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ORIGINAL ARTICLE

Protein rich extruded products from tef, corn and soy protein isolate blends

Sirawdink Fikreyesus Forsido[1] and Hosahalli S. Ramaswamy[2]
[1]Department of Post-Harvest Management, Jimma University, College of Agriculture and Veterinary Medicine P.O. Box 307, Jimma, Ethiopia
[2]Department of Food Science, McGill University, Macdonald Campus, 21,111 Lakeshore Road, Ste-Anne-de-Bellevue, QC Canada H9X 3V9
***Corresponding author:** Email: Hosahalli.Ramaswamy@McGill.Ca

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ABSTRACT

Specific blends of Tef, corn and soybean protein isolates (SPI) were subjected to twin screw extrusion process with the objective of enriching the protein content of Tef and produce a range of extruded products. The proportions of Tef, corn and SPI were selected using a unique 16-run, three-factor, three-level D-Optimal constrained mixture design. The SPI addition was maintained in the 0-20% range to test the effect of protein addition to the cereal mix (Tef and corn accounting the balance 80-100%) on the physical properties of the extruded products. Extruded products were obtained using a co-rotating twin screw extruder under operating conditions optimized in a previous study. The study showed significant differences ($p<0.05$) in color value, rehydration ratio and water solubility index while there were no significant differences among the products in terms of expansion ratio and bulk density. In general, proportion of ingredients induced significant changes in the product quality attributes evaluated. Blends with higher proportion of Tef and SPI (lower proportions of corn) showed a significantly ($p < 0.01$) lower L* value, b* value and higher levels of product hardness. It was demonstrated that Tef has good potential for making good extruded products. The formula containing 20% Tef, 60% corn, and 20% SPI was selected as the best formulation to yield a protein rich extruded product with desirable attributes. Understanding the effect of these variables on the product physical properties was deemed useful for the development of protein-rich extruded products.

Keywords Extrusion, physical properties, constrained mixture design, tef, SPI

INTRODUCTION

Extrusion is one of the most common industrial processes used to make snacks, and it is among the most versatile technological processes for making food products, usually from cereals. Cereals, in turn, are the customary, traditional snack ingredients due to their high starch content (Perez-Navarrete *et al.*, 2006). Extrusion technology has many advantages, including its versatility, high productivity, low cost, and the ability to produce unique product shapes and high product quality (Koksel *et al.*, 2004). Extrusion-cooking is a versatile and feasible alternative for manufacturing snacks and water reconstitutable foods, and it has been the object of studies to enhance the nutritional and functional properties of extrudates for the development of products (Hernandez-Diaz *et al.*, 2007).

Tef [*Eragrostis tef (Zucc.) Trotter*], also called teff or taf, is a unique durable crop grown over a wide range of environmental conditions in Ethiopia and has been utilized as food and supplements majority of the human diet in Ethiopia (Asrat and Frew, 2001). It is as nutritious as major staple cereals like wheat, rice, oats and barley and even better in some aspects, containing more calcium, zinc, iron and potassium and being high in dietary fiber. It is a rich source of vitamins and is considered to be an excellent source of essential amino acids with higher levels than wheat and barley (Seyfu, 1993).

Tef flour is used for making pancake like bread called injera. The flour can also be used to make other food products such as qitta (unleavened bread), porridge and home brewed traditional beverages like "tella" (local beer) and "katikalla"(distilled liquor). Unlike other cereals (wheat, maize, rice and barley) processed at an industrial level, diversified utilization of tef has been limited which could be attributed to its uniqueness to Ethiopia and an age-old processing carried out at a house hold-level (Laike *et al*., 2010).

Soya bean (*Glycine max L.*) is an important source of edible vegetable oil and protein for both humans and animals (Worku and Astatkie, 2010). Soya bean is a low cost, superior protein source available in the world. Besides protein fortification, soy based supplementary foods also provide many other nutritional benefits. Soya protein ingredients and soy protein containing foods may partially replace or be used in addition to animal or other vegetable protein sources in the human diet (Yu *et al*., 2009). According to Muteki *et al*. (2007) there are basically three general degrees of freedom to control the final properties of any product manufactured in a blending operation: the selection of raw materials, the ratios in which to blend them and the processing conditions used to manufacture them. Understanding the relationships between the ingredients is necessary to achieve desired product quality targets and to develop new products (Aguilera and Stanley, 1999). In a recent study, Laike *et al*. (2010) evaluated the effect of extrusion variables on the physical and sensory properties of an extruded product using two tef cultivars. They reported that an increase in barrel temperature, reduction in feed moisture content and an increase in screw speed resulted in higher expansion ratio (hence reduced bulk density) and lower compression resistance of the extruded products. They also reported significant differences ($p<0.05$) in sensory scores for colour, texture and overall acceptance between products with extrusion variables inducing significant changes in the product quality attributes. This study was conducted with significantly lower levels of feed moisture content which would exert much pronounced extrusion effects because of the higher shear-compression-heat related changes.

The objective of this study was to develop protein rich extruded products from tef, corn and SPI blends at a relatively higher level feed moisture content and to yield a minimum 20% protein content in the product. Our preliminary studies showed that it was difficult to obtain an extruded product with good sensory characteristics with tef alone and incorporating more than 20% protein may be difficult to economically justify.

MATERIALS AND METHODS

Materials

The ingredients used for the different feed formulations were: Tef flour with 9.7% moisture content, 11% protein, 75% carbohydrate and 3% fat (Dibaya Flour Mills, Addis Ababa, Ethiopia); corn flour with 12% moisture content, 1.7% fat, 76.7% starch and 10% protein (Brar Natural Flour Mills, Winnipeg, Canada) and SPI with 7.7% moisture content 7% and 90% protein (American Health and Nutrition, Inc. Ann Arbor, MI, USA).

Preparation of Samples

A statistical software package (Design Expert 7.0.0) was used for the generation of test formulations and processing conditions as well as analysis of the results. These formulations were obtained based on a constrained mixture D-optimal design. Table 1 presents coded and actual values of ingredients used as determined. Totally there were 16 sets of experimental conditions. According to the software, the use of specific constraints (like 20% maximum for SPI) is justified because the presence of three components which always generates higher responses than the pure components.

Table 2 shows low and high levels of the three parameters established for each component and Fig. 1 shows the schematic description of this experimental region. The processing conditions such as screw speed, feed rate and temperature were kept at a constant central level (as determined by the previous studies by Yu et al., 2009). All the ingredients were weighed and then mixed in a Hobart NCM mixer (Process Plant and Machinery Ltd., UK) for 20 min. Samples were stored at room temperature for 24 h before extruding. The moisture content of all formulations were estimated prior to extrusion using the oven method (AOAC, 1995) and later adjusted by adding water into the liquid feed of the extruder.

Extrusion Runs

Extrusion was performed in a co-rotating twin screw extruder (DS32-II, Jinan Saixin Food Machinery, Shandong, P.R. China), consisting of three independent zones of controlled temperature in the barrel. The diameter of the screw was 30mm. The length to diameter ratio of the extruder barrel is 20:1. The diameter of the hole in the die is 5mm with a die length of 27mm. The screw speed and the temperature of the third barrel section (metering section) were adjusted to the required levels. The extruder was fed manually through a conical hopper. The extrudates were collected after stable conditions were established, and the moderately wet extruded products were dried in an air convection oven drier at 45^{o}C and an air flow rate of 0.1 m/s to a moisture content of 9–10% (wet base). Dried samples were stored in air tight plastic containers at room temperature and used for the study.

Physical Properties

Several physical parameters were selected from those that have been used to describe the properties of the dried extruded samples.

Color

The color of the extrudate was assessed using a Minolta colorimeter CM-500d (Optical Sensor, Hunter Associates Laboratory Inc., Reston VA, USA) using an aperture of 1.2 cm diameter. In the Minolta colorimeter, the color of a sample is represented by the three color parameters: L*, a* and b* which were recorded for each sample. The L* value gives a measure of the product lightness from 100 for perfect white to 0 for black, as the eye would see it. The redness/greenness is denoted by a* values (ranging from negative values on the red side to the positive values on the green side) and yellowness/blueness are denoted likewise ranging from negative to positive b* values.

Radial Expansion Ratio (RER)

Radial expansion ratio (RER) is defined as the ratio of the diameter of the extrudate to the diameter of the die (Jyothi et al., 2009). It is a factor used to describe the expansion of the product. In order to determine the RER, the diameter of 20 randomly selected samples were measured from each run using a caliper and the average value was used.

Water Solubility Index (WSI)

Water solubility index (WSI) describes the soluble ingredients in the final product. WSI was determined according to the method developed for cereals (Anderson et al., 1969). The ground extrudate was suspended in water at room temperature for 30 min, gently stirred during this period, and then centrifuged at 3000 rpm for 15 min. The supernatant was decanted into an evaporating dish of known weight. The WSI was calculated as the weight of dry solids in the supernatant expressed as a percentage of the original weight of the sample.

Table 1. D-optimal mixture design: coded and actual values in grams in parenthesis

Run	Tef	Corn	SPI
1	0.736 (883.2)	0.264 (316.8)	0.000 (0.0)
2	0.000 (0.0)	0.900 (1080.0)	0.100 (120.0)
3	0.000 (0.0)	0.800 (960.0)	0.200 (240.0)
4	1.000 (1200.0)	0.000 (0.0)	0.000 (0.0)
5	0.000 (0.0)	0.900 (1080.0)	0.100 (120.0)
6	0.518 (621.6)	0.282 (338.4)	0.200 (240.0)
7	0.266 (319.2)	0.734 (880.8)	0.000 (0.0)
8	0.800 (960.0)	0.000 (0.0)	0.200 (240.0)
9	1.000 (1200.0)	0.000 (0.0)	0.000 (0.0)
10	0.862 (1034.4)	0.126 (151.2)	0.012 (14.4)
11	0.000 (0.0)	1.000 (1200)	0.000 (0.0)
12	0.800 (960.0)	0.000 (0.0)	0.200 (240.0)
13	0.675 (810.0)	0.161 (193.2)	0.164 (196.8)
14	0.000 (0.0)	1.000 (1200)	0.000 (0.0)
15	0.500 (600.0)	0.500 (600)	0.000 (0.0)
16	0.000 (0.0)	0.800 (960.0)	0.200 (240.0)

Table 2. Design Constraints

Low	≤ Constraint	≤ High
0	≤ A:Tef	≤ 1.00
0	≤ B:Corn	≤ 1.00
0	≤ C:SPI	≤ 0.20
	A+B+C=	1

Bulk Density (BD)

Bulk density (BD) describes the product density and also can describe the expansion of the product. It was measured by displacement method (Seker, 2005). Extrudates were cut into strands, about 25 mm long, and about 15g strands were taken and weighed (M) and placed in a 100 mL measuring cylinder. Yellow millet seeds were added to fill up the cylinder up to the mark. Then the extrudate samples were separated and the volume of the yellow millet seeds was measured in the same cylinder (V). BD was calculated as follows (Eq. 1):

$$BD = M/(100-V) \quad (1)$$

Hardness (H)

Mechanical properties of the extrudates were determined by a three-point breaking test (Zasypkin and Lee, 1998) using a TA – XT2 texture analyzer (Stable Micro Systems Ltd., Godalming, UK) equipped with a 20Kg load cell.

Extrudates of 35 mm long were placed on two rounded stands 30mm apart. A third rounded crosshead was used to exert force in the middle of the bridge. The cross head was set to move down at 5mm/min until breaking occurred. The hardness was determined as the breaking force. Twenty measurements were made on each product and the average value was used.

Rehydration Ratio (RR)

Rehydration ratio (RR) is used to describe the capability of the water absorption in the sample. Rehydration ratio was measured at 30ºC. The extrudates were cut to obtain 35 mm long strands and about 20g strands were weighted (M_1) and placed in 500ml of water at 30ºC for 15min. The water was drained and the rehydrated samples were weighed (M_2). RR is calculated as follows (Eq. 2):

$$RR = \frac{M2 - M1}{M1} \quad (\%) \qquad (2)$$

Statistical Analysis

The data was subjected to analysis of variance (ANOVA). Statistical significant differences between values were evaluated at $P < 0.05$ level using Design Expert software.

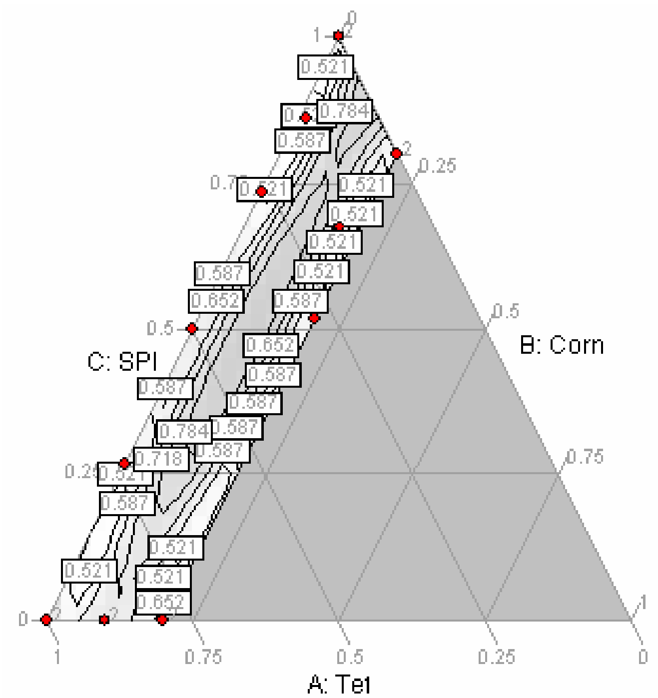

Figure 1. Experimental region from mixture design delimited by low and high constraints established for each component.

RESULTS AND DISCUSSION

Mean values of all physical properties of extruded products along with their standard deviations are summarized in Table 3. Analysis of variance results are summarized in Tables 4 and 5. Models for color (L* and b* values) and hardness were highly significant ($p<0.01$), and models for color (a* value), rehydration ratio, and water solubility index were significant ($p<0.05$) and these quality parameters were affected ($p<0.05$) by the primary ingredient variables, tef, corn and SPI, in both linear and quadratic forms. The models for expansion ratio and bulk density were not significant ($p>0.05$). Various physical properties have been studied in different extruded products. Laike *et al*. (2010) studied physical properties including radial expansion ratio, specific length, bulk density, extrudate hardness, water absorbtion and water solubility indices of extruded tef products. On the other hand, Yu *et al*. (2009) studied expansion ratio, bulk density, breaking strength, water solubility index, rehydration ratio, and color of extruded corn flour and SPI blends.

Table 3. Physical properties of the extruded products (mean values plus standard deviation in parenthesis**)**

Run	L*	a*	b*	ER	RR (%)	WSI	BD (g/mL)	H (N)
1.	40.78 (2.96)	3.55 (0.5)	16.72 (1.06)	1.82 (0.08)	170.13 (0.22)	0.66	0.41 (0.06)	49.46 (11.08)
2.	48.67 (9.22)	4.5 (1.1)	27.09 (3.54)	1.76 (0.10)	202.01 (0.31)	0.47	0.48 (0.02)	52.29 (7.56)
3.	54.35 (11.88)	3.92 (0.9)	27.33 (1.47)	1.9 (0.09)	408.27 (0.37)	0.81	0.38 (0.02)	31.32 (10.77)
4.	38.53 (3.12)	4.36 (0.4)	16.93 (0.56)	1.89 (0.07)	187.18 (0.22)	1.14	0.37 (0.03)	41.77 (16.48)
5.	54.5 (3.41)	3.12 (1.1)	27.61 (1.12)	1.83 (0.06)	300.62 (0.36)	0.71	0.4 (0.03)	46.46 (8.41)
6.	47.8 (1.68)	4.2 (0.9)	21.17 (1.49)	1.83 (0.09)	250.78 (0.18)	0.35	0.4 (0.02)	74.41 (15.60)
7.	53.7 (1.89)	2.7 (0.9)	22.46 (1.64)	1.84 (0.07)	496.18 (0.12)	0.66	0.35 (0.02)	10.55 (3.17)
8.	40.91 (2.92)	4.24 (1.0)	17.84 (1.58)	1.9 (0.08)	114.91 (0.11)	1.28	0.42 (0.02)	92.64 (18.53)
9.	35.25 (3.13)	4.46 (0.5)	15.97 (1.02)	1.96 (0.07)	138.45 (0.16)	0.97	0.36 (0.02)	86.19 (17.20)
10.	38.87 (1.93)	4.47 (0.5)	17.81 (0.87)	1.84 (0.10)	175.81 (0.17)	0.85	0.39 (0.04)	74.06 (16.54)
11.	59.18 (2.43)	1.46(1.0)	26.53 (2.22)	1.84 (0.13)	403.59 (0.28)	0.12	0.37 (0.03)	12.54 (4.16)
12.	41.53 (3.02)	4.88 (0.5)	19.1 (0.76)	1.86 (0.10)	130.14 (0.20)	0.93	0.4 (0.02)	86.8 (20.93)
13.	42.41 (3.57)	4.92 (0.7)	20.62 (0.82)	1.95 (0.08)	214.72 (0.31)	0.96	0.38 (0.03)	68.43 (16.35)
14.	58.17 (2.83)	1.97 (1.0)	27.14 (1.91)	1.89 (0.12)	399.04 (0.41)	0.33	0.37 (0.03)	13.09 (3.37)
15.	45.82 (3.85)	4.47 (0.5)	21.91 (0.87)	1.9 (0.10)	479.4 (0.33)	0.12	0.35 (0.10)	14.84 (4.52)
16.	57.01 (2.43)	4.77 (0.8)	30.64 (1.36)	1.69 (0.07)	270.79 (0.24)	0.6	0.56 (0.06)	12.43 (3.62)

Color

The main treatment effects due to changing tef (A), corn (B) and SPI (C) levels on the color values (L*, a* and b*) are shown in Tables 4 and 5. Figure 2a shows the response surface obtained by fitting a quadratic model to L-value (lightness) and Figure 2b shows its contour graph. Analysis of variance (ANOVA) was used for evaluation of the quadratic model. The lack of fit for the fitted model was not significant demonstrating the adequacy of the model. The fitted model for L* value is shown as Eq. 3 (all independent variables in coded values) indicating quadratic effects with all three variables.

$$L = 36.50A + 58.45B + 447.18C - 0.99AB - 478.58AC - 502.99BC \quad (3)$$

With higher proportion of tef included in the mixture, lower L* value was observed and formulations with higher proportion of corn showed a higher L* value. For any given formulation, there is an initial decrease followed by an increase in L* value as the SPI content was increased.

Color is one of the physical properties often used by food customers and manufacturers to qualitatively assess the quality of feed and food materials (Turner, 1995; Yu *et al*., 2009). Processing conditions during extrusion often lead to color change by non-enzymatic browning which results from Maillard reaction between proteins and reducing sugars (Berset, 1989).

Tef used in our study was relatively dark in comparison with the other ingredients used (i.e., corn flour and SPI). Therefore, as the proportion of tef in the formulation increased, the extrudate brightness (L* value) progressively decreased.

Table 4. Analysis of Variance (ANOVA)

Source	L		a		b		ER		RR		WSI		BD		H	
	df	SS	df	SS	df	SS	df	SS	Df	SS	df	SS	df	SS	df	SS
Model	5	896.45	5	13.31	5	328.17	5	0.022	5	19.39	5	1.22	5	0.019	5	11220.35
Residual	10	37.65	10	3.02	10	13.75	10	0.045	10	5	10	0.54	10	0.024	10	2113.64
R^2	0.9597**		0.8150*		0.9598**		0.3309ns		0.795*		0.6947*		0.4456ns		0.8415**	

*P<0.05; **P<0.01; ns=not significant

Table 5. Analysis of variance for the p value of experiment data to constrained mixture model

	L	a	b	ER	RR	WSI	BD	H
Model	< 0.0001	0.0020	< 0.0001	0.4706	0.0032	0.0201	0.2443	0.0009
Linear Mixture	< 0.0001	0.0008	< 0.0001	0.1890	0.0014	0.0073	0.1013	0.0002
AB	0.8730	0.2477	0.2942	0.6793	0.0348	0.0714	0.7020	0.2260
AC	0.0097	0.1506	0.8679	0.9550	0.0773	0.5087	0.8144	0.0283
BC	0.0071	0.0934	0.9707	0.8844	0.0720	0.4611	0.7162	0.0332

A: Tef; B:Corn; C:SPI

Another color parameter of interest is b* value (its position between yellow and blue in the Hunter color space). Figure 3a shows the response surface of b* values (yellowness/blueness) and Figure 3b shows its contour graph. The figures show that large b* values were observed for formulations having high corn and SPI, and lower tef proportions. The fitted model for b* value is shown in Eq. 4 (all independent variables in coded values, the A,B and C representing, tef, corn and SPI) indicating quadratic effects with all three variables.

$$\textbf{b* value} = 16.38A+26.63B+40.17C-4.03AB-15.50AC-3.40BC \qquad (4)$$

If we are interested in a light colored as well as protein rich product, it will be wise to choose higher proportion of SPI and corn, and lower proportion of tef. From optimization using point prediction, it was observed that proportions of 20:60:20 (tef: corn: spi) gave an acceptable light colored and protein rich extrudate. Decreasing the tef levels from 100% to zero resulted in an increased extrudate yellowness (b*) by 52 %, which could be attributed to the differences in the yellow or whiteness of raw ingredients used and interactions between them. Baik *et al.* (1995) examined discoloration of dough for oriental noodle and found out that the color differences between wheat flour noodle doughs was highly correlated with differences in starch (as measured by gelatinization, differential scanning calorimetry, or amylose-amylopectin parameters) or protein (as measured by dough mixing and bread making).

Water Solubility Index (WSI)

As extruded product characteristics, WSI is a very important parameter in representing the degree of gelatinization (cooking) (Laike et al., 2010). Figure 4a shows the response surface of WSI and Figure 4b shows its contour graph. The WSI of extrudates were significantly ($p<0.05$) affected by proportion of tef, corn and SPI in the blends (Tables 4 and 5). Analysis of variance (ANOVA) indicated a quadratic model with the lack of fit being not significant. The fitted model for WSI is shown in Eq. 5 (all independent variables in coded values, with A, B and C as before) indicating quadratic effects with all three variables.

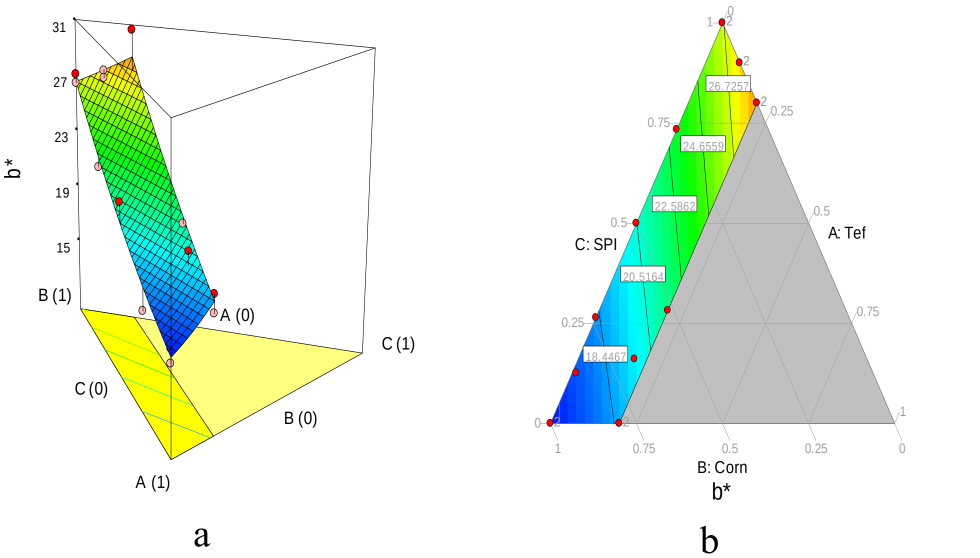

Figure 2. Effects of formulation on L-value (a) Surface response and (b) contour graph

WSI= 1.08A+0.32B-9.00C-1.45AB+12.28AC+13.64BC (5)

WSI increased significantly ($p<0.05$) from 0.12 to 1.28 as tef and SPI proportions increased from 0% to 80% and 20%, respectively.

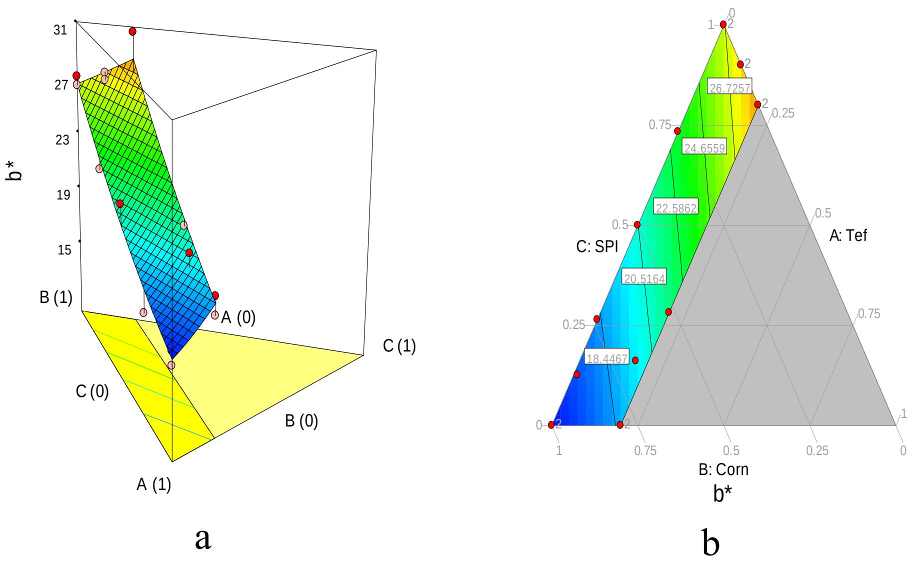

Figure 3. Effects of formulation on b-value (a) Surface response and (b) contour graph

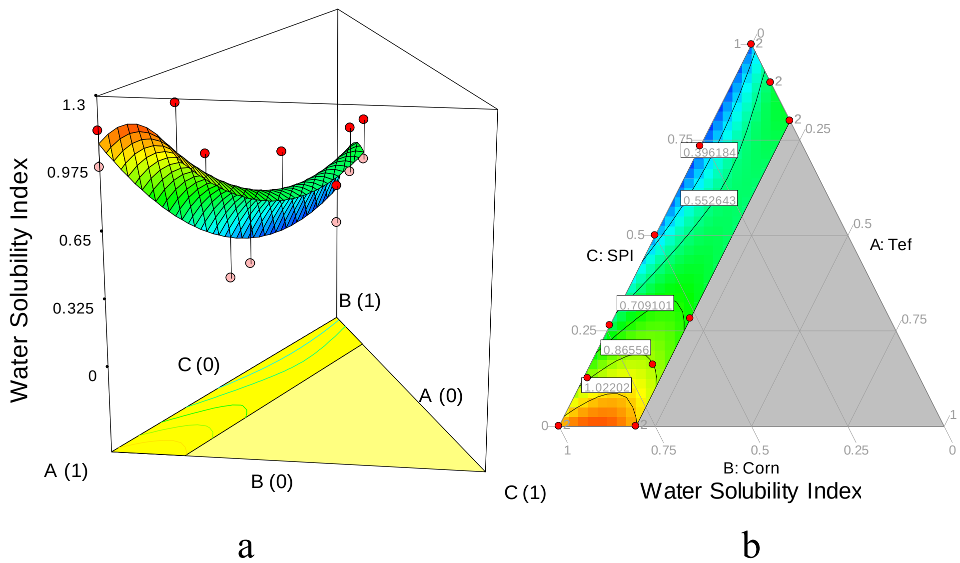

Figure 4. Effects of formulation on water solubility index (a) Surface response and (b) contour graph

Formulations with higher tef content showed a higher WSI and those with higher corn content showed the reverse. At higher levels of corn, increasing the level of SPI tended to increase WSI.

Water solubility index is an indicator of degree of gelatinization. Starch gelatinization is associated with the disruption of granular structure causing starch molecules to disperse in water (Wajira and Jackson, 2006). Gelatinization, which leads to transformation of raw starches to a cooked digestible material, is one of the important effects that extrusion has on starch component of foods (Qing-Bo *et al*., 2005).

The water solubility index indicates the extent of molecular degradation (Ollet *et al*., 1990). The increase in WSI therefore shows macromolecular degradation with the intensity of extrusion condition. Large amount of soluble materials are released from tef and SPI as compared with that of corn flour.

Hardness (H)

Figure 5a shows the response surface of hardness as influenced by proportion of ingredients and Figure 5b shows its contour graph. The hardness of extrudates were significantly ($p<0.05$) affected by proportion of tef, corn and SPI in the blends (Tables 4 and 5). The fitted model did not show any lack of fit. The fitted model for WSI is shown in Eq. 6 (with A, B and C representing tef, corn and SPI)

$$\mathbf{H = 67.66A+11.60B-2128.13C-58.23AB+2882.95AC+2760.29BC} \quad (6)$$

The increase in tef content increased hardness, whereas increase in corn and SPI contents decreased hardness (Figure 5a). Hardness values ranged from 10.55 to 92.64N, and the lowest value corresponded to the sample containing 26.6%, 73.4% and 0% tef, corn and SPI respectively.

Lobato *et al*. (2010) suggested that food texture is a result of its microstructure, which depends on the influence of physical forces on chemical components. The texture of extruded food products is greatly influenced by the extrudate composition.

Generally, the addition of fiber to an extruded product results in increased product density and hardness. Great differences have been observed with increasing amounts of fiber as a result of its effect on air cell wall thickness (Yanniotis et al., 2007). Meanwhile, Valentina *et al*. (2010) reported tef flour samples have 3.37% of dietary fiber. This might have contributed to the increased hardness of extrudates with increasing levels of tef.

Samples with high values of hardness may be considered sensorially undesirable. In many cases, hardness higher than 200 N is not a desirable attribute for expanded snacks (Lobato *et al*., 2010). The prepared new products in this study have far less hardness (maximum hardness was 93 N).

Rehydration ratio (RR)

Extruded products are usually rehydrated prior to consumption like in breakfast cereal, or used as an ingredient in cooking preparations. The rehydration ratio is an important parameter for such considerations as it will define the ability of how much liquid the product can absorb (Yu *et al*., 2009).

The rehydration ratio was significantly ($p<0.05$) affected by the type of formulation (proportion of tef, corn and SPI) (Tables 4 and 5).The fitted regression equation for RR is shown in Eq. 7 (all independent variables in coded values and A, B and C represent tef, corn and SPI).

$$\mathbf{RR = 1.30A+4.14B+87.51C+5.36AB - 107.80AC-109.41BC} \quad (7)$$

Figures 6a and 6b indicate the response surface plot and contour graph of RR as influenced by the proportion of ingredients. The figures show that mixtures containing higher concentrations of corn in combination with lower amounts of tef and SPI yield high RR. The effects of the proportion of ingredients on RR were straight forward at least for tef and corn. RR increased with corn content and decreased with amount of tef. Whereas for SPI, the response surface curve concaved at mid-SPI content showing there was an initial decrease followed by an increase in RR as a function of SPI level. Correlation analysis showed that RR was negatively related to WSI (r=-0.67). RR was also found negatively related to BD (r= −0.31).

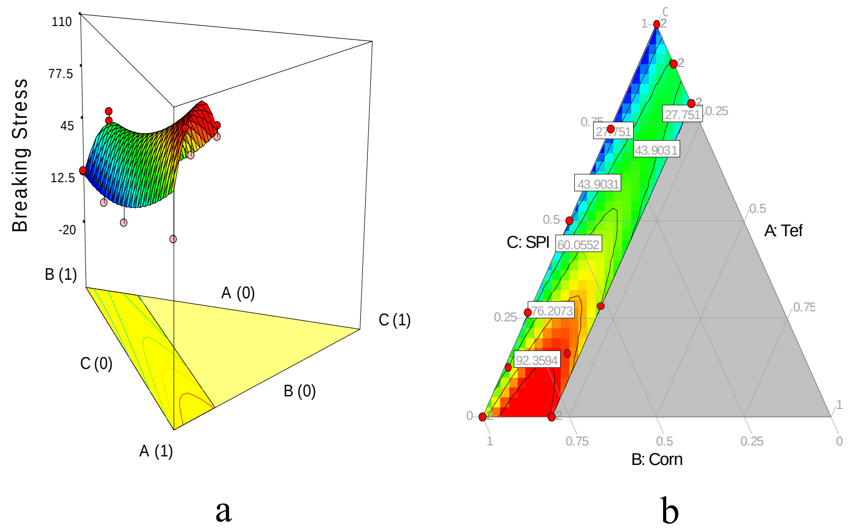

Figure 5. Effects of formulation on breaking stress (a) Surface response and (b) contour graph

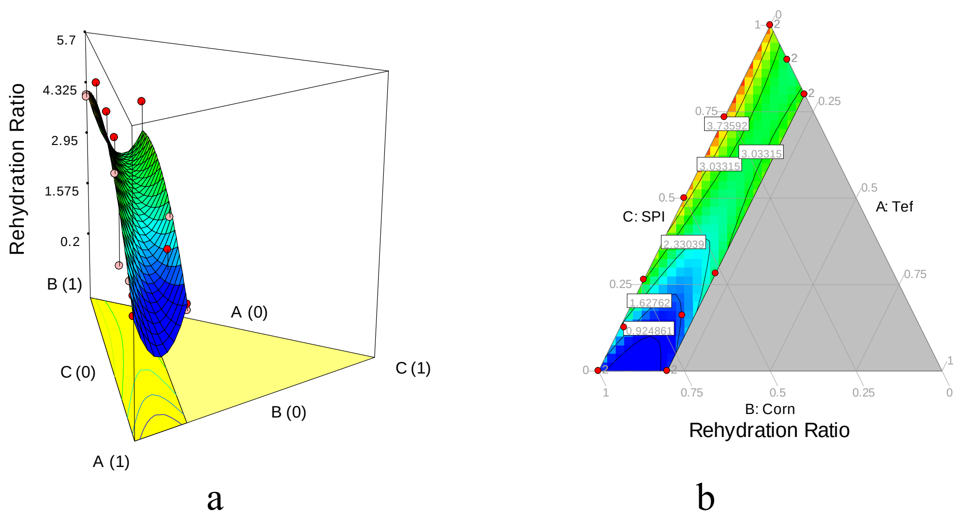

Figure 6. Effects of formulation on rehydration ratio (a) Surface response and (b) contour graph

Radial expansion ratio (RER)

ER is an important quality parameter in products like breakfast cereals and ready-to-eat snack foods. In products intended for further cooking, this may not be very important; in fact, large ER, which promotes increased porosity, may result in softer texture in cooked products. Hence, choosing the optimal level depends on the intended product (Yu *et al*., 2009).

Diagnostic tools like normal plot of residuals indicate that the residuals are more or less normally distributed. However, values of "Prob > F" is 0.4706 indicates that model terms are not significant. The lack of fit was not significant relative to the pure value. R-Squared is very low (0.3309) and a negative "Pred R-Squared" implies that the overall mean is a better predictor of expansion ratio than the current model (Eq. 8).

$$ER = +1.90A+1.86B+2.14C-0.089AB-0.30AC-0.77BC \quad (8)$$

There is no significant difference in the RER of the 16 different formulations. This indirectly indicates that tef has a comparable potential with that of corn for the preparation of puffed products. RER increased with a an increase in the concentration of tef, while the corn flour and SPI had the opposite effect even if the difference among the different experimental runs was not statistically significant. RER values varied from 1.69 to 1.96. When the extrusion process is carried out at temperatures above 100°C, the moisture present is superheated inside the extrusion barrel due to internal high temperature and high-pressure conditions (Park *et al*. 1993). As the product exits the die nozzle, the moisture flash-evaporates instantaneously due to the pressure drop. As a result, the extruded product is expanded, and the characteristic texture of the extrudate is formed with a porous structure (Yu *et al*., 2009). Lobato *et al*. (2010) reviewed that volumetric expansion, either radial or longitudinal, of extruded starch-based materials is a consequence of extensive flash-off of internal moisture and flow properties of molten mass. The latter depends on the degree of gelatinization, which is determined by processing conditions and raw material composition (Jin *et al*., 1994). Park *et al*. (1993) also observed that the feed composition, which can affect the water binding capacity, determines suitable feed moisture and this in turn can affect the radial expansion.

Another factor that can affect expansion behavior of extruded products is amount of fiber present in the raw material. Above a critical concentration, the fiber disrupts the continuous structure of the melt, hindering its elastic deformation during expansion. Fibers can also bind some of the water present in the matrix, thus reducing its availability for expansion (Moraru and Kokini, 2003), and therefore modifying the hardness. Lue *et al*. (1991) reported that inert component (fiber) in feed material resulted in poor formation and low retention of expanded air pockets.

Bulk density (BD)

Bulk density is a very important parameter because it impacts container fill and thus storage and transport (Mercier et al., 1989). It depends on the size, shape and the extent of expansion during extrusion (Kurt *et al*., 2009). According to Tables 4 and 5, the model for BD was not significant ($p>0.05$). Changing the level of tef or corn from 0 to 100%, or SPI from 0 to 20%, did not show any clear pattern on the unit density values. Additionally, the influence of proportion of ingredients was not as pronounced as with the other parameters mentioned above. The bulk density values of the extrudates ranged from 0.35-0.56 g/ml, depending on the treatment combination used. The highest bulk density (0.56 g/ml) was observed for the treatment combination of 0% tef, 80% corn and 20% SPI. It is difficult to compare these results with previous studies because the general focus of the earlier studies has been to evaluate effects of extrusion parameters on bulk density than the influence of ingredients.

Both RER and BD represent the extent of puffing of the extrudates. Therefore, it might be expected that these two properties would be negatively correlated, with higher RER contributing to lower BD, but Park *et al*. (1993) reported that this is not always the case. The reason could be that RER only considers the expansion in the radial direction, perpendicular to extrudate flow, whereas BD considers the expansion in all directions (Falcone and Phillips, 1988). In this study, a significant inverse relationship (r=−0.81) was found between ER and BD. Park *et al*. (1993) and Falcone and Phillips (1988) also found a similar result.

CONCLUSION

This study was conducted with the broad intention of enhancing the value of tef based products and investigating its suitability for incorporation into extruded food products. This could have significant implication in Ethiopia and other African countries where tef is widely used. It helps to improve the protein value of tef based products which are consumed by a large Ethiopian population as a staple food and also permits the exploration of the addition to tef to other products to improve their mineral and fiber content. Changing the levels of these ingredients significantly affected color (L*, a* and b*) rehydration ratio and water solubility index. This study ascertained the potential of tef for producing extrusion cooked food products. Promising results were obtained for tef-based product development. Further studies on the effect of enriched tef based extruded products on the general well being and improvement of their nutritional status would help to promote these products. The results would be useful in selecting ingredients for value added food preparations.

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