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Research Article

Process Parameters Optimization for the Manufacture of Extruded Teff-based Gluten Free Snacks

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Abstract: This research study was aimed to develop nutritious and sensorial acceptable teff based expanded product through optimization of extrusion process parameters. The experimental study was performed using response surface methodology face centered central composite design. Teff, maize and decorticated lentil composite flour was extruded through twin screw food extruder at different barrel temperature (120, 140, 160°C), feed moisture content (14, 17, 20%) and blend ratio BR_1 (70T:20M:10L), BR_2 (60T:25M:15L) and BR_3 (50T:30M:20L) at constant screw speed (340 rpm). The physical, functional, textural and sensory characteristics of extrudates were inspected and their responses were examined. Maximum expansion ratio (4.85), maximum water absorption index (7.80), minimum hardness (13.49 N/g) and minimum bulk density (0.108 g/cm^3)were found at 140°C barrel temperature, 14% feed moisture content with blend ratio of 60% Teff, 25% Maize and 15% Lentil (60T:25M:15L). Acceptable extrudates with added vanilla powder additive were significantly ($p<0.05$) better in colour, flavor, crispiness and overall acceptability. The model developed could be used for designing of extrusion process parameters in order to get extrudates with desirable characteristics.

Keywords: Blend ratio, expanded product, extrusion process parameters, gluten-free snacks, process optimization, teff

INTRODUCTION

Extrusion cooking is a process of forcing a material to flow under a different temperature, pressure and feed moisture content through a shaped hole (die) at a predetermined rate to achieve different extruded products. Extrusion technology has led to production of a wide variety of cereal based foods, protein supplements and sausage products. Several products are developed by extrusion i.e., pasta, breakfast cereals, bread crumbs, biscuits, crackers, baby foods, snack foods, confectionery items, texturized vegetable protein, modified starch, pet foods, dried soups and dry beverage mixes (Chang and Ng, 2009). The extruded products which are high in fiber content could be improved in its overall nutritional content and taste by incorporation of protein rich ingredients. Among other materials, incorporation of legume flour has positive impact on levels of proteins and dietary fiber of extruded snacks (Berrios, 2006). In developing countries such as Ethiopia, where many people can hardly afford high protein foods due to their relative expensive costs. There is urgent need for cheaper foods rich in protein for individuals, taking into consideration their age, sex, physical activity and physiological needs. The diet of an average Ethiopian consists of foods that are mostly carbohydrate based. Therefore, there should need for strategic use of inexpensive high protein resources that complement the balanced amino acid profile of the staple diet in order to enhance their nutritive value and overcome nutritional problems.

Teff (*Eragrostisistef* (Zucc) Trotter) is one of the major and indigenous cereal crops in Ethiopia, where it is believed to have originated and has the largest share of area under cereal crop production. This cereal is considered high in nutritional quality, but limited information is available about its usefulness in snack blends formulation and manufacturing. Teff flour is primarily used to make a fermented, sour dough type, flat bread called *Injera*. The crop is also an excellent source of fiber and iron and has high amount of calcium, potassium and other essential minerals. Teff flour blending in all extruded food product can enrich the products with iron and other essential minerals (Melese, 2013). The maize grain contains, on average, about 61.50 to 77.40% starch (dry basis). This high starch quantity provides a good ingredient for the production of expanded extruded product (Zehr *et al*., 1995; Radosavljević, 2002). Lentils (Lens culinaris) are a member of the legume family and have been an

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Table 1: Coded levels of the process parameters

Code	Factor	Low level (-1)	Center point (0)	High level (+1)
A	BT (^{O}C)	120	140	160
B	FMC (%)	14	17	20
C	BR (%)	50T:30M:20L	60T:25M:15L	70T:20M:10L

where, BT: Barrel Temperature; FMC: Feed Moisture Content; BR: Blend Ratio; T: Teff; M: Maize; L: Lentil

important component of the human diet for many centuries. Lentil seeds are rich sources of proteins and have gained recent attention for their many healthy characteristics, including being a low food of glycemic index, nutrient rich and a natural source of phytochemicals and antioxidants (Combe *et al*., 2004; Miller *et al*., 2009). The low levels of phytonutrients like tannins, together with higher protein and iron levels and shorter cooking time than most other pulses (faba bean, pea) make lentils very suitable for human consumption (Savage, 1988). Wheat bran and other fiber-rich cereal ingredients are generally used to increase the fiber content in snacks and breakfast cereal products. However, these ingredients contain gluten, which represents a physiological problem for people who suffer of the celiac disease.

Thus, the present investigation was aimed to commence the development of expanded extrudates rich in protein and dietary fiber from teff-based blends and assess the effect of the extrusion process parameters on the quality of the final product through process optimization of the extrusion process for the developed extrudates.

MATERIALS AND METHODS

The raw materials maize variety, (BH660) was collected from Bako agricultural research center. The teff variety, kuncho with voucher number DZ-Cr-387 and Lentil variety 'Alemaya' in 2012/13 crop production were obtained from Debrezeit Agricultural Research Center (DZARC). Samples were cleaned to remove all foreign matter, broken and immature grains, if any. Lentil was decorticated using decorticator (AB, Alvan Blanch Decorticator, England, 2007). All the grains were ground to get fine flour sieve aperture (710 μm). Then after, composite flour was obtained in desired proportion by mixing in flour mixer. Flour samples were then extruded through twin screw extruder based on the various process parameters and.

Experimental design: The effects of extrusion cooking parameters on teff based extrudates properties were evaluated. Results from preliminary trials were used to select suitable extrusion cooking parameters including screw configuration, die size and to reduce the number of variables in the experimental design. Blended flour was extruded through twin screw food extruder at different barrel temperature (120, 140, 160°C), feed moisture content (14, 17, 20%) and blend ratio BR_1 (70T:20M:10L), BR_2(60T:25M:15L) and BR_3 (50T:30M:20L) at constant screw speed of 340 rpm.

Extrusion cooking parameters: Three important control factors such asbarrel temperature (X_1), Feed moisture content (X2) and Blend ratio(X3) are considered in this study. Other factors are kept at their fixed level. In order to show the effect of factors and build empirical model for each response variables such as WAI,WSI, expansion ratio and hardness, experiments were conducted based on Central Composite Design (CCD) according to the method described by Montgomery *et al*. (2003). The CCD is capable of fitting second order polynomial and is preferable if curvature is assumed to be present in the system. Temperature of the barrel was measured by a thermocouple inserted along the length of the extruder. The temperature of zone 3, which is located just before the die, was an independent variable in this thesis work and it was varied at 120, 140 and 160°C and the screw speed were 340 rpm which was constant and the blend ratio of the raw materials were adjusted to be 70:20:10(BR_1), 60:25:15(BR_2) and 50:30:20(BR_3); respectively (Table 1). The dough was prepared in mixer for each batch operation to moisture content of 14, 17 and 20%, respectively and the amount of water needed to bring the samples to the required moisture content was calculated and added slowly while being stirred in a mixer. After mixing, the contents in the mixer were sealed in a polyethylene bag and the moisture was equilibrated overnight in at 4°C in a refrigerator. The blend mixtures were allowed to warm to room temperature before extrusion the next day. After preliminary trials, the extrusion variables were adjusted as described below. Once conditions for extrusion temperatures and moisture contents were chosen, a central composite design was conducted with the variables of extrusion temperature, moisture and blend ratio. Extruded cereal strands were cut manually into lengths of 5 cm and cooled in open air. The final product was sealed in plastic bags until needed for analysis.

Extrudates physical and functional properties:

Expansion ratio (ER): The extrudates produced were dried at 105°C for 3 min before further analyses. The expansion ratio (diametric), ER is defined as the ratio of the diameter of the extrudates to the diameter of the die hole according to the method described by Fan *et al*. (1996).The extrudate expansion ratio was calculated as:

$$\text{Expansion ratio} = \frac{Diameter\ of\ the\ extrudates}{Diameter\ of\ die}$$

Specific length (cm/g): The specific length, Lsp (cm/g) of the extrudates (Fig. 1) was calculated as the ratio of

Fig. 1: Extruded Teff-based snack products

the extrudate based on the procedure expressed by Fan *et al*. (1996):

$$\text{Specific length} = \frac{Length\ of\ extrudates}{Weight\ of\ extrudates}$$

Water absorption index (%): Water absorption index of the flour, formulated flour and extrudate was determined according to Anderson *et al*. (1969):

$$= \frac{Weight\ of\ sedment}{Weight\ of\ dry\ solids} * 100$$

Water solubility index, WAI (%): The supernatant preserved from WAI measurement was evaporated at 96^{o}C temperature for overnight. The WSI was calculated as:

$$= \frac{Weight\ of\ dissolved\ solids\ in\ supernatant}{Weight\ of\ dry\ solids} * 100$$

Bulk density (g/cm^3): Bulk density of the extrudates was calculated as the ratio of weight of extrudates to the volume of extrudates (Mason and Hoseney, 1986) assuming that the product has a cylindrical shape using the following equation:

$$\text{Bulk density} = \frac{Weight\ of\ extrudates}{Volume\ of\ extrudates}$$

Extrudates hardness (N/g): A universal texture analyzer (Model-TA Plus, England, 2005) was used in compression mode to record the required force to break extruded products. The extruded sample (5 cm) was placed on the specimen holder platform transversally over a metal sheet support (1 cm thick) and operated in the compression mode with a sharp testing blade (3 mm thick, 6.94 mm wide). The texturometer head moved the probe down at a rate of 80 mm/min until it broke the extrudates.

Sensory quality attributes evaluation: The sensory assessments were conducted by 27 trained panelists, who were selected from the Ethiopian Public Health Institute (EPHI) staff.

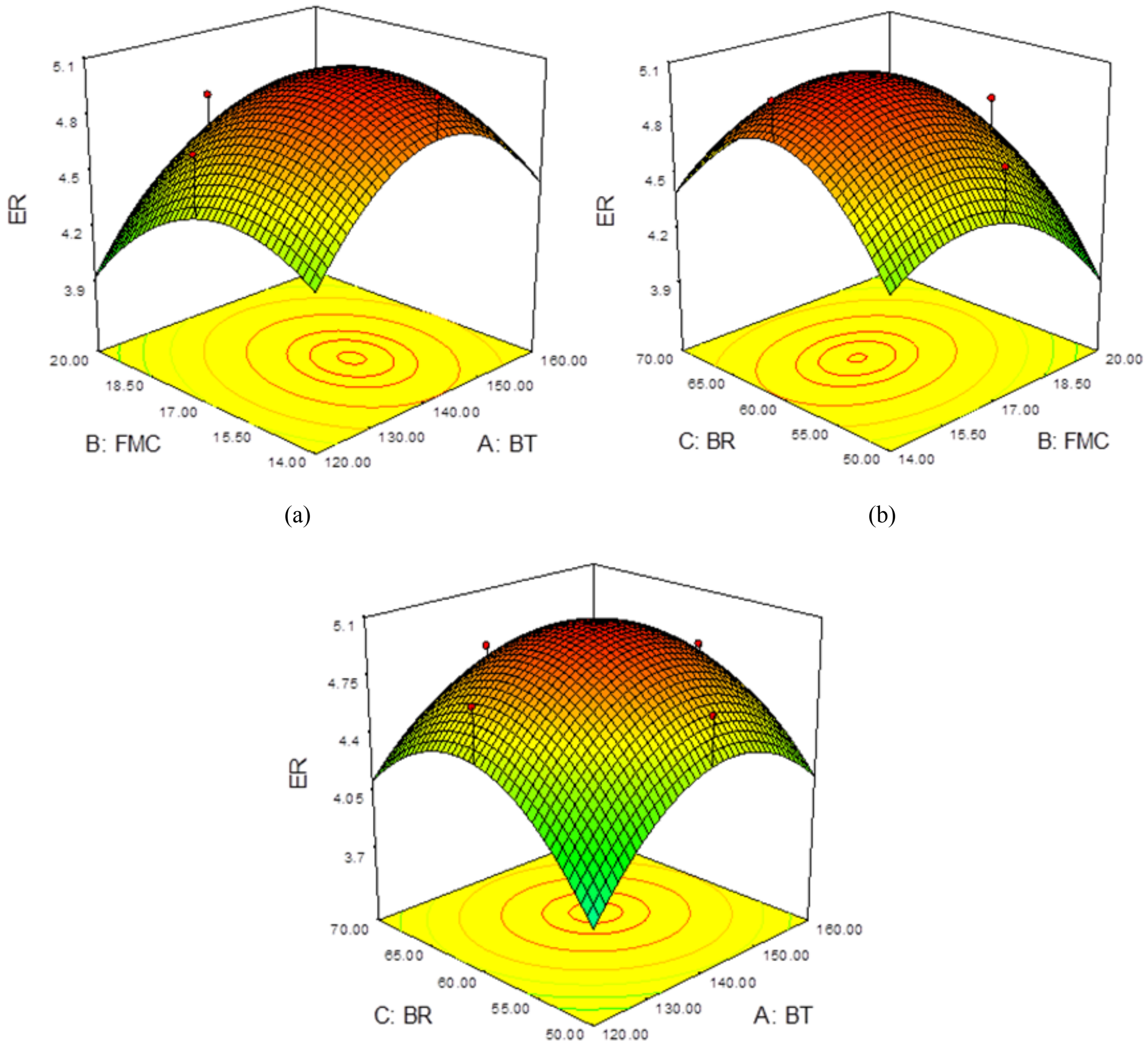
Responses: The influence of independent variables (extrusion parameters and material ratios) was analyzed using RSM design expert stat-Ease software version 7.0 to determine the optimum extrusion parameters. To accomplish the objective of the study determining which factor level takes the response variable to a maximum or a minimum was important. Therefore, a more complex model should be proposed to take into consideration the plane curvature formed by the factors and the response variable. In this case, it is possible to work with a central composite design to find ‘optimum values’ for the factors selected.

RESULTS AND DISCUSSION

Expansion of the extrudates: The maximum expansion ratio 4.85 was obtained at coded point (0, 1, 0). With increasing the barrel temperature, the expansion ratio was increased till maximum value was achieved and slightly decreased with further increasing in temperature beyond its optimum value. As temperature increased from 120°C to 140°C, expansion ratio was increased from 3.04 to 4.85 and decreased to slightlyat and beyond 160°C. Extrudate expansion is a complex phenomenon which occurs usually during high temperature and low moisture extrusion cooking. It is the consequence of several events such as phase transition, nucleation, extrudate swell, bubble growth and bubble collapse with bubble dynamics dominantly contributing to the expansion phenomenon (Chang, 1992).

It has been observed that suitable feed moisture depends on not only the extrusion condition, but also the feed composition, which can affect the water binding capacity (Park *et al*., 1993). It might be seen from the Fig. 2, that increase in lentil proportion in feed composition resulted in decrease in expansion ratio, expansion ratio of the extrudate which is in agreement with the work done by Fan *et al*. (1996) and Chessari and Sellahewa (2001). The interaction effect of process parameters showed that the highest ER was observed at 14% fed moisture content, 140°C barrel temperature and 60:25:15 blend ratio.

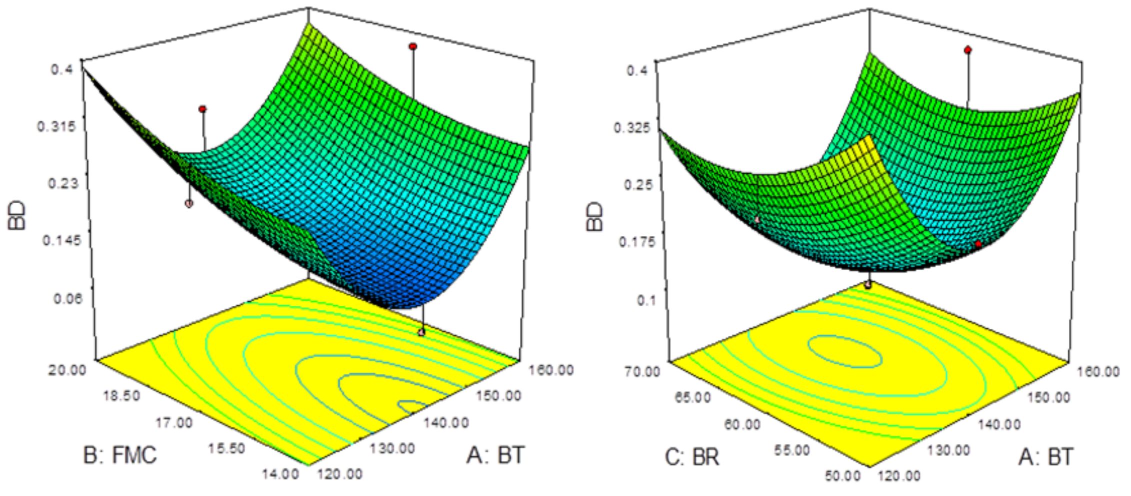
Bulk density of the extrudates: The bulk density of extrudates ranges from 0.108 to 0.389 g/cm^3. The high dependence of bulk density and expansion on feed moisture would reflect its influence on elasticity characteristics of the starch based material. Increased feed moisture content during extrusion may reduce the elasticity of the material through plasticization of the melt, resulting in reduced SME and decreasing the expansion and increasing the density of extrudate. Bulk density was low at BR$_2$ blend ratio, 140°C and 14% feed moisture content. Bulk density increased with increased in moisture content of extrudates produced (Fig. 3). Similar results were reported by Patil *et al*. (1990). According to Meng *et al*. (2010), melting temperature plays an important role in changing the rheological properties of the extruded melts, which in



(a) (b)

(c)

Fig. 2: Response surface plots for expansion ratio as a function of; (a): feed moisture content and barrel temperature; (b): blend ratio and feed moisture content; (c): blend ratio and barrel temperature keeping all other processing parameters constant



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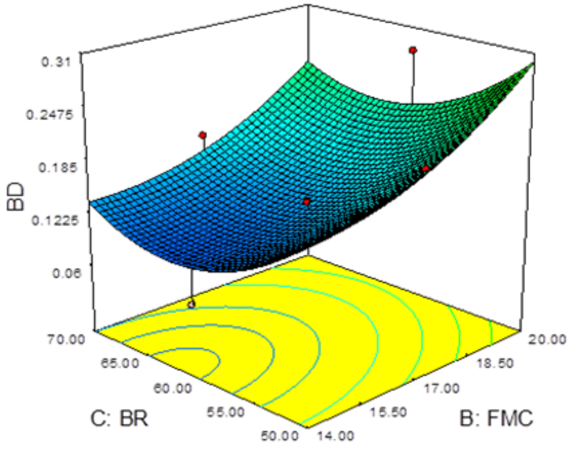

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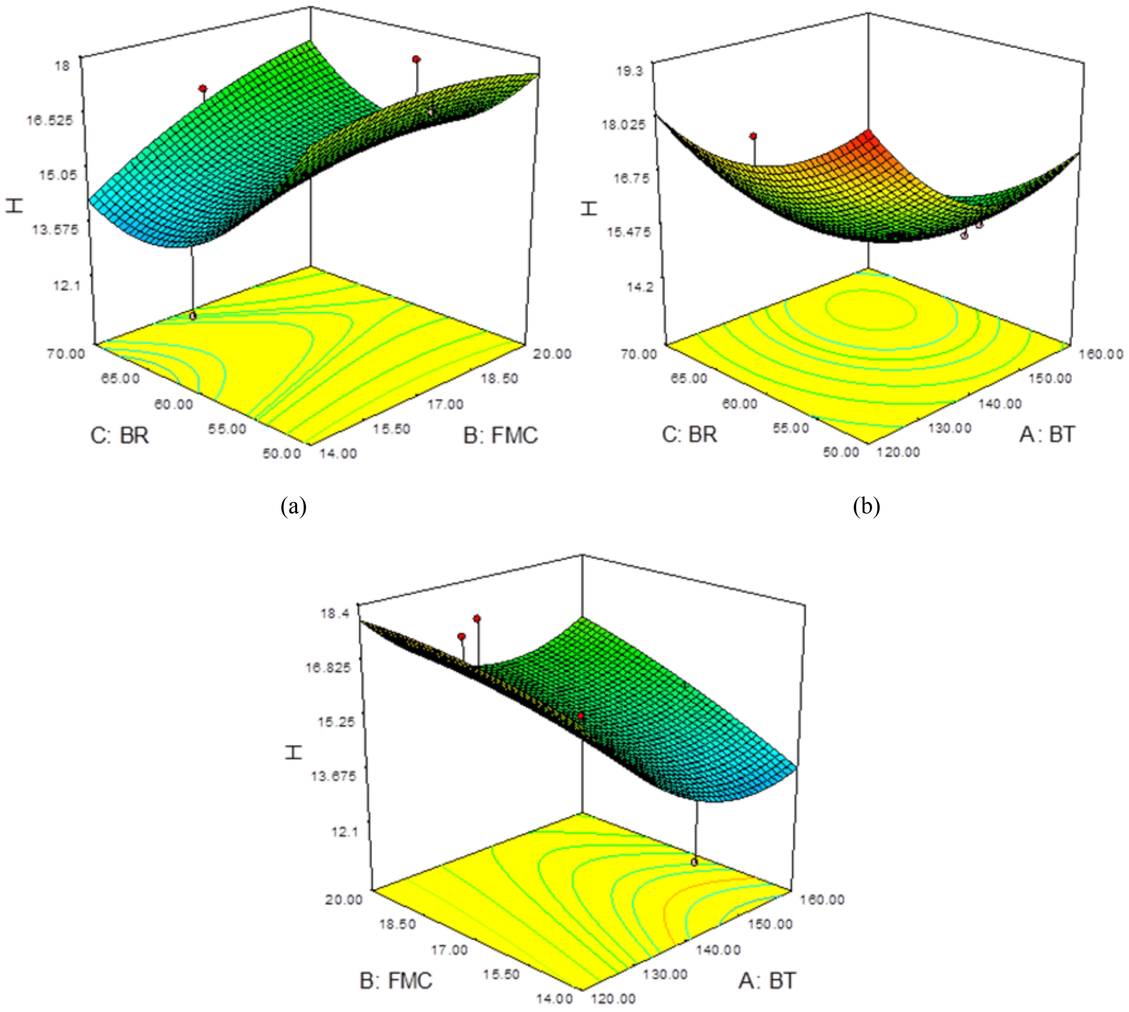
Fig. 3: Response surface plots for bulk density as functions of; (a): feed moisture content and barrel temperature; (b): blend ratio and barrel temperature; (c): blend ratio and feed moisture content keeping all other processing parameters constant



(a)

(b)

(c)

Fig. 4: Response surface plots for hardness as function of; (a): blend ratio and feed moisture content; (b): blend ratio and barrel temperature; (c): feed moisture content and barrel temperature keeping other processing parameters constant

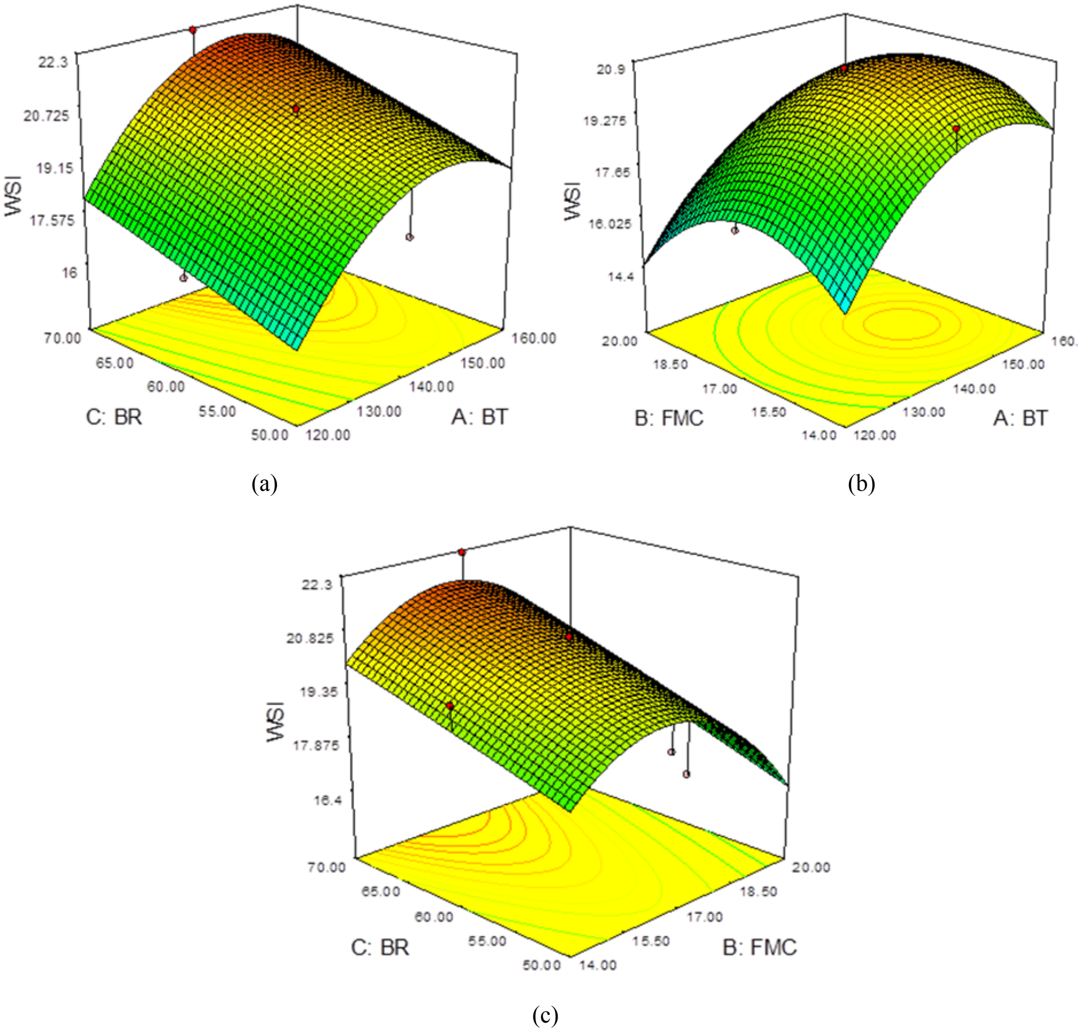
turn affect the degree of expansion. The bulk density also describes the degree of expansion undergone by the melt as it exits the extruder (Meng *et al*., 2010). Regression analyses indicate that bulk density decreases with decrease in moisture.

Hardness of the extrudates: The results showed a trend increase expansion, decreasing density and decreasing breaking force with barrel temperature from 120-140°C. The effects of extrusion conditions on extrudate hardness can also found in the 3D surface plot (Fig. 4).

Previous studies have also reported that the hardness of extrudate increases as the feed moisture content increases (Badrie and Mellowes, 1991). This might be due to the reduced expansion caused by the increase in moisture content (Liu *et al*., 2000). The increase in moisture elevates the density of the extruded snack. Denser products exhibit more resistance to fracturing. The extrusion temperature seems to have the opposite effect on the hardness of samples than moisture had. The more expanded product becomes crispier, which results in a softer texture. The hardness of the extrudates increased with the feed rate. The extruded dough in high feed rates is subjected to lower shear forces due to lower residence time, which cause less degradation and therefore a lower degree of cooking. In this way, the resulting products generate a more rigid structure.

Increasing the fiber component in the formulation decreased extrudate diameter, with little to no effect on longitudinal expansion of extrudates (Lue *et al*., 1994). Decreases in the net volumetric expansion results in a more compact extrudate texture and increases breaking strength.

Water Absorption Index (WAI): The water absorption index is the amount of water absorbed by starch and can be used as an index of gelatinization (Anderson *et al*., 1970). WAI depends on the



(a) (b)

(c)

Fig. 5: Response surface plots for water solubility as function of; (a): blend ratio and barrel temperature; (b): feed moisture content and barrel temperature; (c): blend ratio and feed moisture keeping other processing parameters constant

availability of hydrophilic groups that bind water molecules. Value of WAI of extrudate at (0, 0, 1) was 7.278 and extrudate at (0,-1, 0) showed highest WAI 7.89 than other extrudates. The water absorption index of the extrudates increased with increase of lentil flours in the blends (Fig. 5). The gelatinization is the conversion of raw starch into a cooked and digestible material by the application of water and heat. And also, gelatinization is one of the important effects that extrusion has on the starch component of foods. Our finding showed that the maximum WAI value was higher in the extruded formula (0,-1, 0) and it may be related to its starch content.

Increases in moisture content reduce the water absorption index. Moisture content, acting as a plasticizer during extrusion cooking, reduces the degradation of starch granules, this result in an increased capacity for water absorption (Hagenimana *et al.*, 2006). Water absorption index was higher for lower temperature as shown in response surface plot (Fig. 5a and b).

Water solubility index: Water Solubility Index (WSI), often used as an indicator of degradation of molecular components. WSI measures the amount of soluble components released from the protein and other molecules after extrusion. High WSI is an in vitro indicator of good digestibility (Guha *et al.*, 1997). The water solubility index of the extruded formulas increased when lentil flour was part of combination with ratio more than 10%. In this study, the higher and lower values of WSI of the extrudates were 22.21 at (0, 0, 1) and 13.17 at (-1, 1, -1).

The high mechanical shear caused breakdown of macromolecules to small molecules with higher solubility. The increase in WSI with increasing temperature was consistent with the results reported by other researchers (Dogan and Karwe, 2003; Suksomboon *et al.*, 2011) reported that increasing feed moisture content progressively decreased the WSI of extruded snack from rice and soya flour blend. It was observed that WSI increased initially with the increase in moisture content (Fig. 5a), which may be due to proper gelatinization and lateral expansion of the starch, whereas further decrease with increase in moisture content may be attributed to the lateral expansion because of plasticization of melt (Ding *et al.*, 2005).

SENSORY QUALITY EVALUATION OF EXTRUDED TEFF-BASED GLUTEEN FREE SNACKS

Quality characteristics of extruded snacks that are critical for consumer acceptance are mainly the sensory characteristics. Sensory evaluation is important in product development, product improvement and optimization. The sensory attributes of color, appearance, flavor, crispiness and over all acceptability of extrudates were evaluated by nine trained panel members. The sensory scores for most of the products had a mean value greater than 6.54 indicating that they were very liked by the panelists.

Comparison among the averages of sensory attributes (colour, appearance, flavour, crispiness and overall acceptability) of six without adding vanilla powder and six with addede vanilla powder extruded products showed that, the addition of vanilla enhance all sensory attributes. As shown in Table 2, it was observed that blend ratio, barrel temperature and feed moisture content had significantly ($p<0.05$) affect all the characteristics of the sensory attributes of the extrudates. Blend ratio had an impact on the crispness of the extruded snacks. At 60T:25M:15L blend ratio extrudates had higher scores of crispness, followed by (70T:20M:10L) extrudates blend ratio. In contrary, feed moisture content had a depressing effect on the crispness of most of the samples. This fact may be recognized to the reduction of expansion of extruded dough, which results when higher feed moisture is employed. As it is presented in Table 2, the mean flavour value of the extrudates was ranged from 6.03 to 7.66. There was significant difference between the flavour scores of extrudates at which it was produced at different extrusion parameters and vanilla addition. The

Table 2: Sensory quality evaluations of extrudates (Teff-based gluteen free snacks)

Independent process parameters					Sensory attributes				
S/N	A	B	C		Color	Appearance	Flavor	Crispiness	OAA
1	0	1	0	X	7.03 ± 0.08^{i}	6.93 ± 0.16^{g}	6.09 ± 1.22^{k}	5.70 ± 0.95^{ij}	6.70 ± 0.81^{h}
2	0	1	0	Y	7.18 ± 0.21^{e}	6.94 ± 0.21^{f}	6.19 ± 0.76^{l}	5.70 ± 0.64^{ij}	6.77 ± 0.79^{g}
3	0	0	-1	X	6.66 ± 0.07^{l}	6.78 ± 0.33^{i}	6.73 ± 0.04^{h}	7.21 ± 0.1^{ce}	7.05 ± 0.02^{f}
4	0	0	-1	Y	7.33 ± 0.34^{d}	6.75 ± 0.19^{j}	7.14 ± 0.32^{e}	7.21 ± 0.71^{ce}	7.13 ± 0.14^{e}
5	1	0	0	X	7.11 ± 0.01^{g}	6.79 ± 0.95^{h}	7.19 ± 0.08^{d}	6.78 ± 0.08^{h}	7.04 ± 0.74^{f}
6	1	0	0	Y	8.04 ± 0.43^{a}	7.55 ± 0.88^{c}	7.55 ± 0.61^{b}	6.14 ± 0.43^{g}	7.18 ± 0.33^{e}
7	0	0	0	X	7.08 ± 0.22^{h}	7.74 ± 0.14^{b}	6.80 ± 0.18^{g}	7.19 ± 0.32^{df}	7.25 ± 0.88^{d}
8	0	0	0	Y	7.12 ± 0.54^{f}	7.76 ± 0.33^{a}	7.36 ± 0.29^{c}	7.19 ± 0.06^{df}	7.30 ± 0.26^{c}
9	1	-1	1	X	6.68 ± 0.65^{k}	6.54 ± 0.45^{l}	6.03 ± 0.74^{l}	5.44 ± 0.11^{lk}	5.60 ± 0.59^{j}
10	1	-1	1	Y	6.70 ± 0.18^{j}	6.59 ± 0.21^{k}	6.11 ± 0.09^{j}	5.44 ± 0.13^{lk}	5.63 ± 0.04^{l}
11	0	-1	0	X	7.66 ± 0.55^{c}	7.09 ± 0.03^{e}	7.13 ± 0.02^{f}	8.33 ± 0.41^{ba}	8.21 ± 0.17^{ba}
12	0	-1	0	Y	7.81 ± 0.43^{b}	7.15 ± 0.32^{d}	7.66 ± 0.05^{a}	8.34 ± 0.64^{ba}	8.56 ± 0.21^{ba}

$^{a-J}$All values are means of triplicate ±SD, values within the same column with different letters are significantly different ($p<0.05$); where, X = without vanilla and Y = with vanilla; where, OAA-Overall acceptability; Coded levels of parameters (A, B, C); Factors (BT, FMC and BR); where, A-BT (°C) /Barrel temperatures; B-FMC (%) /Feed moisture content; C-BR (%) /Blend ratio lowest mean colour score (6.03) was obtained at 60T:25M:15L blend ratio at 17% feed moisture content and 120°C barrel temperature; respectively. Mean value of sensory evaluation extruded product at 140°C barrel temperature, 14% feed moisture content and 60T:25M:15L blend ratios were significantly better in colour (8.04±0.43), flavour (7.66±0.05), crispiness (8.34±0.64) and overall acceptability (8.56±0.21) than others (Table 2). The results indicated that BR_2 that contain (60:25:15) blend ratio at 140°C barrel temperature and 14% feed moisture content with vanilla flavour could be used to produce quality extruded product with acceptable sensory properties.

CONCLUSION

This research was complemented with the comprehensive objective of enhancing the importance of gluten free teff based product and scrutinizing its suitability for integration into extruded food products with various blending ratios. This could have significant implication in Ethiopia and other African countries where teff is widely used. Thus, the optimization of process parameters for the manufacturing of Gluten Free Extruded Teff-based snack revealed that extrusion cooking at 140°C barrel temperature, 14% feed moisture content with 60% teff, 25% maize and 15% lentil in the feed ratio produced enhanced quality extrudates with maximum expansion ratio (4.85), minimum bulk density (0.11 g/cm^3) and hardness (13.49 N/g). Furthermore, acceptable sensory evaluations were obtained among various products; and additive with vanilla flavor were significantly better in colour, flavor, crispiness and overall acceptability. Feed moisture content and barrel temperature were found to be the most significant process parameters that affected the expansion ratio, hardness and bulk density of the extrudates.

Protein-energu malnutrtion is still the major nutrtional disorder among preschool chidren of the developneng country. This can be reduced via proper feeding of teff weaning blends of extudates. Thus, the processed extrudates can help to improve the nutritional value specifically protein, mineral and fiber compositions which in turn can play in reducing protein-energy malnutrition problem in the African region.

Finally, the research finding ascertained the prospective use of teff for manufacturing of extruded gluten free value added food products (Gluten free teff and teff based breakfast cereal snacks and many more) which might bring export earnings from teff based products in the near future. Ethiopia can fetch revenue by processing of teff flour and renovating into various value added products which can turn the potential into reality via research and development, technology transfer and establishment of manufacturing industries to produce products and thereby share the World huge gluten free value added products market in the upcoming Growth and Transformation Plans (GTP's) periods of the country. Through research and development process teff and teff based breakfast cereal snacks can be used in augmenting the National food fortification program of Ethiopia.

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REFERENCES

Anderson, R.A., H.F. Conway, V.F. Pfeifer and E.L. Griffin, 1969. Gelatinization of corn grits by roll and extrusion cooking. Cereal Sci. Today, 14: 4-12.

Anderson, R.A., H.F. Conway and A.J. Peplinski, 1970. Gelatinization of corn grits by roll cooking, extrusion cooking and steaming. Starch- Stärke, 22: 130-135.

Badrie, N. and W.A. Mellowes, 1991. Texture and microstructure of cassava flour extrudate. J. Food Sci., 56: 1319-1322.

Berrios, J.J., 2006. Extrusion cooking of legumes: Dry bean flours. Encycl. Agric. Food Biol. Eng., 1: 1-8.

Chang, C.N., 1992. Study of the mechanism of starchy polymer extrudate expansion. D.Phil Thesis, The State University of New Jersey, Rutgers, New Brunswick, N.J., pp: 291.

Chang, Y.H. and P.K.W. Ng, 2009. Effects of extrusion process variables on extractable ginsenosides in wheat-ginseng extrudates. J. Agr. Food Chem., 57: 2356-2362.

Chessari, C.J. and J.N. Sellahewa, 2001. Effective Control Processing. In: Gay, R. (Ed.), Extrusion Cooking: Technologies and Application. CRC Press, United States of America, Boca Raton, ISBN: 978-084-9312-07-6, pp: 83-107.

Combe, E., T. Pirman, J. Stekar, M.L. Houlier and P.P. Mirand, 2004. Differential effect of lentil feeding on proteosynthesis rates in the large intestine, liver and muscle of rats. J. Nutr. Biochem., 15(1): 12-17.

Ding, Q.B., P. Ainsworth, G. Tucker and H. Marson, 2005. The effect of extrusion conditions on the physicochemical properties and sensory characteristics of rice-based expanded snacks. J. Food Eng., 66: 283-289.

Dogan, H. and M.V. Karwe, 2003. Physicochemical properties of quinoa extrudates. Food Sci. Technol. Int., 9(2): 101-114.

Fan, J., J.R. Mitchell and J.M.V. Blanshard, 1996. The effect of sugars on the extrusion of maize grits: I. The role of the glass transition in determining product density and shape. Int. J. Food Sci. Tech., 31: 55-65.

Guha, M., S.Z. Ali and S. Bhattacharya, 1997. Twin-screw extrusion of rice flour without a die: Effect of barrel temperature and screw speed on extrusion and extrudate characteristics. J. Food Eng., 32: 251-267.

Hagenimana, A., X. Ding and T. Fang, 2006. Evaluation of rice flour modified by extrusion cooking. J. Cereal. Sci., 43: 38-46.

Liu, Y., F. Hsieh, H. Heymann and H.E. Huff, 2000. Effect of process conditions on the physical and sensory properties of extruded oat corn puff. J. Food Sci., 65: 1253-1259.

Lue, S., F. Hsieh and H.E. Huff, 1994. Modeling of twin-screw extrusion-cooking of corn meal and sugar-beet fiber mixtures. J. Food Eng., 21: 263-289.

Mason, W.R. and R.C. Hoseney, 1986. Factors affecting the viscosity of extrusion-cooked wheat starch. Cereal Chem., 63: 436-441.

Melese, T., 2013. Nutritional status of Ethiopian weaning and complementary foods: A review. Open Access. Sci. Rep., 2(2): 1-9.

Meng, X., D. Threinen, M. Hansen and D. Driedger, 2010. Effects of extrusion conditions on system parameters and physical properties of chickpea flour-based snack. Food Res. Int., 43: 650-658.

Miller, C.K., M.D. Gutshcall and D.C. Mitchell, 2009. Change in food choices following a glycemic load intervention in adults with type 2 diabetes: Research and professional brief. J. Am. Diet. Assoc., 109(2): 319-324.

Montgomery, J.L., F.C. Parrish Jr., D.G. Olson, J.S. Dickson and S. Niebuhr, 2003. Storage and packaging effects on sensory and color characteristics of ground beef. Meat Sci., 64(4): 357-363.

Park, J., K.S. Rhee, B.K. Kim and K.C. Rhee, 1993. Single-screw extrusion of defatted soy flour, corn starch and raw beef blends. J. Food Sci., 58: 9-19.

Patil, R.T., D.S. Singh and R.E. Tribelhorn, 1990. Effect of processing conditions on extrusion cooking of soy rice blend with a dry extrusion cooker. J. Food Sci. Technol., 27: 376-378.

Radosavljević, M., 2002. Cornstarch as an Important Renewable Resource. Maize Research Institute, ZemunPolje, Belgrade-Zemun, Yugoslavia, pp: 23-31.

Savage, G.P., 1988. The composition and nutritive value of lentils. J. Nutr. Abs. Rev., 58: 319-343.

Suksomboon, A., K. Limroongreungrat, A. Sangnark, K. Thititumjariya and A. Noomhorm, 2011. Effect of extrusion conditions on the physicochemical properties of a snack made from purple rice (Hom Nil) and soybean flour blend. Int. J. Food Sci. Tech., 46: 201-208.

Zehr, B.E., S.R. Eckhoff, S.K. Singh and P.L. Keeling, 1995. Comparison of wet milling properties among maize inbred lines and their hybrids. Cereal Chem., 72: 491-497.