x B – 10.46 x C – 3.11 x D + 4.38 x (A x D) + 6.79 x (B x C)- 7.44 x (B^2)	24.66	<0.0001	0.468	0.87	0.84	0.78
Expansion ratio	2.60 – 0.25 x B – 0.46 x C – 0.21 x D + 0.22 x (A x B) + 0.47 x (B x C) – 0.44 (B^2)	52.65	<0.0001	0.256	0.94	0.92	0.88
Apparent density	0.21 – 0.08 x A + 0.16 x B – 0.07 x C – 0.02 x D + 0.07 x (A x B) + 0.05 x (B x C) + 0.03 x (A^2)+ 0.10 x (B^2) + 0.03 x (C^2)	39.80	<0.0001	0.094	0.95	0.93	0.86
Porosity	0.86 + 0.05 x A - 0.11 x B – 0.05 x C – 0.02 x D + 0.05 x (A x B) + 0.03 x (B x C) - 0.02 x (A^2)- 0.07 x (B^2) - 0.02 x (C^2)	44.90	<0.0001	0.133	0.96	0.93	0.88

A: screw speed (rpm), B: moisture content (%) C: RDF ratio (%) D: die temperature (°C)

While screw speed had no substantial effect on expansion ratio (p 0.05), screw speed had a considerable effect on the apparent density and porosity of ECS with RDF ($p<0.0001$) (Table 2). Şeker [23] reported similar results for the influence of screw speed were declared for the bulk density of the extruded products produced from starch-soy protein mixture decreased as the screw speed increased. The moisture content, the RDF ratio, and die temperature influenced apparent density and porosity ($p<0.05$), especially on expansion ratio ($p<0.0001$). The negative coefficient of moisture content, RDF ratio, and die temperature demonstrated that expansion ratio and porosity declined with rising moisture content, RDF ratio, and die temperature. Also, Figure 1C represents that the increase in the RDF ratio and die temperature caused a decreased expansion ratio. Expansion ratio, apparent density, and porosity were affected by both screw speed and moisture content and RDF ratio and moisture content. The quadratic effects of both moisture content and RDF ratio on the apparent density and porosity of extruded snacks were significant ($p<0.05$).In contrast, the quadratic effects of die temperature on the expansion ratio, apparent density, and porosity of snack samplings were not meaningful ($p>0.05$) (Table 2). Leonard and coauthors [24] reported that high-temperature products containing high fiber and protein have low expansion and high bulk density. The effect of moisture content and RDF ratio on porosity ECS with RDF is displayed in Figure 1D. The increment in moisture content and RDF ratio induced a decline in porosity but increased apparent density, yielding fewer puffed snack samples. Expansion ratio was negatively correlated with apparent density ($R=-0.636$, $p<0.001$) and positively associated with porosity ($R=0.664$, $p<0.001$). This was attributed to RDF, rich in dietary fiber, reducing the use of water during expansion by disrupting the continuous melting structure in the barrel and binding some of the water in the structure [18]. Thus, as the fiber content increases, the average cell size, expansion rate, and crispiness decrease; apparent density, hardness, and tensile strength increase during the cell wall [25]. It is impossible to obtain products with good expansion and pore structure from fiber sources alone.

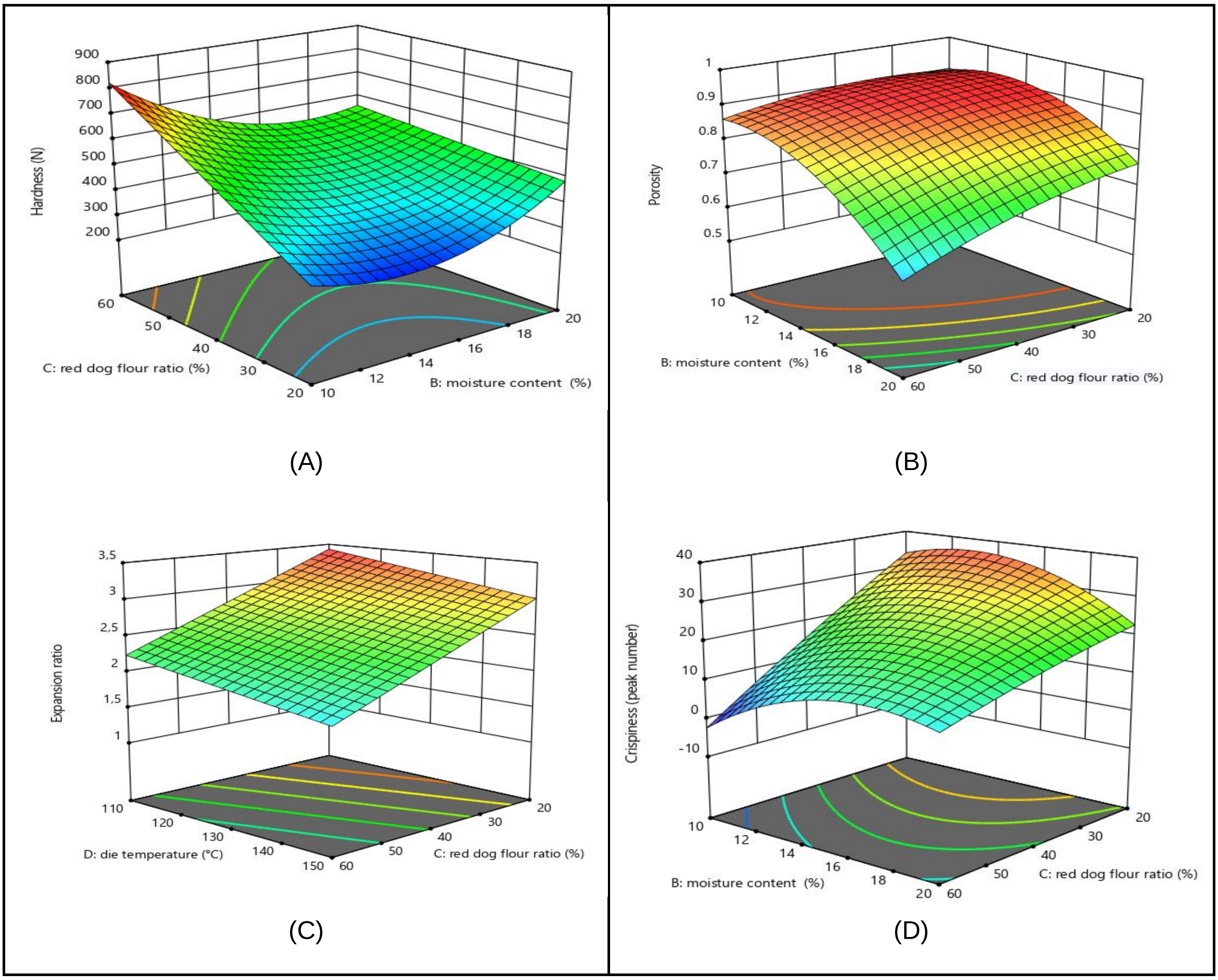

Figure 1. Response surface plots at optimized conditions for the effects of RDF ratio, moisture content, and die temperature on hardness, crispiness, expansion ratio, and porosity of 20% ECS with RDF*.

Verification of ECS with RDF

Box Benken RSM was used to model extruded snacks' physical and textural properties in this study. The lowest hardness and apparent density, the highest crispiness, expansion ratio, and porosity were chosen to optimize the extruded snack sample. The optimization conditions were determined as 20% RDF, 468 rpm screw speed, 110 °C die temperature, and 13,42% moisture content. The coefficient of determination of regression equations changed from 0.87-0.96 with significant probability values ($p<0.0001$) and non-significant lack of fit values ($p>0.05$). The most suitable models used to determine the texture properties of extruded snacks were second-order ($p<0.01$) for hardness, crispiness, expansion ratio, apparent density, and porosity, and the two-factor interaction model was significant ($p<0.01$) for brittleness.

In the study's continuation, the optimum amount of RDF (20% ECS with RDF*) was gradually increased, and four different ratios of ECS with RDF (25, 30, 35, and 40 %) were determined RSM. The limit was determined as 40% since ECS with RDF have lower textural and physical properties, observed in RDF ratio above 40%. Extrusion conditions were respectively screw speed: 554, 575, 575, and 575 rpm, moisture content: 13.40, 14.19, 14.79, and 14.95; RDF ratio: 25%, 30, 35, and 40 die temperature: 110 °C in all production conditions. The ECS's hardness, brittleness,crispiness, expansion ratio, apparent density, and porosity values ranged from 350.82-384.02 (N), 1107.2-1426.17 (N xs), 29.75-34.33 (peak number), 2.71-3.02, 0.11-0.13 (g/cm3), and 0.91-0.92, respectively. According to the result, it has been determined that adding up to 40% of RDF to corn snacks allows the production of acceptable ECS. Estimated texture and physical analysis results for all ECS with RDF were consistent with the results of the validation trials given by RSM and were statistically indifferent ($p>0.05$).

Chemical composition and nutritional properties of raw materials and ECS

The chemical composition of RDF and corn grit were summarized as 2.46±0.01, 0.42±0.04 ash, 4.58±0.01, 0.93±0.09 fat, and 16.15±0.07, 7.75±0.07 protein, respectively. Likewise, Çelik and coauthors [26] declared similar results for RDF, such as protein content of 14.63-15.23%, the fat content of 2.51-3.22%, ash content of 2.32-2.55%, respectively. Ačkar and coauthors [27]reported that the chemical composition of corn grit was 14% moisture, 0.4-0.5% ash, 0.8-1.3% fat, and 7.9-9.0% protein. Compared to ECS without RDF, ECS with RDF were higher ash, fat, and protein content, but the fat content was more inferior in snack samples than raw material (Table 3). An increment in the protein content after extrusion cooking was informed for corn/common bean flours mixtures based snacks [28]and for insect based extruded products [29]. After extrusion cooking, a significant reduction of fat content may be attributed to the starch-lipid complex formed [20]. Lipids form complexes with amyloses under high temperature and pressure and cannot be extracted with solvents such as hexane or petroleum ether. Since there is a decrease in the amount of free fatty acids in the environment, it oxidizes later, and the rancid taste formation in the products takes longer [30].

Table 3. Chemical properties of raw materials and ECS

Raw materials/ Products	Moisture content (%)	Ash (%)	Fat (%)	Protein (%)
RDF	10.57±0.40	2.46±0.01	4.58±0.01	16.15±0.07
Corn grit	10.58±0.06	0.42±0.04	0.93±0.09	7.75±0.07
ECS without RDF	7.25±0.08 c	0.44±0.01e	0.10±0.02 e	8.00±0.12 d
20% ECSwRDF*	7.25±0.08 c	0.78±0.04 d	0.19±0.02 d	10.70±0.14 c
25% ECSwRDF	7.94±0.05 a	0.93±0.03 c	0.23±0.01 dc	11.10±0.00 c
30% ECSwRDF	7.69±0.14 b	0.96±0.03 c	0.26±0.03 bc	11.55±0.07 b
35% ECSwRDF	7.03±0.09 dc	1.12±0.04 b	0.30±0.01 b	11.70±0.14 ab
40% ECSwRDF	6.97±0.08 d	1.25±0.03 a	0.37±0.04 a	12.10±0.28 a
p	0.001	< 0.001	0.005	0.002

Data are expressed on a dry weight basis. 20 % ECSwRDF*: Optimized ECS with RDF.ECSwRDF: ECS with RDF, 25 % ECS with RDF: 554 rpm, 13,40% moisture content, 110 °C die temperature, 30 % ECS with RDF: 575 rpm, 14,19% moisture content, 110 °C die temperature, 35 % ECS with RDF: 575 rpm, 14,79% moisture content, 110 °C die temperature, 40 % ECS with RDF: 575 rpm, 14,95% moisture content, 110 °C die temperature

Results of phytic acid of the raw materials and products were summarized in Table 4. Even though there was a slight increase in the amount of phytic acid according to the increasing RDF ratio, the amount of phytic acid in the products was generally low. The extrusion process significantly reduced phytic acid contents in products compared to raw materials. These results agree with previous findings of Yağcı and coauthors[10] who observed a considerable decrease in the levels of antinutritional elements for fermented chickpea-based extrudates. A potential reason for the substantial reduction of antinutritional elements might be the hydrolyzing of the inositol hexaphosphate to lessen molecular weight forms during the extrusion [20]. In addition, moisture content, raw material, die temperature, and feed rate is the most effective extrusion parameters in reducing antinutritional components [31]. Kaur and coauthors[32]. investigated the effects of wheat, barley, and oat bran antinutritional properties under certain extrusion conditions (115 °C die temperature and 20% moisture content). They reported that the highest decrease in phytate content was in wheat bran (64.40%), followed by barley bran (63.55%) and oat bran (26.47%).

The result of total phenolic content, DPPH scavenging activity, and TEAC are exhibited in Table 4. There was a decrease in the total phenolic content and TEAC of products under extrusion conditions compared to the raw material. This was attributed to the decreasing the number of phenolic substances under extrusion conditions due to the polymerization effect at high moisture content and the reducing the extraction and solubility of phenolic compounds [33]. Likewise, Yao and Ren [34] reported similar results for extrusion caused to reduction total phenolic content and DPPH radical scavenging antioxidant capacity for adzuki beans. However, incorporating the increasing ratio of the RDF into the extruded corn snack improved the total phenolic content and TEACs of the extruded corn snack.

Table 4. Nutritional properties of raw materials and ECS

Raw material /Products	Phytic acid (mg/100g)	Total phenolic content (mgGAE/100g)	Antioxidant capacity (%)	TEAC (mMol Trolox/g)	IDF (%)	SDF (%)	TDF (%)
RDF	2105.09±15.92	264.06±0.25	89.16±1.10	1.12±0.00	24.00±0.24	1.29±0.03	25.29±0.21
Corn grit	2147.30±210.95	144.50±0.25	94.00±0.94	1.13±0.01	3.53±0.19	0.20±0.29	3.73±0.48
ECS without RDF	1114,46±19.49bc	25,09±2,37e	88.38±0.45 a	0.41±0.00 c	2,86±0.01 e	1,01±0.00 c	3,87±0.01 f
20% ECSwRDF*	968.11±0.00 c	54.49±0.48 d	87.96±1.29 a	0.80±0.01 b	7.61±0.54 c	1.12±0.40 c	8.73±0.14 e
25% ECSwRDF	1125.71±0.00 bc	72.21±0.47 c	89.04±0.68 a	0.82±0.02 b	6.99±0.39 d	3.16±0.61 ab	10.15±1.00 d
30% ECSwRDF	1221.40±103.48 b	77.20±0.00 b	89.18±0.07 a	0.83±0.03 b	9.28±0.08 b	3.01±0.74 b	12.29±0.82 c
35% ECSwRDF	1266.43±119.40 b	77.53±0.47 b	89.41±0.83 a	1.08±0.02 a	8.87±0.03 b	3.82±0.26 a	12.69±0.29 b
40% ECSwRDF	1519.72±47.77 a	84.80±0.23 a	87.19±0.16 a	1.08±0.01 a	11.05±0.25a	3.63±0.17 ab	14.68±0.08 a
p	0.005	< 0.001	0.160	< 0.001	< 0.001	< 0.001	< 0.001

Data are expressed on a dry weight basis. 20% ECSwRDF*: Optimized 20% ECS with RDF, 25% ECS with RDF: 554 rpm, 13,40% moisture content, 110 °C die temperature, 30 % ECS with RDF: 575 rpm, 14,19% moisture content, 110 °C die temperature, 35 % ECS with RDF: 575 rpm, 14,79% moisture content, 110 °C die temperature, 40 % ECS with RDF: 575 rpm, 14,95% moisture content, 110 °C die temperature

IDF, SDF and TDF amount of the raw materials, ECS with RDF, are shown in Table 4. The RDF and corn grit's fiber content were summarized as 24.00±0.24, 3.53±0.19 IDF, 1.29±0.03, 0.20±0.29 SDF, and 25.29±0.21, 3.73±0.48 TDF, respectively. IDF, SDF, and TDF amounts of corn grits seem similar to results reported in the literature [35]. Incorporating the increasing ratio of RDFinto the extruded corn snack improved the IDF, SDF, and TDF content of ECS with RDF. Due to the high pressure, temperature, and shear force applied in extrusion technology, physicochemical and structural changes may occur, insoluble dietary fibers may become soluble [35, 36]. The breaking of bonds between fibers and other molecules and the emergence of small soluble forms can occur during the extrusion process [37]. Gajula and coauthors[38] added 0, 10, 20, and 30% wheat bran to wheat flour and performed a pre-baking process with an extruder. As a result of pre-cooking, soluble dietary fiber content increased from 22% to 73%, while insoluble dietary fiber content decreased. The addition of 20% RDF significantly increased the IDF, SDF, and TDF of ECS. It can be concluded that RDF is a good dietary fiber source. Şahin and coauthors [39] reported a similar result that 10% bran, a good dietary fiber source, and addition significantly increased the extruded snack's IDF, SDF, and TDF content.

The mineral content of raw materials and 20% of ECS with RDF results are summarized in Figure 2. RDF has superior Fe, K, Mg, P, and Se amounts compared to corn grit. So, the addition of RDF into the corn snacks seemed to improve the amounts Fe, K Mg, P, and Se. Generally, minerals are heat stable. Extrusion technology does not change the mineral content of extruded products, and the mineral content is generally preserved during extrusion—a similar conclusion reported in the literature [40]. In a study, there was a 38% increase in total Fe content in products produced due to extrusion [41]. Low humidity and bran-rich abrasive foods wear out the screw and die of the extruder over time, removing metals. These parts must be replaced or renewed over time; otherwise, they may cause a build-up in extruded foods [42]. In the extrusion of wheat bran and broken rice flour, an increase in Ca, P, Fe, and Cu contents occurred. It was thought that the increase might be due to the water used during production [43].

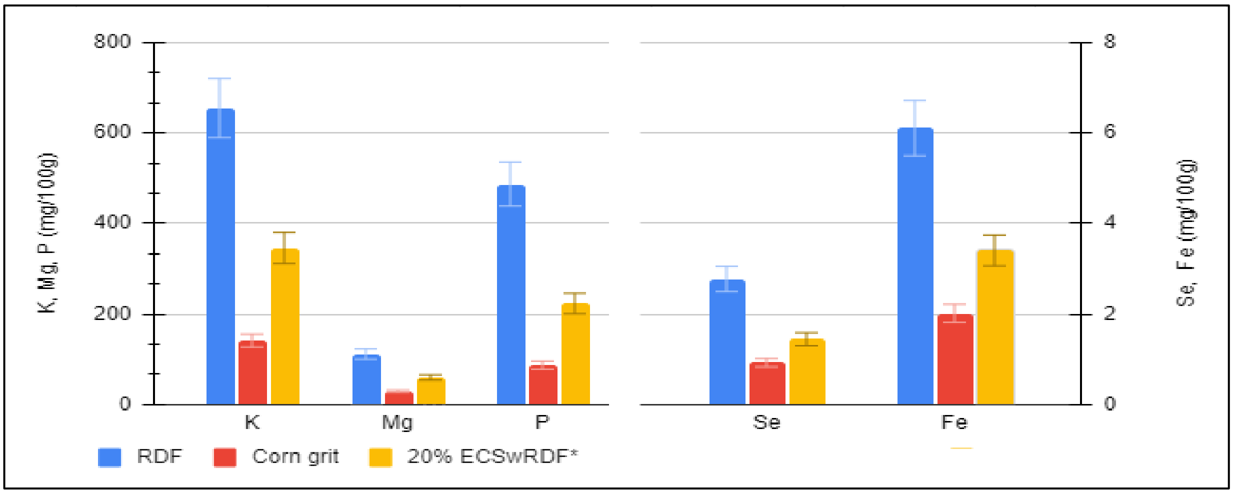

Figure 2. Mineral content results of raw materials and 20% ECS with RDF* (mg/100 g)

Ten semi-trained panel members performed sensory analysis assessed ECS with RDF and for color, taste, odor, texture (hardness, crispness, and brittleness), pore structure, and overall acceptability using the 7-point hedonic scale (Figure 3). Color, taste, porosity, and overall acceptability were positively affected by 20%-30% addition ratio of RDF. It means that RDF improved the color, taste, porosity, and overall acceptability score of snack samples. According to the ANOVA results, the increasing ratio of RDF had a significant ($p<0.01$) effect on color, taste, brittleness, hardness, brittleness, porosity, and overall acceptability of the ECS. However, there were no significant differences ($p> 0.01$) in the odor of extruded snacks. RDF is a milling fraction that remains at the end of the process, thus containing fine bran, endosperm, and germ particles, especially the aleuron layer. RDF has a unique flavor and aroma with these layers. This is appreciated by consumers, adding up to 30% to snacks. Textural properties, especially hardness and crispiness, are important quality parameters for snack-type products. The brittleness values of ECS with RDF were positively affected by 40% RDF addition. When all ratings were evaluated, 30% ECS with RDF was liked by consumers.

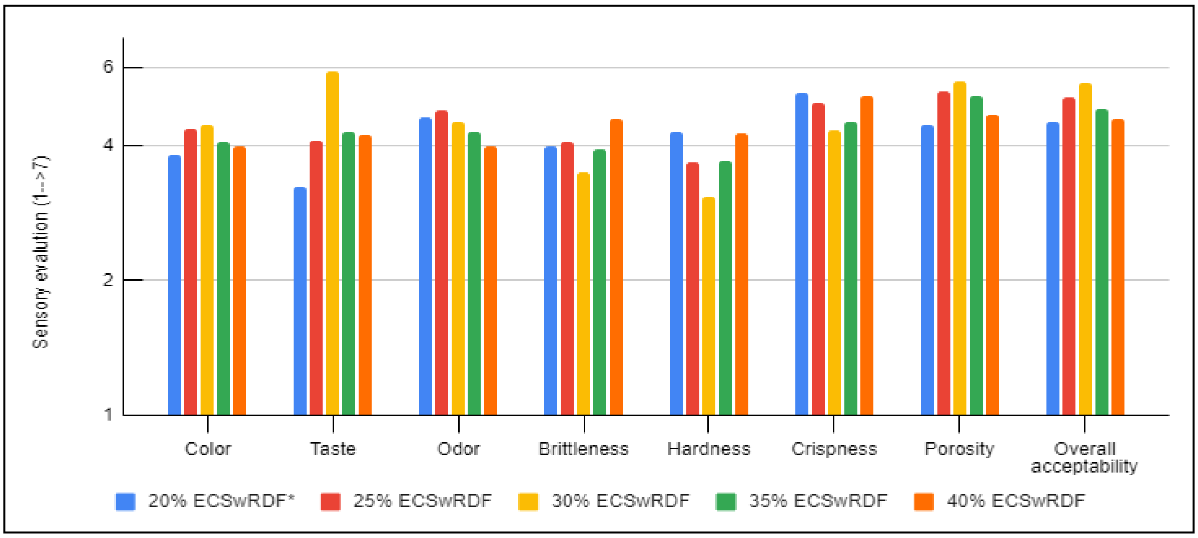

Figure 3. Sensory evaluation of ECS with RDF

CONCLUSION

The present study has defined extrusion parameters for adequate nutritional snack food from an RDF-based mixture. Texture results and physical analysis results of ECS with RDF were consistent with the results of the validation trials and were statistically indifferent with utilizing ANOVA for each response ($p>0.05$). The optimization condition was 13.5% moisture content, 20% RDF ratio, 468 rpm screw speed, and 110°C die temperature. The RDF addition into ECS increased the ash, protein, dietary fiber content, and bioactive component compared to ECS without RDF. However, while the high addition of RDF increased phytic acid content, the extrusion condition with high temperature, pressure and shear force in a short time reducedphytic acid content remarkably. Also, the addition of RDF increased the mineral content. 30 % ECS with RDF gains more appreciation than other ECS with RDF from the panelist. RDF addition improved the chemical, nutritional and functional properties of ECS. These findings will allow readers to open new fields of study to evaluate RDF.

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