DEVELOPMENT OF EXTRUDED SNACK FROM FOOD BY-PRODUCTS: A RESPONSE SURFACE ANALYSIS

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ABSTRACT

Response surface methodology was used to investigate the effects of extrusion conditions including the moisture content of blend (12–18%), barrel temperature (150–175C), screw speed (200–280 rpm) and change in feed composition on the product characteristics of the snack food developed from rice grit in combination with durum clear flour, partially defatted hazelnut flour (PDHF) and fruit wastes. The blend was made up of rice grit (67%), durum clear flour (8–20%), PDHF (5–15%) and fruit waste (3–7%). The response variables were radial expansion ratio, color, and textural and sensory properties of the extruded snacks. Increasing the PDHF content caused a decrease in the radial expansion ratio, hardness and lightness of the snacks. The textural properties and color of produced snacks were affected by the fruit waste addition. Increasing the moisture content and decreasing the temperature caused an increase in the expansion ratio for most compositions. The extruded snacks with lower PDHF content had the highest levels of overall acceptance in the sensory panel. There was no significant effect ($P < 0.05$) of fruit waste addition on the sensory properties of the snacks.

PRACTICAL APPLICATIONS

Large amounts of side products of the food industry, in particular fruit and vegetable waste, evolved during production (most of which cause environmental pollution), preparation and consumption of foods. Because of this, it is necessary to collect and use these wastes for the production of new foods, which is important from the point of environmental pollution and a country's

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economy. This study aimed to produce a ready-to-eat, puffed and value-added snack food by using the side products of various food industries. Durum clear flour of macaroni production, partially defatted hazelnut flour of hazelnut oil production and fruit wastes of various fruit juice production might be evaluated as the components of the extruded snack food product. The contribution of the present work is to propose an alternative technology for the utilization of food-processing wastes for the development of a useful, value-added extruded food product.

INTRODUCTION

In recent years, studies on the evaluation of food wastes are rapidly expanding around the world. Food-processing wastes are promising sources of compounds, which may be used because of their favorable technologic or nutritional properties. Food-processing wastes cause the loss of several valuable constituents, which are important for nutrition such as dietary fiber, antioxidants, essential fatty acids, antimicrobials, minerals, etc. These substances have many health benefits and many functional properties (Laufenberg *et al.* 2003). Grape skin and seeds are rich sources of monomeric phenolic compounds, such as catechin and epicatechin, and these compounds act as antimutagenic and antiviral agents. Grape seed extracts may be exploitable for the preservation of food products as well as for health supplements and nutaceuticals (Moure *et al.* 2001). Tomato seeds from tomato cannery waste have been reported to have appreciable amounts of digestible amino acids, methionine, cystine and lysine (Persia *et al.* 2003). Many fruit and vegetable residues, i.e., apple pomace and orange peel, are rich in dietary fiber, which prevents and treats many diseases such as intestinal problems, cancer and diet-related health problems (Wang and Thomas 1989; Larrea *et al.* 2005). Many authors investigated the use of apple pomace (Wang and Thomas 1989; Carson *et al.* 1994) and orange pulp (Larrea *et al.* 2005) as a source of dietary fiber and potential ingredient in bakery products.

Durum clear flour is a by-product that is obtained during the semolina production by collecting the line fractions of certain streams of the flour, which is extracted during grinding and composed of approximately 13–16% of the milled durum wheat. Durum clear flour is relatively high in bran, high in protein (14–16%), ash (1.5–2%) and starch (about 65%) and slightly gray in color (Kiliç 1999). Durum clear flour is generally utilized as additives for improving gluten strength of low gluten grains such as rye and some bakery products such as bread. Among the nut species, the hazelnut has a great importance because of its special nutritional composition of proteins (15–19%), carbohydrates (15–17%), fat (60%) and vitamins (Alphan *et al.* 1996).

Defatted hazelnut flour is residual of the hazelnut after the extraction of the oil parts from the main fruit. It is high in protein (35–41%), fiber (10%) and other nutritional constituents (Anon 1979).

Extrusion cooking process is efficient, economical to run and produces a wide range of food products, many of which cannot be produced easily by any other process. It has been used to produce a wide variety of foods, including snacks, ready-to-eat cereals, confectioneries, texturized meat substitutes and extruded crisp breads (Suknark *et al*. 1997). The advantages of extrusion are evident, especially in the simplification of processing techniques for the manufacture of existing products as well as in the development of novel types of food. The extrusion cooking of fruit wastes, defatted hazelnut flour and durum clear flour in combination with a cereal grain such as rice is of even greater interest, because it can be used as a convenient product with product acceptability.

There is no available information on the product characteristics of extrudates as affected by incorporating durum clear flour, partially defatted hazelnut flour (PDHF) and fruit waste into a rice-based extruded product. The objective of this study was to investigate the effects of extrusion conditions such as screw speed, moisture content, temperature and change in feed composition on the product characteristics of the snack food developed from rice grit in combination with durum clear flour, fruit wastes and PDHF.

MATERIALS AND METHODS

Raw Materials

Durum clear flour was obtained from the Tat Macaroni Industry and Trading Corporation (Gaziantep, Turkey). PDHF was obtained from the Ordu Oil Industry, Inc. (Ordu, Turkey) and rice grit was obtained from the Üçel Food Industry and Trade Corporation (Gaziantep, Turkey). Sucrose (Helin, İstanbul, Turkey) was purchased from the market. Orange peel, grape seeds and tomato pomace were obtained from the Namsan Food Industry and Trade Corporation (Bursa, Turkey). They were sun-dried by spreading the samples on cloth for 3 days under the effect of the sun's rays and milled into powder for the extrusion cooking process. They were all stored at 4C for further usage in the experiments.

Chemical Analysis

Moisture, ash, protein and fat analyses of raw materials were carried out using standard procedures of the Association of Official Analytical Chemists

(AOAC 1990). Carbohydrates were calculated by difference. All analyses were expressed as the mean (±SD) of triplicate analyses.

Blend Preparation

Milled orange peel (80.0%, dry basis [d.b.]), grape seeds (10.0%, d.b.) and tomato pomace (10.0%, d.b.) were mixed in a laboratory mixer (Kitchen Aid, Michigan, USA). This blend was used as the fruit waste blend in the production of the extruded snack. Rice grit (67%), sucrose (3%), durum clear flour, PDHF and fruit waste blend were blended in a 5-kg batch according to the design of the experiment. Using the mixer, the blends were conditioned by adding sprayed water while tumbling in a rotating drum and mixed for 30 min at a high speed to insure homogeneity of the feeding material before extrusion. The moisture content of the prepared blends was determined by an infrared moisture analyzer (Sartorius, Goettingen, Germany) at 105C. The proximate compositions of the raw materials used in the blend preparation are shown in Table 1.

Extrusion

American Extrusion International 300B Bake Type (South Beloit, IL) single-screw industrial scale extruder was employed for this study. The extruder was equipped with a 304.8-mm barrel, feed screw, standard 12-hole die and standard baked knife blades. The extruder has one heating zone with electrical resistance heaters and thermocouple sensor to monitor the temperature. The screw was 75 mm in diameter and 290 mm long. The screw had constant pitches and gradual decrease in flight depth from 4.5 to 1 mm through the exit of the die. The die consisted of a 12-hole die with each hole being 2 mm in diameter. Before the extrudate was collected, care was taken to ensure that the flights at the feed section were kept full throughout the extrusion run.

TABLE 1.
PROXIMATE COMPOSITIONS (g/100 g) OF DURUM CLEAR FLOUR, PARTIALLY DEFATTED HAZELNUT FLOUR (PDHF), FRUIT WASTE BLEND AND RICE GRIT

Component (%)	Durum clear flour	PDHF	Fruit waste blend	Rice grit
Moisture	7.39 ± 0.08	2.90 ± 0.06	8.27 ± 0.08	11.45 ± 0.04
Fat	2.93 ± 0.05	17.26 ± 0.06	2.01 ± 0.02	0.79 ± 0.04
Protein	13.38 ± 0.01	33.51 ± 0.03	4.99 ± 0.05	5.92 ± 0.03
Ash	1.93 ± 0.04	6.61 ± 0.02	3.64 ± 0.03	0.41 ± 0.02
Carbohydrate*	74.37	39.72	81.09	81.43

The results are expressed as the average of triplicate analyses.
* Determined by difference.

During each extruder run, the machine was allowed to equilibrate for 5–10 min until a stable torque was achieved. Extrudates were collected on metal screens to allow excess steam to flash off. Once cooled, all the samples were transferred in polyethylene bags and stored in a cool and dry place.

Experimental Design and Statistical Analysis

The combined design was used to investigate the relationships between the process variables (screw speed, moisture content and barrel temperature), mixture components (durum clear flour, PDHF and fruit waste blend) and response variables used in this study. This design combines process variables, mixture components and categorical factors in one design. When there are constraints on the mixture components, and the number of mixture components and process variables increase, the D-optimal criterion is often used for generating a design (Myers and Montgomery 2002).

A D-optimal design was used for the design of the experiment with three independent variables including feed moisture content (12–18%), temperature (150–175C), screw speed (200–280 rpm) and three dependent mixture components having different durum clear flour (8–20% d.b.), defatted hazelnut flour (5–15% d.b.) and fruit waste contents (3–7% d.b.), using a commercial statistical package, Design-Expert version 7.0 (Stat-Ease, Minneapolis, MN). The levels of each variable were established according to preliminary trials. The quadratic model was used as a design model, which included the candidate points of the vertices, the edge centers, the axial check blends, interior check blends and the overall centroid. The three levels of independent variables were coded as −1, 0 and 1. Coded levels for process variables are given in Table 2. Blend formulations are given in Table 3. A total of 70 different combinations were studied using the response surface methodology to investigate the effect of these process and component variables on response variables. The response variables were the radial expansion ratio, textural properties and HunterLab color (*L*, *a* and *b*) of the extruded snacks.

The experimental data were evaluated using the response surface methodology. Data were modeled by multiple regression analysis, adopting

TABLE 2.
CODED LEVELS FOR THE INDEPENDENT VARIABLES

Variables	Coded level		
	−1	0	+1
Barrel temperature (C)	150	162.5	175
Feed moisture content (%)	12	15	18
Screw speed (rpm)	200	240	280

TABLE 3.
BLEND FORMULATIONS IN EXTRUSION EXPERIMENTS

Blend formulations	%		
	DCF	PDHF	FW
1	20	5	5
2	20	7	3
3	18	5	7
4	16	11	3
5	15.6	9.4	5
6	14.3	9.7	6
7	13	10	7
8	12.8	12.2	5
9	12	15	3
10	8	15	7

DCF, durum clear flour; PDHF, partially defatted hazelnut flour; FW, fruit waste.

a backward stepwise analysis and only the variables significant at $P < 0.01$, $P < 0.05$ and $P < 0.1$ levels were selected for the model construction. The goodness-of-fit of the models was evaluated using the adjusted r^2, approximate r^2 for the prediction values based on the predicted error sum of squares (PRESS) statistic and analysis of the residual plots. The statistical significance of the terms in the regression equation was examined by analysis of variance (ANOVA) for each response.

Determination of Product Properties

Radial Expansion Ratio. The radial expansion of the extruded snacks was calculated by dividing a cross-sectional area of the extrudates to the cross-sectional area of the die orifice (Thymi *et al*. 2005). A Vernier caliper (Mitutoyo, Japan) was used to measure the diameters of the snacks. Ten samples were used for each extrudate to calculate the average.

Color. The color measurement was done using HunterLab ColorFlex (A60-1010-615 Model Colorimeter, HunterLab, Reston, VA). The extrudate was milled with a laboratory mill. The Hunter color values were expressed as L (lightness or darkness), a (redness or greenness), b (yellowness or blueness). The colorimeter was calibrated against a standard white plate ($L = 91.08$; $a = -1.12$; $b = 1.25$). Three readings were averaged.

Textural Properties. The textural characteristics of the extrudate were measured according to the method of Veillard *et al*. (2003) with the TA.XT2i

Texture Analyzer (Texture Technologies Corp, Scarsdale, NY/Stable Micro Systems, Godalming, Surrey, U.K.) and the software Texture Expert (version 2.03; Texture Technologies Corp, Scarsdale, NY, and Stable Micro Systems, Godalming, Surrey, U.K.). The instrument was fitted to the standard 25-kg load cell supplied with the texture analyzer. A rectangular probe (38-mm width and 51-mm length) attached to the arm of the analyzer was used to compress the sample at a constant speed of 1 mm/s against the flat plate fixed on the loading frame. The sample was compressed to 70% of the sample's original height and the force-deformation displacement was recorded. The trigger force of the analyzer was 5 g. All sample sizes were 10 mm in length. Five replicates were conducted for the samples from each treatment. Texture parameters such as hardness and area (energy required for given displacement) were calculated from the force-deformation curve. The peak force represents the resistance of the extrudate to the initial penetration and is believed to be the hardness of the extrudate, whereas the area under the curve is used to determine the energy required to bite or chew the products (Ding *et al.* 2005).

Sensory Evaluations. A preliminary product selection was made in order to reduce the number of samples to be submitted to the panel. First, the extrudates having the maximum expansion ratio were selected from each product formulation. Then, the products were selected according to fruit waste and PDHF content so that extrudates with minimal and maximal PDHF content at each fruit waste percentage were selected. In total, six samples were used to perform the sensory evaluation. Nine-point hedonic scales were adopted and the categories were rated from 1 (absent/extremely dislike) to 9 (very high/extremely like) in order to evaluate the snack characteristics, which are orange and hazelnut flavors (absent to very high), color (extremely dislike to extremely like), texture (extremely dislike to extremely like) and overall acceptability (dislike extremely to like extremely) (Mendonça *et al.* 2000). The test panel consisted of 46 semitrained panelists (20- to 45-year-old males and females) who are students and staff members of the Department of Food Engineering at Gaziantep University. The panelists were selected in the preliminary sessions and experienced with the products and terminology. Duncan's multiple range test was used to differentiate the sensory data.

RESULTS AND DISCUSSION

Radial Expansion Ratio

The physical properties and expansion characteristics of extruded snack products have an important role in the acceptability of the final product. The expansion ratio of the extrudates seeks to describe the degree of puffing undergone by the dough as it exits the extruder. The stored energy was released in the expansion process, increasing the radial expansion ratio (Thymi *et al.* 2005). The extrusion of most combinations of durum clear flour, PDHF and fruit waste produced expanded snacks at most extrusion conditions; however, blends having 15% PDHF usually failed to extrudate into products with consistent shapes and degrees of expansion.

Table 4 shows the coefficient of equations obtained by fitting of the experimental data. The analytical results indicated that the model was acceptable ($P < 0.01$) and could be used to predict values for radial expansion ratio. The radial expansion ratio was significantly affected ($P < 0.01$) by the linear effects of the PDHF, durum clear flour and waste contents. Durum clear flour and waste content had a significant effect and positive correlation with radial expansion ratio. On the other hand, the radial expansion ratio was negatively affected by the linear coefficient of the PDHF. The effect of the PDHF content was more than that of both durum clear flour and fruit waste contents (also evident by comparing the coefficients of x_1, x_2 and x_3 in Table 4).

The radial expansion ratios measured for all the extruded samples ranged between 1.24 ± 0.24 and 10.05 ± 0.17. The expansion ratios of the extruded snacks were similar to the published values of rice-based extrudates (Ilo *et al.* 1999; Asare *et al.* 2004; Ding *et al.* 2005). The response surface plot for the radial expansion ratio as a function of components is shown in Fig. 1. As presented, when the PDHF content increased, the radial expansion ratio decreased. Decrease in expansion may be because of the dilution of total starch available for expansion with addition of PDHF. The addition of PDHF may affect the extent of starch gelatinization and the rheologic properties of the melted material in the extruder because of its relatively high protein content. Prinyawiwatkul *et al.* (1995) presented that the addition of protein to a starchy extrusion system may retard expansion by the increased firmness of plasticized extrudates. Bhattacharya (1997) reported that extrudates produced from rice–green gram blends have lower expansion ratios than rice alone. A similar finding was observed for the rice–cowpea–groundnut blend; cowpea and groundnut additions to rice resulted in a decrease in the expansion ratio (Asare *et al.* 2004). The expansion ratio of snacks may also be reduced by the addition of lipid in PDHF to the blend at increased PDHF content. The addition of lipid in the extrusion is generally found to retard the degree of gelatinization and affect dough rheology in the barrel (Schweizer *et al.* 1986).

The moisture content had a significant interaction ($P < 0.05$) with durum clear flour, PDHF and waste content (Table 4). Increasing the moisture content from 12 to 18% caused an increase in the expansion ratio for most blend formulations. A similar trend was observed for sorghum extrudates; increasing the moisture content from 13 to 18% increased the radial expansion (Phillips

TABLE 4.
ESTIMATED COEFFICIENT OF FACTORS IN THE PREDICTIVE MODEL FOR THE DIFFERENT RESPONSES

	Radial expansion ratio	Hardness (N)	Total area (N × s)	*L*	*a*	*b*
Variables						
x_1	1.371***	−1.687***	−3.540***	8.745***	0.419***	0.529***
x_2	−1.919***	2.650***	−4.425***	−8.691***	−1.808***	0.547***
x_3	0.834***	−71.846***	−287.74***	−3.052***	7.130***	−0.721***
x_1x_2	ns	−0.343***	ns	ns	ns	−0.0132
x_1x_3	ns	3.602***	13.515*	0.278***	ns	0.0724
x_1x_4	-6.906×10^{-3}**	ns	ns	ns	ns	ns
x_1x_6	ns	ns	ns	−0.0217*	ns	ns
x_2x_3	ns	3.175**	14.355**	0.279***	ns	0.0593
x_2x_4	0.052**	ns	ns	0.222***	0.122**	ns
x_3x_4	−0.047**	ns	6.813**	ns	ns	ns
x_2x_5	1.041×10^{-3}*	ns	ns	ns	5.725×10^{-3}*	ns
x_2x_6	6.101×10^{-3}***	ns	ns	0.0231**	4.274×10^{-3}***	ns
x_3x_5	ns	0.338***	0.859***	0.0195**	ns	ns
$x_2x_4x_6$	ns	ns	ns	ns	-2.137×10^{-4}***	ns
$x_2x_5x_6$	ns	ns	ns	-9.500×10^{-5}***	ns	ns
$x_1x_3x_5$	ns	−0.0166***	−0.041***	ns	ns	ns
$x_2x_3x_5$	ns	−0.0151**	−0.040***	ns	ns	ns
$x_1x_4^2$	ns	ns	ns	ns	1.368×10^{-3}**	ns
$x_1x_5^2$	ns	ns	ns	-7.963×10^{-5}***	-1.559×10^{-5}***	ns
$x_2x_4^2$	ns	ns	ns	7.855×10^{-3}**	ns	ns
$x_2x_5^2$	ns	ns	ns	ns	-1.167×10^{-5}***	ns
$x_3x_5^2$	ns	ns	ns	ns	1.186×10^{-4}**	ns
Model						
F value	8.58†	7.38†	10.72†	27.11†	8.18†	35.09†
r^2	0.686	0.583	0.764	0.862	0.655	0.732
Adjusted r^2	0.606	0.504	0.692	0.831	0.574	0.711
Predicted r^2	0.502	0.456	0.595	0.783	0.523	0.680
Lack of fit (*P* value)‡	0.7820	0.1195	0.2796	0.1650	0.7622	0.1124

* Significant at $P < 0.1$; ** significant at $P < 0.05$; *** significant at $P < 0.01$.

† Significant at a $P < 0.0001$ level.

‡ Want the selected model to have nonsignificant lack of fit ($P > 0.05$).

L, lightness; *a*, redness; *b*, yellowness; x_1, durum clear flour (%); x_2, partially defatted hazelnut flour (%); x_3, fruit waste (%); x_4, moisture content (%); x_5, screw speed (rpm); x_6, temperature (C); ns, nonsignificant.

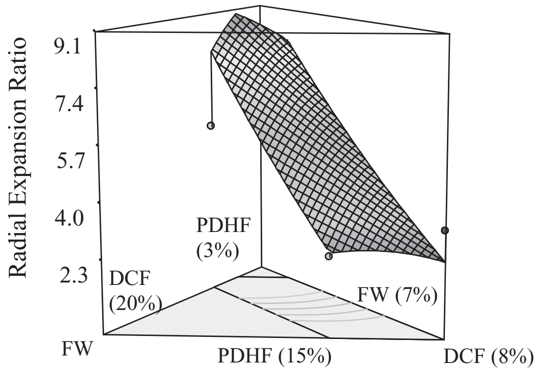

FIG. 1. RESPONSE SURFACE PLOT FOR RADIAL EXPANSION RATIO AS A FUNCTION OF COMPONENTS AT 12% MOISTURE CONTENT, 200-rpm SCREW SPEED AND 150C BARREL TEMPERATURE

DCF, durum clear flour; PDHF, partially defatted hazelnut flour; FW, fruit waste.

and Falcone 1988). The effect of moisture content is mostly dependent on the blend formulations. At a high PDHF content, such as 12.5%, the increasing moisture content increases the expansion of the extrudates, while at a low PDHF content, such as 5%, the elevation of the moisture content had no effect on expansion (Fig. 2A). The moisture and PDHF interaction showed a positive interaction, which may suggest that increasing the amount of PDHF added in the blend required a corresponding increase in the moisture content in order to achieve the same level of radial expansion ratio. The elevated moisture requirement was probably because of the increase in protein content, which needs more moisture to hydrate (Li *et al*. 2005).

The interactions between screw speed and durum clear flour, PDHF and waste content did not show significant influences on expansion at $P < 0.05$ level. The temperature affected the expansion with a significant interaction ($P < 0.05$) with PDHF. The temperature generally had a negative effect on expansion for most compositions (Fig. 2B). The expansion decrease at higher extruder temperatures can be attributed to increased dextrinization and weakening of structure and was observed for temperatures higher than 150C, which was used in this study (Mendonça *et al*. 2000).

Textural Properties

The textural properties of extruded products are generally described by the hardness and crispness. The hardness of an expanded extrudate is a perception of the human being and is associated with the expansion and cell structure of the product. The maximum peak force from the texture analyzer

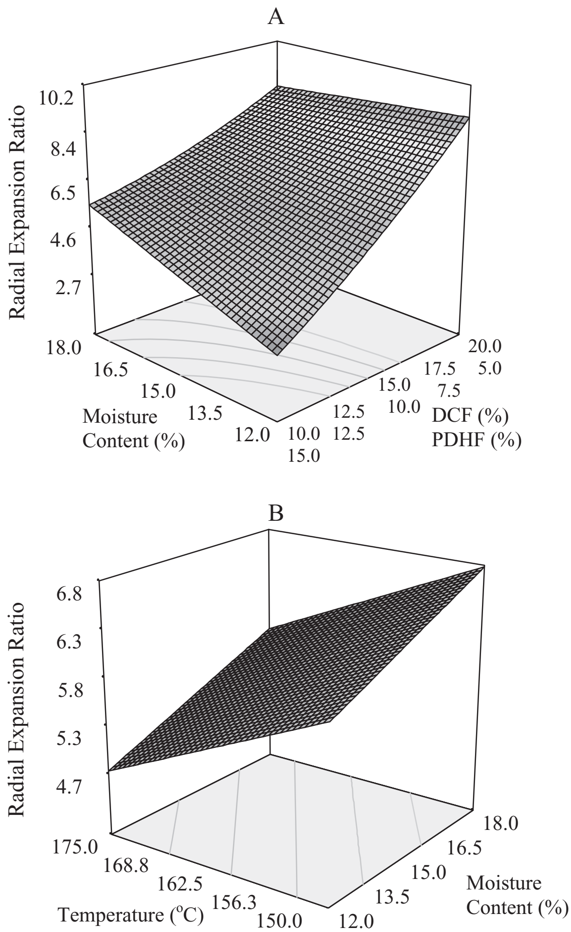

FIG. 2. RESPONSE SURFACE PLOTS FOR RADIAL EXPANSION RATIO
(A) Moisture content and durum clear flour (DCF) and partially defatted hazelnut flour (PDHF) at 5% fruit waste (FW) content, 200-rpm screw speed and 150C barrel temperature. (B) Moisture content and temperature at 15.6% DCF, 9.4% PDHF, 5% FW contents and 200-rpm screw speed.

represents the resistance of the extrudate to the initial penetration and is believed to be the hardness of the extrudate (Ding *et al*. 2005). The coefficient of the regression models obtained for hardness (N) and total area ($N \times s$) values of the extruded snacks following the response surface regression procedure are presented in Table 4. Although the r^2 for these responses does not seem to be very good, it was considered acceptable because these analyses generally show great variability with respect to process and component variables used in this study. Mendonça *et al*. (2000) observed similar results for the corn bran-added snacks; the r^2 for the hardness and fracturability ranged from 0.61 to 0.62. The entire main effects and interaction of effects were calculated for the significant models for hardness and total area. The composition of the extruded snack was found to have a linear effect ($P < 0.01$) on the hardness and total area values. Not only single parameters showed significant influences on the hardness and total area values of the products, but also interactions among them and process variables showed significant effects in determining the textural properties of the extruded snacks (Table 4).

For extruded foods, it was desirable to have low values for hardness (Mendonça *et al*. 2000). Hardness measured for all extrudates varied between 14.93 ± 1.41 and 33.38 ± 1.78 N. The response surface for the hardness showed a saddle shape as shown in Fig. 3. Fruit waste and PDHF contents were the most important parameters affecting the hardness of the extrudates in a complex manner. Both high and low fruit waste contents in the blend resulted to the lowest values for hardness, whereas intermediate level of fruit waste resulted in harder extrudates at increased PDHF content. However, at a low PDHF content, increasing the fruit waste content in the blend increased the hardness of the extrudates as shown in Fig. 3.

Increasing the PDHF content up to ~12% improved product hardness; however, beyond this value, extrudate hardness increased. Decrease in the hardness of the extrudates may be related with the addition of oil in the PDHF to the blends, which improved the extrusion process and texture. Fat provides a powerful lubricant effect in extrusion cooking and it improves texture; however, excess fat reduces product expansion (Cheftel 1986). Suknark *et al*. (1997) reported that when partially defatted peanut flour was substituted to starch at low levels (15–30%), the shear strength of the extrudates decreased. Similar findings were reported for the rice flour–amaranth blends; they reported that increasing the amaranth content up to 21% decreased the breaking strength of the extrudates, but further increase in the amaranth content increased the breaking strength of the extrudates (Ilo *et al*. 1999). The increasing hardness of the extrudates with further PDHF addition may be because of the increasing protein content of the blend. Proteins absorb more water, lowering the extent of starch gelatinization and expansion (Suknark *et al*. 1997) and thus, probably increasing the hardness of extrudates. Bhattacharya and Hanna (1987) reported that extrudates, which have greater gelatinization, increased the expansion and extended the starch bonds, resulting in weakened bonds, thus reduced hardness.

No significant effect of moisture content and temperature on hardness was observed for the given data. Screw speed significantly affected the hardness in the interaction with waste content ($P < 0.01$), and also in the triple interaction with durum clear, fruit waste and PDHF content (Table 4). At low

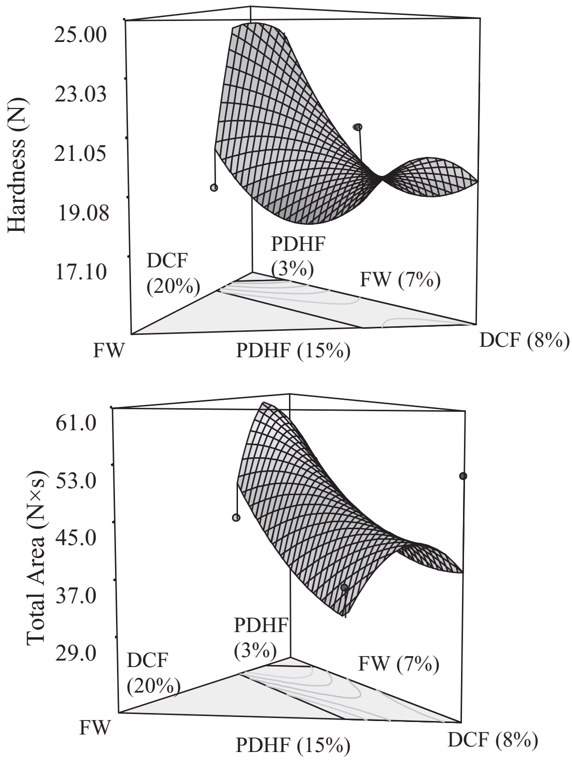

FIG. 3. RESPONSE SURFACE PLOT FOR TEXTURAL PARAMETERS (HARDNESS AND TOTAL AREA) AS A FUNCTION OF COMPONENTS AT 12% MOISTURE CONTENT, 200-rpm SCREW SPEED AND 150C BARREL TEMPERATURE

DCF, durum clear flour; PDHF, partially defatted hazelnut flour; FW, fruit waste.

and high fruit waste content, the increasing screw speed increased the hardness, whereas at intermediate waste content (5%), there was no effect of screw speed on hardness (Fig. 4). A low screw speed is associated with high residence time; consequently, the food material inside the extruder receives more input of thermal energy in a low shear environment. High input of thermal energy because of high residence time (at low screw speeds) leads to the creation of an enhanced level of superheated steam; hence, the product will have a good expansion, which creates flaky and porous structures because of the formation of air cells; the stress during shear will also be low (Bhattacharya 1997).

The change in the total area ($N \times s$) with respect to the composition showed a similar trend with the hardness as shown in Fig. 3. As in hardness, the total area was maximum at intermediate fruit waste content, whereas it

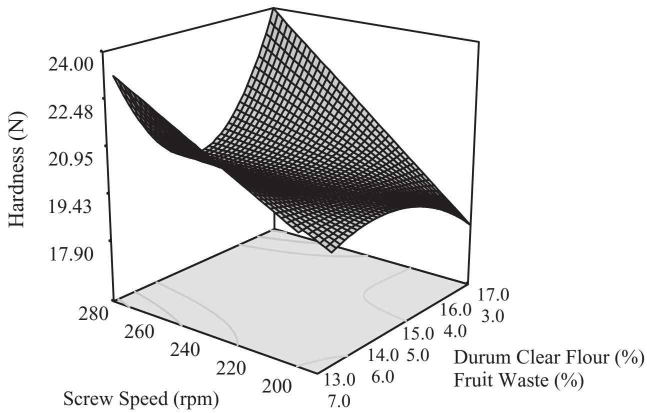

FIG. 4. RESPONSE SURFACE PLOT FOR HARDNESS AS A FUNCTION OF SCREW SPEED, DURUM CLEAR FLOUR AND FRUIT WASTE CONTENT AT 12% MOISTURE CONTENT, 10% PDHF CONTENT AND 150C BARREL TEMPERATURE

decreased with increasing PDHF content. This may be related to the reduced expansion with increasing PDHF content. The reduced starch conversion and compressed bubble growth would result in a dense product and reduced crispness (area under the force-deformation curve) (Ding *et al*. 2005), as observed in this work.

Color

The color of the sample is denoted by the three color parameters: the Hunter *L*, *a* and *b*. The *L* value gives a measure of the lightness of the product color. The redness and yellowness are denoted by the *a* and *b* values, respectively. The measured values of the color parameters of extruded blends varied in the range from 50.41 ± 0.49 to 61.19 ± 0.74 for lightness (*L*), 5.92 ± 0.20 to 8.14 ± 0.02 for redness (*a*) and 14.25 ± 0.72 to 18.06 ± 0.05 for yellowness (*b*). The model coefficients accounting for the individual and combined effect of components and extrusion process parameters are reported in Table 4. The ANOVA test for *L*, *a* and *b* of extruded snacks was significantly ($P < 0.01$) enhanced with the linear terms of durum clear, PDHF and fruit waste content. The color coefficients also had significant interactions among the components and process variables.

The color of the product tends to turn slightly darker when the PDHF percentage increased in the formulation (Fig. 5). The increase in darkness can be attributed to the darkness of the PDHF compared to the nearly white rice and durum clear flour. Sacchetti *et al*. (2004) reported the darkening effect of

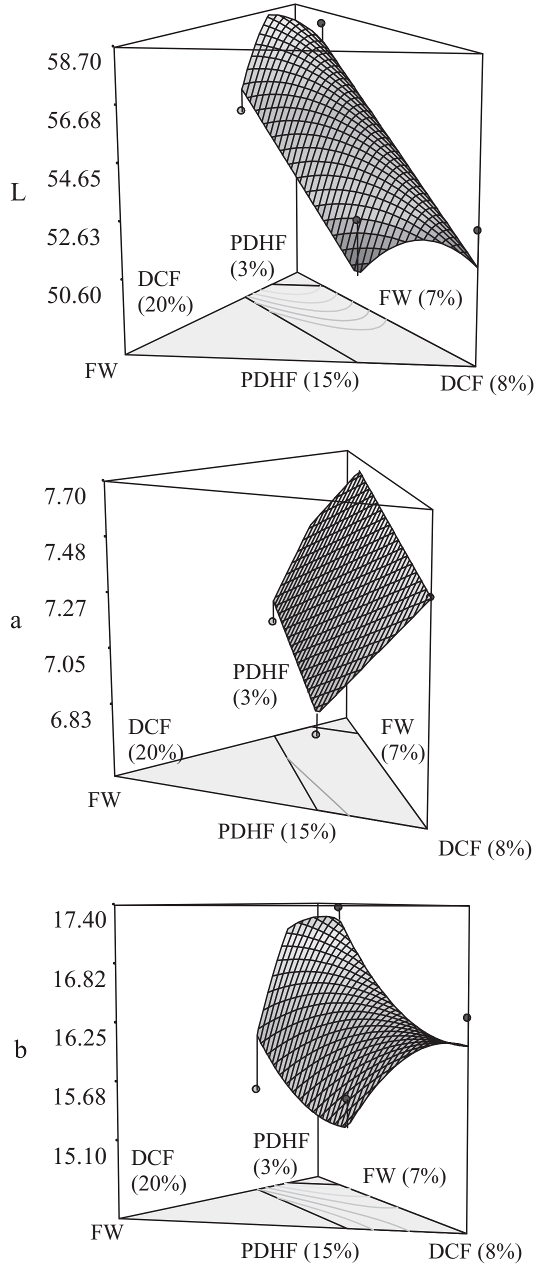

FIG. 5. RESPONSE SURFACE PLOT FOR COLOR VALUES (lightness [*L*], redness [*a*] and yellowness [*b*]) AS A FUNCTION OF COMPONENTS AT 12% MOISTURE CONTENT, 200-rpm SCREW SPEED AND 150C BARREL TEMPERATURE
DCF, durum clear flour; PDHF, partially defatted hazelnut flour; FW, fruit waste.

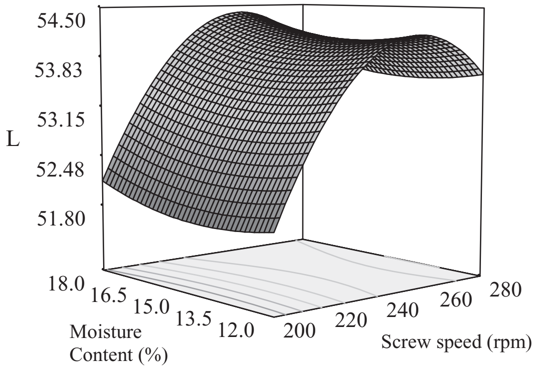

FIG. 6. RESPONSE SURFACE PLOT FOR THE LIGHTNESS (*L*) VALUE AS A FUNCTION OF MOISTURE CONTENT AND SCREW SPEED AT 13.5% DURUM CLEAR FLOUR, 13.5% PARTIALLY DEFATTED HAZELNUT FLOUR, 3% FRUIT WASTE CONTENT AND BARREL TEMPERATURE OF 150C

chestnut flour addition to the rice. The lightness of the extrudates increased up to 5% waste content; however, further increase in waste content caused lightness to decrease. Ahmed (1999) reported the decrease in lightness of corn-based extrudate with increasing flaxseed addition. He concluded that decrease in the *L* value may have been the result of more browning reaction because fiber addition increased the extrudate temperature or might have been caused by the pigments present in flax flour.

The extrusion temperature appeared to have no significant effect on extrudate lightness, whereas lightness increased with increasing screw speed at low waste content (Fig. 6). On the other hand, when the waste content of the initial blend was increased, lightness increased up to 240-rpm screw speed; further increase caused a decrease in *L*. Increasing the screw speed would decrease the residence time in extrusion cooking and thus reduces color change (Ilo *et al.* 1999). Increasing the moisture content generally increased the lightness of product. A similar trend was reported for the extruded maize grits (Ilo and Berghofer 1999).

The response surface plot for the redness and yellowness (Fig. 5) of the extrudates showed gradual increase in redness and yellowness with increasing additions of fruit waste. This trend can be attributed to the color of the fruit waste, which contains orange peel, tomato pomace and grape seeds. On the other hand, the addition of PDHF to the blend caused both redness (*a*) and yellowness (*b*) to decrease.

The effect of process parameters on the redness was not significant in linear relation, but significant in the interaction with component variables. The representation of values of the extrudates as a function of barrel temperature

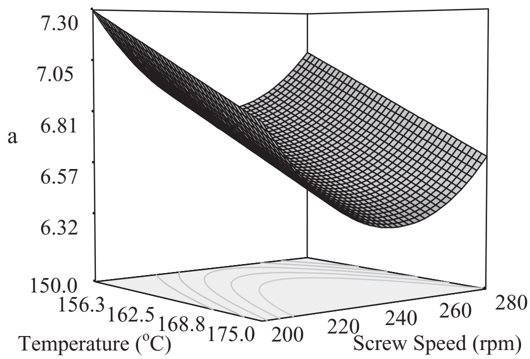

FIG. 7. RESPONSE SURFACE PLOT FOR THE REDNESS (*a*) VALUE AS A FUNCTION OF TEMPERATURE AND SCREW SPEED AT 18% DURUM CLEAR FLOUR, 7% PARTIALLY DEFATTED HAZELNUT FLOUR, 5% FRUIT WASTE CONTENTS AND 12% MOISTURE CONTENT

and screw speed is given in Fig. 7. The effect of the temperature on redness was found to be dependent on blend formulations as indicated by the linear interaction with PDHF and the triple interaction with PDHF and moisture contents. The redness generally decreased with increasing barrel temperature at most blend formulations. Some of the pigments naturally present in fruit waste may have been damaged by the thermal treatment and some browning may have made up the color loss. The redness decreased with increasing screw speed at low waste content. At high waste content, the redness decreased up to 240-rpm screw speed; further increase caused an increase in the *a* value. Increasing the moisture content generally decreased the redness of the product at most compositions of the blend. Ilo and Berghofer (1999) observed the same trend for the extruded maize grits. The regression analysis of the measured data for the yellowness (*b*), as presented in Table 4, showed that there was no significant effect of process variables on *b* values.

Sensory Evaluation

The photographs of samples used for the sensory analysis are given in Fig. 8. The statistical evaluation of sensory properties of the extruded snacks is given in Table 5. The results showed that most products showed no distinctive orange and hazelnut flavors. The intensity scores for the hazelnut flavor were greater with respect to the orange flavor. Hedonic scores for the sensory quality of snacks having various formulation ranged from 2.9 (dislike slightly) to 6.6 (like moderately) for all attributes. The samples with lower PDHF levels (5–7%) had higher color scores (5.6–6.4) than the high PDHF (12.2–15%)

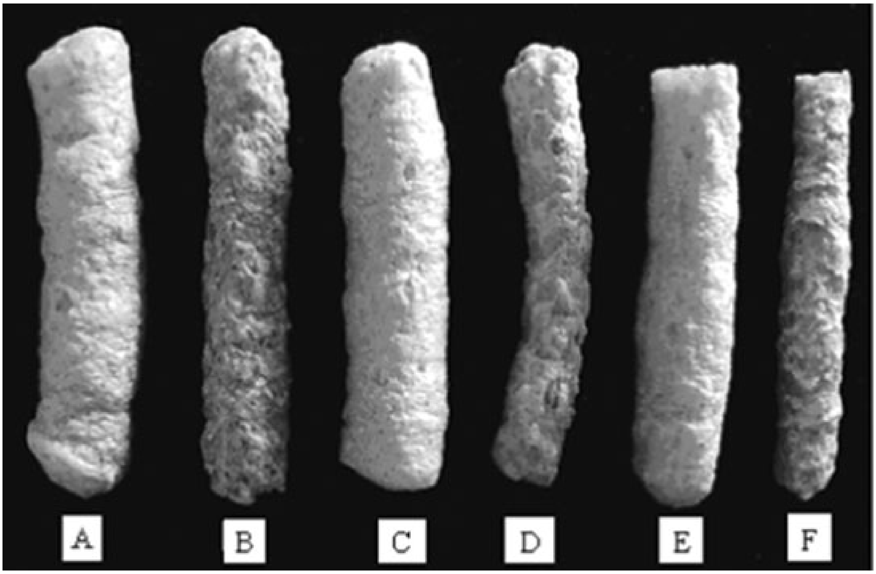

FIG. 8. PHOTOGRAPHS OF SNACK SAMPLES EVALUATED BY THE SENSORY PANEL
(A) DCF = 20%/PDHF = 7%/FW = 3%, (B) DCF = 12%/PDHF = 15%/FW = 3%,
(C) DCF = 20%/PDHF = 5%/FW = 5%, (D) DCF = 12.8%/PDHF = 12.2%/FW = 5%,
(E) DCF = 18%/PDHF = 5%/FW = 7% and (F) DCF = 8%/PDHF = 15%/FW = 7%.
DCF, durum clear flour; PDHF, partially defatted hazelnut flour; FW, fruit waste.

with color scores of 2.9–3.4. This was probably because of the darker color of the PDHF compared to fruit waste and durum clear flour. This result was consistent with the data obtained by instrumental measurement, such that the color of the product became darker when the PDHF percentage increased in the snack formulation. There was no significant effect ($P < 0.05$) of fruit waste addition on sensory scores for the color.

Textural properties of all snacks, especially crispness and breakability values, generally took high scores from the panelists. Snack formulation did not significantly affect ($P < 0.05$) the sensory hardness. On the other hand, the snack having 5% fruit waste and 12.2% PDHF had lower sensory score for the crispness and breakability. Mostly, the snacks having lower PDHF content were preferred with respect to crispness scores. The overall acceptability scores varied significantly ($P < 0.05$) among samples, with scores ranging from 3.6 (dislike slightly) to 6.6 (like moderately). The extruded snacks with lower PDHF content had the highest levels of overall acceptance than the snacks with higher PDHF content. There was no significant effect ($P < 0.05$) of fruit waste addition on sensory properties of produced snacks.

TABLE 5.
MEAN SCORES FOR SENSORY PROPERTIES OF SNACKS

Snack formulation (%) DCF/PDHF/FW	Sample name	Intensity ratings*		Hedonic ratings†				
		Orange flavor	Hazelnut flavor	Color	Hardness	Crispness	Breakability	Overall acceptability
20/7/3	a	1.5a	3.3ab	5.6b	5.4a	6.2b	5.7ab	6.1c
12/15/3	b	1.9a	3.1ab	2.9a	5.4a	6.1b	6.3ab	4.6b
20/5/5	c	1.6a	3.4b	5.7b	5.2a	6b	5.9ab	6.2c
12.8/12.2/5	d	2a	2.4a	3.4a	5.2a	4.7a	5.4a	3.6a
18/5/7	e	2.1a	2.9ab	6.4b	5.8a	6.2b	6.5b	6.6c
8/15/7	f	2.1a	3.2ab	3.4a	6.8a	5.7b	6ab	4.4b

Values with the same letter are not significantly different at $P < 0.05$ level.
* On a 9-point scale, 1 = absent, 9 = very high.
† On a 9-point scale, 1 = extremely dislike, 9 = extremely like.
DCF, durum clear flour; PDHF, partially defatted hazelnut flour; FW, fruit waste.

CONCLUSION

The extrusion of most combinations of durum clear flour, PDHF and fruit waste produced expanded snacks at most extrusion conditions; however, blends having 15% PDHF usually failed to extrudate into products with consistent shapes and degrees of expansion. Durum clear flour and fruit waste content had a significant effect and positive correlation with the radial expansion ratio. On the other hand, increasing the PDHF content limits product expansion. Increasing the moisture content and decreasing the temperature caused an increase in the expansion ratio for most compositions. Increasing the PDHF content up to ~12% improved product hardness; however, beyond this value, extrudate hardness increased. No significant effect of moisture content and temperature on hardness was observed for the given data. The color of the product tends to turn slightly darker when the PDHF percentage increased in the formulation. The gradual increase in redness and yellowness was observed in snacks with additions of fruit waste. Among the experimental conditions used in the present study, well-expanded snack products with acceptable sensory attributes were obtained at low PDHF content. As it has been summarized, the extrusion of newly designed combinations of rice flour and waste materials gave desirable products according to their physical properties. These kinds of products could help in utilizing the waste materials for the production of valuable products in the future. However, the nutritional aspects of the produced products still need to be searched.

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