Evaluation of Processing Conditions for Lentil and Corn Blend Extrudate

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Abstract. An expanded food product was obtained from lentil-corn flour mixture by extrusion cooking. The lentil flour addition was maintained at 10%, 30% and 50% mixed with cereal or (corn) flour which was maintained at 50%, 70% and 90%. Operating conditions were cooking temperature; blend ratio and moisture contents of the feed mixture. Physicochemical properties of the extruded product were investigated.

The proportions of lentil and corn were selected using a unique 17-run, three-factor, and three-level using response surface methodology. Response variables were physical properties (specific length, degree of expansion and bulk density) and functional properties (water absorption index, water solubility index and water hydration capacity) and then sensory quality of the product.

It was demonstrated that lentil has good potential for making extruded products rich in protein and fiber. The best model which gives a protein rich extruded product with desirable physical and functional attributes were 47.8% lentil flour, 52.2% corn flour (db) processed at 15.82% moisture content and 181.97 °C temperature. The product was fully expanded and well cooked with almost uniform in sizes and shapes at these optimum conditions. Hence, the processing factors must be at its optimal values to achieve high extrudate quality and consistence.

Keywords: Extrusion · Corn · Lentil · Physicochemical properties · Response surface methodology

1 Introduction

Cereal grains are staple foods worldwide. They are used for production of different classes of foods; these include breakfast cereals such as corn flakes, breads, and pastries, brewing of both alcoholic and non-alcoholic drinks. In different cultures and societies staple foods, are also produced for use as accompaniments for soups, gravies and stews and they supply the basic energy requirement of the consumers. They are also used for the production of different snack foods which are eaten to prevent hunger before main meals or just (as enjoyment) for the fun of eating them, but they are deficient in some essential amino acids like lysine. To produce nutritious products,

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cereals are usually fortified with pulse proteins (lysine). Maize is the most important cereal crop both in area coverage and production in Ethiopia [1]. In nutritional terms, maize grain is mainly useful as a source of carbohydrate and energy. In recent years; the use of maize in Ethiopia has increased at a more rapid rate than other cereals. It is being used for human consumption, animal feed and as a source of raw materials in various industries. Lentil (*Lens culinaris Medic*.) on the other hand is an important crop belonging to the *Leguminosae* family used predominantly as a human food source. It is one of the prominent sources of plant proteins, having a protein content of 21–31% (w/w) [2]. Storage proteins of lentils consist of about 80% (w/w) of total seed proteins [3]. Legumes are important sources of nutrition in developing countries and in vegetarian diets. Lentils are leguminous crops that are excellent sources of protein, carbohydrate, fiber, minerals and nutrients. Lentils are produced in the high altitude areas of Ethiopia. National average lentil yields of Ethiopia since 2002 have been 509 and 876 (2008) kilograms per hectare. Ethiopia is the 6^{th} lentil producing country in the world. Chickpeas, a variety of beans and their mixtures, peas, cowpeas, sorghum and legume blends has been extruded, but there are very few studies on lentils (*lens culinaris*).

Extrusion cooking technologies are used to manufacture many forms of food stuff from cereals and other ingredients. The range of products includes breakfast cereals, snack foods, pregels (modified starches used in food products), breading crumbs and animal feeds. Ingredients, such as maize flour and grits, wheat flour and other food components, are passed through an extrusion cooker under pressure, mechanical shearing stresses and elevated temperature, and expand rapidly as they are forced through the outlet die [4]. Extrusion cooking of cereal flours into a wide variety of products is well documented, but extrusion of starchy legumes has been studied to a lesser extent. Extrusion cooking is used to texturize starch and protein based materials. Extruders minimize the operating costs and higher productivity than other cooking process, combining energy efficiency and versatility [5]. The evolution of snack foods has been classified as the first, second, and third generation snacks. Third-generation snacks are indirectly, expanded snacks made by extrusion processing followed by additional puffing steps by deep-fat frying or hot air stream to achieve the final texture [6].

Several researchers have reported that inclusion of lentil in the daily diet has many beneficial effects in controlling and preventing various metabolic diseases, such as diabetes mellitus and coronary heart disease [6]. In addition, pulses have been considered to be appropriate for weight management; they have low fat content and are rich in protein, fiber and resistant starch, which lead to delayed gastric emptying, resulting in an earlier sense of fullness during a meal, reduced hunger, and increased satiety after a meal [7].

In developing countries like Ethiopia, where many people can hardly afford high protein foods due to their 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 is the 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 malnutrition problem. This research intends to show the possibility of enriching the starchy foods with legumes.

The ultimate goal of this work is to develop Ready-to-Eat snack food product from a blend of lentil-cornmeal bled by using a Twin screw extruder and optimize extrusion conditions or parameters for the extrudate. Additionally, the study describes changes in the physicochemical properties of the product with parameters of moisture content of feed, barrel temperature and screw speed of the extruder and functional properties of the products such as water absorption index (*WAI*), water holding/hydration capacity (*WHC*), water solubility index (*WSI*) and sensory as well as textural analysis.

2 Materials and Methods

Red lentil (*Lens culinaris*), Alemaya variety were obtained from Debre Zeit Agricultural Research Center (DZARC) and BH-660 maize variety was taken from Bako area. Red lentil type was selected due to its relatively higher yield in the farm and white maize due to its high yield and area coverage of farming.

Based on the preliminary proximate composition and physicochemical studies, three blends of flours A, B and C were developed. The three different flour mixture were prepared in a ribbon blender (Model AB, Alvan blanch Type, England) for 20 min.

After blending, the mixture was packed in plastic bags and stored at 4 ± 1 °C for further use. The moisture content of each blend was adjusted to 13, 16, and 19% (on wet basis) directly in the extruder before extrusion processing using a calibrated, proportioning pump (water injection pump). This approach was used because the lentil and corn flour blend became sticky and difficult to feed if adjusted to 13, 16, and 19% moisture prior to extrusion. The ratio used for the combination of the flours for products was arrived at using the material balance calculations.

The flour mixture was then subjected to extrusion test at all combinations of the operating parameters (feed moisture and processing temperature) (Table 1).

Table 1. The formulated blends of flours A, B and C; barrel temperature and feed moisture content.

Factor/variable	Coded levels		
	−1	0	+1
BT (^{o}C)	160	180	200
FMC (%)	13	16	19
BR % (g/100 g)	10:90	30:70	50:50

Where BT - barrel temperature; FMC - feed moisture content; BR - lentil: corn blending ratio

The raw and extruded samples were milled with laboratory miller and proximate analysis (in Duplicates) was performed on each sample according to [8] procedures for proximate analysis. Proximate composition of both flours was reported on dry mass basis. The software, Design-Expert 7, Response surface method, Box-Behnken Design with one-way ANOVA (analysis of variance) were used for comparison of means [15]. Significance was accepted at 0.05 level of probability ($p < 0.05$). The extrusion variables studied was feed moisture content, barrel temperature and legume/cereal blend ratio. Treatments were done in replicate (Table 2).

Table 2. Experimental set up with feed flow rate of 51 g/min at the working atmospheric Po of 45 bars.

Pattern	Runs	Barrel Temp (°C)	Blend ratio (% lentil)	Moisture content (%)	Liquid-flow rate or stroke (%)
+−0	1	200	10	16	9.22
++0	2	200	50	16	9.20
0−−	3	180	10	13	9.00
0−+	4	180	10	19	9.68
0+−	5	180	50	13	9.05
−0−	6	160	30	13	9.30
−+0	7	160	50	16	8.58
−−0	8	160	10	16	8.47
000	9	180	30	16	9.65
−0+	10	160	30	19	10.3
000	11	180	30	16	11.2
+0+	12	200	30	19	10.7
000	13	180	30	16	8.90
0++	14	180	50	19	9.17
+0−	15	200	30	13	9.30
000	16	180	30	16	9.68
000	17	180	30	16	9.80

The samples were extruded based on the above experimental setup and steady state is reached when there is no visible drift in torque and dies pressure [9]. The extrudate were manually cut to a uniform length of 4 cm to calculate some physical properties. The extruded products were placed on a table and allowed to cool for 30 min at room temperature for the measurement of weight and diameter [10].

Physical properties (specific length, degree of expansion and bulk density) and Functional Properties (water absorption index (WAI), water solubility index (WAI) and water hydration capacity (WHC)) and sensory evaluation of the product has been carried out.

3 Results and Dıscussıon

3.1 Chemical Composition of Raw Materials and the Extrudate

The chemical composition of corn and dehulled lentil flour used in this study is presented in (Table 3) below. The crude protein content of the corn was 7.88%, which is the lowest when compared with other cereals, whereas crude protein content of lentil was 17%.

Table 3. Proximate composition of raw corn and dehulled lentil flours.

Component (%)	Corn*	Lentil*
Moisture (%db)	1.78 ± *0.06*	1.40 ± 0.06
Protein (N * 6.25)	*7.88* ± *0.13*	17.00 ± *0.57*
Crude fat	*4.56* ± *0.44*	*1.15* ± *0.08*
Crude fiber	*2.14* ± *0.40*	*2.65* ± *0.40*
Total ash	1.40 ± *0.28*	2.38 ± *0.56*
Total carbohydrate**	82.24 ± 0.55	75.42 ± 0.36
Energy (Kcal/100 gm)	416.52 ± 0.08	380.03 ± 0.02

In extrusion of cereal flour and starch-based products, the qualities of the raw material such as the composition of starch, protein, lipid and fiber dictates that product quality attributes, among others are the expansion and functional properties [5].

As presented in (Table 4), raw blends of lentil and corn flour were significantly ($p < 0.05$) higher in protein than corn, fat and carbohydrate content than lentil alone. The same could be said with regard to ash and crude fiber contents. The increase in nutrients content of blend with legume over the blend with corn could be because of the balancing of the nutrients among the cereals and legumes. The carbohydrate content decreased along the increase in the legume content, in the blend ratio. The decrease in carbohydrate content although appears to be mostly significant, it could be because of increased solubility of carbohydrates due to the addition of legumes were expected to enrich protein and mineral content in the final snack product.

In (Table 5), below the mixture of lentil and corn after extrusion contained a better content of crude protein (as an example protein content of 12.36% at processing condition of 50:50 blend ratio at 160 °C barrel temperature and 16% feed moisture content) than the mixture of corn and lentil before extrusion (11.94% for 50:50 blend ratio). Corn has the highest total carbohydrate 82.24% (g/100 g) than lentil which contained 75.42% (g/100 g). Generally, the mixture has the higher total carbohydrate than lentil alone. Crude fiber (2.14%) and total ash (1.40%) of corn were lower than crude fiber (2.65%) and total ash (2.38%) of lentil. Crude fiber (2.14%) of corn before extrusion were greater than crude fiber (1.86%) after extrusion of the mixture and crude fat (1.15%) of lentil before extrusion is lower than crude fat (1.31%) after extrusion as seen at 50:50 blend ratio, 160 °C barrel temperature and 16% moisture content processing condition as an example. The value of extrudate total ash increases as blend

Table 4. Proximate composition and mineral contents of lentil and corn raw flour blends.

Component (%db)	Raw blends (n = 3)		
	10:90(LF:MF)*	30:70(LF:MF)*	50:50(LF:MF)*
Moisture	1.74 ± 0.081	1.66 ± 0.062	1.60 ± 0.13
Protein (N × 6.25)	8.80 ± 0.23	10.62 ± 0.38	11.94 ± 0.03
Crude fat	4.22 ± 0.50	3.54 ± 0.22	2.86 ± 0.42
Crude fiber	2.60 ± 0.41	2.50 ± 0.38	2.40 ± 0.23
Total ash	2.28 ± 0.33	2.08 ± 0.18	1.89 ± 0.37
Total carbohydrate**	76.10 ± 0.31	77.46 ± 0.14	79.31 ± 0.05
Energy (Kcal/100 gm)	377.58 ± 0.72	384.18 ± 0.21	390.82 ± 0.01
*Total minerals (****mg/100 g*)*			
Calcium	11.90	21.7	31.5
Magnesium	126.51	125.5	124.5
Phosphorus	234.11	282.3	330.5
Iron	3.21	4.15	91.60
Potassium	353.82	487.40	621.01

ratio of lentil increases. The addition of lentil to corn for snack production shows increment in mineral content in the final product as mentioned by previous research findings for lentil in Pakistan [11]. This result revealed that lentil may also provide sufficient amount of minerals to meet the human daily mineral requirement besides protein content.

3.2 Effects of Extrusion Conditions on Physical Properties

The amount of complexed amylose decreased, the expansion ratio increases and percentage of water soluble carbohydrate decrease leading to decreased in bulkiness [12]. In this study the bulk density at 50:50(LF: MF) blend ratio is 0.44 g/cm^3 while it is 0.36 g/cm^3 at 10:90(LF:MF) blend ratio shows that when the corn ratio increases the water insoluble carbohydrate also increases that gives lower bulk density than lower corn flour extrudate. Higher temperatures had been reported to enhance extrudate expansion [13]. For example at 200 °C barrel temperature expansion ratio is 1.326 while at 160 °C the expansion ratio is 1.164 as shown in (Table 6) below.

Bulk density is a very important parameter in the production of expanded and formed food products, as the bulk density considers expansion in all directions [14]. A quadratic model was selected in the design program for this response to test for its adequacy and to describe its variation with independent variables.

$$\text{Bulk density} = \frac{\text{Mass of sample}}{\text{Volume of sample}} \tag{1}$$

Table 5. Proximate chemical composition of extruded snack products produced at different operating conditions.

	*g/100 g																	
	Extruded Blends (n = 3)																	
	BR	BT	MC	BR	BT	MC	BR	BT	MC	BR	BT	MC	BR	BT	MC	BR	BT	MC
	10:90 LF:MF	200 °C	16%	50:50 LF:MF	200 °C	16%	50:50 LF:MF	160 °C	16%	30:70 LF:MF	160 °C	13%	30:70 LF:MF	180 °C	16%	50:50 LF:MF	180 °C	19%
Moisture	8.55 ± 0.03			8.63 ± 0.50			8.32 ± 0.23			8.16 ± 0.02			9.34 ± 0.07				8.48 ± 0.01	
Protein (N × 6.25)	9.05 ± 0.05			12.17 ± 0.19			12.36 ± 0.13			9.96 ± 0.04			10.00 ± 0.01				13.13 ± 0.04	
Crude fat	1.51 ± 0.03			1.45 ± 0.08			1.31 ± 0.04			1.42 ± 0.06			1.47 ± 0.03				1.294 ± 0.01	
Crude fiber	1.49 ± 0.05			1.85 ± 0.02			1.86 ± 0.03			1.64 ± 0.06			1.72 ± 0.02				1.83 ± 0.021	
Total ash	1.20 ± 0.03			2.10 ± 0. 68			2.40 ± 0.68			1.99 ± 0.06			1.69 ± 0.06				2.80 ± 0.04	
Carbohydrate **	78.22 ± 0.25			73.80 ± 0.73			73.75 ± 0.04			76.83 ± 0.35			75.87 ± 0.11				72.46 ± 0.16	
Energy (Kcal/100gm)	362.65 ± 0.33			356.93 ± 0.04			356.23 ± 0.05			359.94 ± 0.30			356.71 ± 0.07				354.02 ± 0.33	
*Total minerals (****mg/100 g*)*																		
Calcium	11.76			31.40			31.50			21.72			21.72				31.52	
Magnesium	126.30			124.30			124.52			125.46			125.45				124.52	
Phosphorus	234.05			330.05			330.53			282.33			282.23				330.45	
Iron	3.11			91.53			91.50			4.25			4.15				91.54	
Potassium	353.78			487.34			621.06			487.04			621.10				487.41	

Table 6. Data for physical properties of the extruded products.

Run	F-1 BT (°C)	F-2 BR (%)	F-3 FMC (%)	R-1 B_d	R-2 L_{Sp}	R-3 E_R
1	200	10:90	16	0.51 ± 0.52	3.44 ± 0.33	1.326 ± 0.34
2	200	50:50	16	0.44 ± 0.43	2.35 ± 0.47	1.432 ± 0.34
3	180	10:90	13	0.54 ± 0.32	1.09 ± 0.37	1.162 ± 0.35
4	180	10:90	19	0.36 ± 0.11	2.09 ± 0.44	1.123 ± 0.45
5	180	50:50	13	0.45 ± 0.47	1.59 ± 0.25	1.396 ± 0.21
6	160	30:70	13	0.47 ± 0.37	1.66 ± 0.12	1.398 ± 0.35
7	160	50:50	16	0.52 ± 0.62	1.77 ± 0.11	1.421 ± 0.42
8	160	10:90	16	0.41 ± 0.31	1.62 ± 0.41`	1.164 ± 0.44
9	180	30:70	16	0.37 ± 0.26	3.89 ± 0.72	1.321 ± 0.72
10	160	30:70	19	0.48 ± 0.32	2.50 ± 0.74	1.083 ± 0.47
11	180	30:70	16	0.43 ± 0.33	3.48 ± 0.65	1.271 ± 0.66
12	200	30:70	19	0.37 ± 0.22	2.83 ± 0.18	1.184 ± 0.34
13	180	30:70	16	0.37 ± 0.29	3.88 ± 0.43	1.326 ± 0.23
14	180	50:50	19	0.47 ± 0.35	1.74 ± 0.66	1.102 ± 0.25
15	200	30:70	13	0.49 ± 0.27	1.28 ± 0.25	1.321 ± 0.33
16	180	30:70	16	0.41 ± 0.31	3.72 ± 0.33	1.25 ± 0.27
17	180	30:70	16	0.38 ± 0.32	3.90 ± 0.13	1.31 ± 0.11

*Where: BR = lentil proportion with corn flour (g lentil flour/*100 g *blend flour), FMC = feed moisture content (%), BT = barrel temperature (°C), Lsp = specific length, Bd = bulk density, ER = expansion ratio. F = factor and R = response; mean values ± SD*

Final equation in terms of coded factors for Bulk Density is:

$$\begin{aligned}\text{Bulk Density} = {} & +0.38 - 8.750\text{E}-003 * \text{A} + 7.500\text{E}-003 * \text{B} - 0.034 * \text{C} - 0.045 * \text{A} * \text{B} \\ & - 0.033 * \text{A} * \text{C} + 0.050 * \text{B} * \text{C} + 0.043 * \text{A}^2 + 0.045 * \text{B}^2 + 0.028 * \text{C}^2\end{aligned} \tag{2}$$

Where*; A: Barrel temperature, B: Blend ratio, C: Feed moisture content and E - Exponetial function.*

As it can be observed in Eq. (2), the linear terms of C, interaction term of A * B, B * C and square terms of $A^{2,}$ B^2 and C^2 were highly influencing variable coefficients affected the model of bulk density of extrudate. There was strong correlation between the feed moisture content and bulk density of extrudate than other factors as seen from the design. As the value of feed moisture content decreased the value of bulk density decreased [22].

The Model F-value of 6.85 implies the model is significant. There is only a 1.47% chance that a “Model F-Value” this large could occur due to noise. Values of “Prob > F” less than 0.050 indicate model terms are significant.

"Adeq Precision" measures the signal to noise ratio. A ratio greater than 4 is desirable. The ratio of 7.376 indicates an adequate signal. This model can be used to navigate the design space [15].

Inorder to come across the variation of responses with respect to independent variables, series of a three dimensional response surfaces were drawn using Design-Expert 7. Since the study involved three variables with constant variable of screw speed (200 rpm), it was necessary to fix the value of two variables to see the effect of the other variable to interpret their interaction effect up on the responses. The relation ship developed between dependent and independent variables were used to plot response surfaces and representative plots. As shown from the graph below (Fig. 1) the increase in barrel temperature will leads to a decrease in bulk density with increasing blend ratio. Results on bulk density showed that the linear terms of moisture content and blend ratio were significant, indicating their strong linear effects. The interaction effects were positive with moisture content and blend ratio. Whereas the interaction effect of barrel temperature and blend ratio were positive until barrel temperature reaches 180 °C and then negatively interacted. The interaction effect of barrel temperature and moisture content is negative. When the results were compared with those at 13 and 19% moisture content, decrease in bulk density with increase in moisture content was observed. An increase in bulk density was noticed at 10% and 50% lentil blend ratio. The graph is concaved down showing that the bulk density was significantly decreasing ($p < 0.05$) as the increase in these variables.

Sample extruded at barrel temperature of 180 °C had the highest product moisture (9.34%). In this study, a decreasing trend of product moisture content from 9.34% to 8.55% and 8.16% for barrel temperature of 180 °C, 200 °C and 160 °C were observed, respectively.

Products extruded at 160 °C showed lower product moisture (8.16%). This was due to moderate bulk density and lower feed moisture content retains the lowest moisture puffing. On the other hand, high moisture contents were associated with less expanded

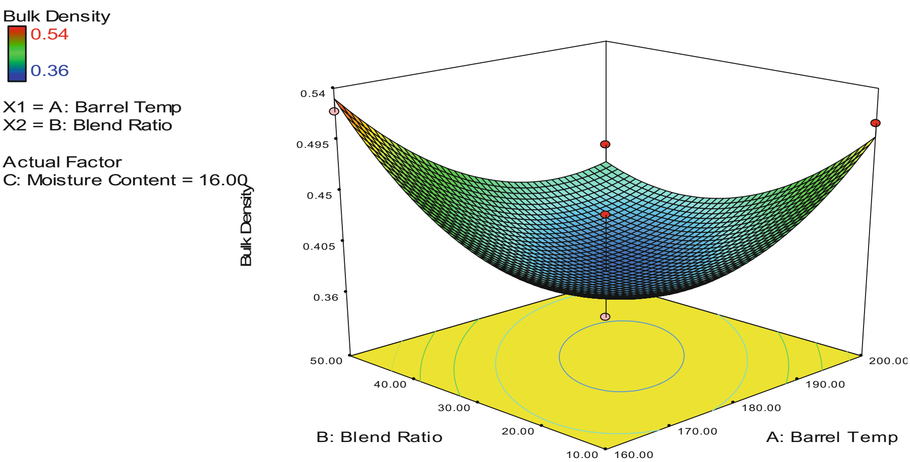

Fig. 1. Effect of barrel temperature and blend ratio on bulk density.

extrudate and required additional energy input to remove the water [16]. Moisture content of products showed increment from 8.16% to 9.34% for extruder feed moisture content of 13% and 19% respectively. Extrusion at 160 °C gave the lowest product moisture for extrudate. Samples extruded at 19% feed moisture content was relatively soft and moist as compared to extrudate at 13%. Insufficient vaporization occurring at high feed moisture content might be one of the causes for softness of the extrudate [17].

Expansion ratio (E_R) 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 important; in fact, large E_R which promotes increased porosity, may result in softer texture in cooked products. The maximum values of E_R for the expanded extrudate were lied between 180 and 200 °C barrel temperature; 13 and 17% moisture content and 30 to 50% blend ratio beyond that the value of E_R decreases from 3D. Blending with legume flours increased leads to decrease in expansion ratio of extrudate.

$$D_r = \left(\frac{D_e}{D_d}\right) \tag{3}$$

Where: D_r is diametric expansion ratio, D_e is diameter of extrudate in cm, D_d is diameter of die whole in cm.

$$\text{Expansion Ratio} = +\,1.32 + 0.025 * A + 0.072 * B - 0.098 * C - 0.038 * A * B + 0.044 * A * C - 0.064 * B * C + 0.031 * A^2 - 0.019 * B^2 - 0.11 * C^2 \tag{4}$$

Where*: A: Barrel temperature, B: Blend ratio, C: Moisture content of Feed, A * B: Barrel temperature * Blend ratio, A * C: Barrel temperature ** Moisture *content of Feed, B * C: Blend ratio * Moisture content of feed.*

Values of "Prob > F" was less than 0.0500 (i.e. 0.0057) indicate model terms (B, C, BC,C^2) are significant model terms.

The graphic (Fig. 2) representation of the expansion ratio is somewhat concaves down showed maxima for both temperature and blend ratio. More uniform texture and the most expanded products were obtained at 180 °C and 16% moisture of the feed. The predictive equations obtained for these analyses, allowed a range of products with variable characteristics attending the various consumption standards to be obtained.

Thus direct linear relationship between low moisture feed content and high expansion ratios of the extruded products are typical for cereals (due to high starch content). Therefore, this paper shows that lentil, behaves as proteinaceous food component with a region of maximum expansion ratio for feed moisture content and barrel temperature. Although protein content in lentil-corn flour is seem relatively low as shown in raw blends (Table 5) which is approximately 10.5% on dry solid basis. This protein probably actively participates to the super molecular network formed upon the extrusion process which later make a cross linkage with that of corn starch's undergoing denaturation and gelatinization process. But moisture content have negative effects up on the value for expansion ratio as shown from the 3D plot (Fig. 3).

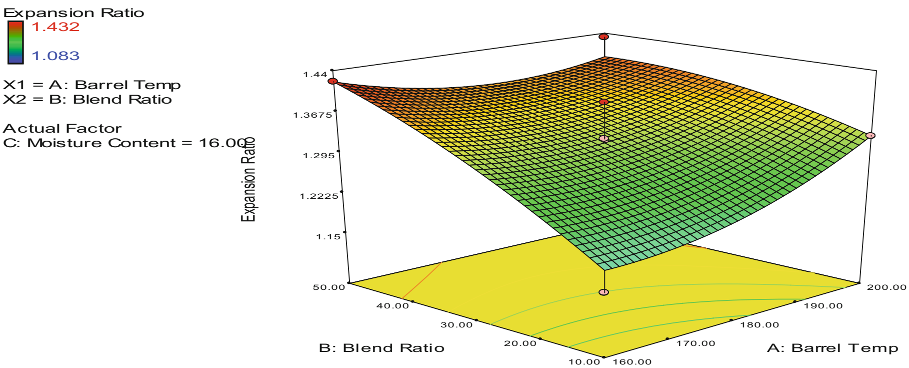

Fig. 2. Effect of barrel temperature and blend ratio on expansion ratio.

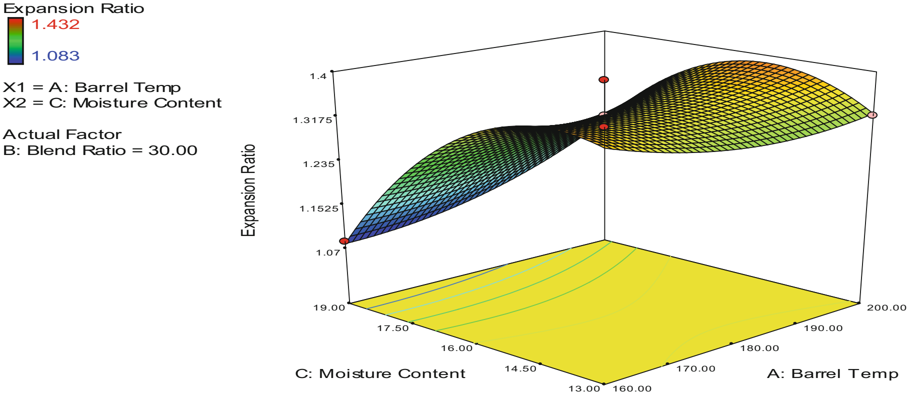

Fig. 3. Effect of barrel temperature and moisture content on expansion ratio.

Both bulk density (B_{den}) and *expansion ration*(E_R) represent the extent of puffing of the extrudate. Therefore, it might be expected that these two properties would be negatively correlated, with higher E_R contributing to lower B_{den}, but this may not always be the case. The reason could be as E_R only considers the expansion in the radial direction, perpendicular to extrudate flow, whereas B_{den} considers the expansion in all directions.

Specific length is also another deteriminental factor of the extrudates. The second degree polynomial model for $\boldsymbol{L_{SP}}$ versus feed moisture content, blend ratio and barrel temperature resulted into an equation:

$$\text{Specific Length} = +3.79 + 0.29 * A - 0.099 * B + 0.44 * C - 0.31 * A * B + 0.18 * A * C - 0.21 * B * C - 0.53 * A^2 - 0.97 * B^2 - 1.19 * C^2 \quad (5)$$

Where: *A: barrel temperature, B: blend ratio, C: moisture content of feed.*

In this case C, B^2, and C^2 are significant model terms. The linear model coefficients further indicated that the effect of the linear term of feed moisture content and barrel temperature was positive except blend ratio. All the quadratic term were positive, respectively. The magnitude of the coefficients indicated that feed moisture content had more effect than barrel temperature and blend ratio respectively on specific length of the extrudate as seen from Eq. 4 above.

This work confirmed for moderate corn (rich in oil in the germ portion of it) and the specific length was increased. The decrease in specific length for higher lentil and very lower corn levels as shown from the graphs below might be because the amylose-lipid complex formation was insignificant to increase specific length due to dilution of the oil (Figs. 4, 5).

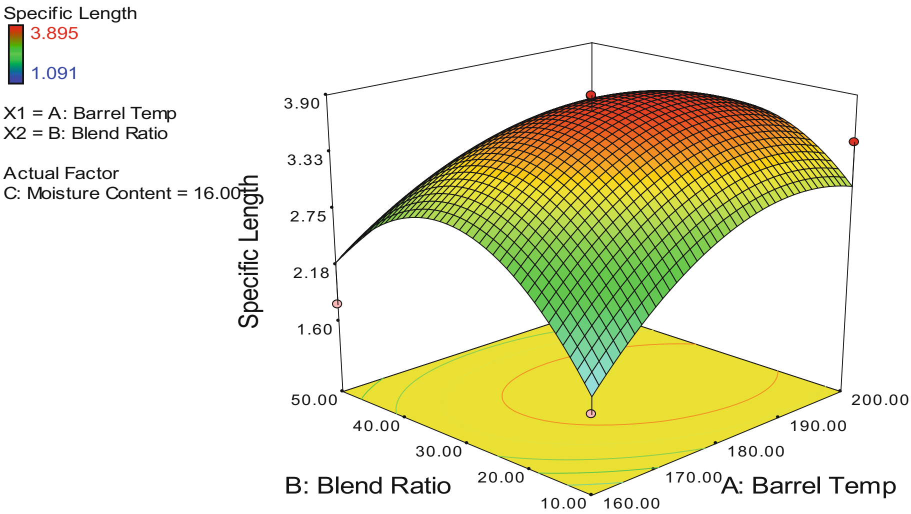

Fig. 4. Effect of barrel temperature and blend ratio of the feed on specific length.

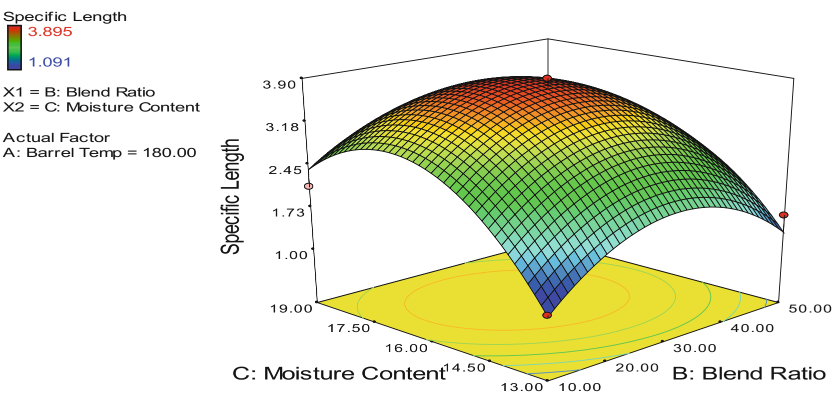

Fig. 5. Effect of feed moisture and blend ratio on specific length.

3.3 Effects on Functional Properties

Gelatinization which leads to transformation of raw starch to a cooked digestible material is one of the important effects that extrusion has on starch component of foods. As extruded product characteristics, water absorption index (*WAI*), water solubility index (*WSI*) and water holding capacity (*WHC*) are very important parameters in describing the degree of gelatinization (cooking) in the Twin extruder to process the blends [18]. Pure Corn has WAI and WSI value of 5.793 ± 0.06 and 11.79 ± 1.42, respectively [19] at operating conditions of 16% moisture content, 200 °C and 6.84 kg/h flow rate which has similarity with the result in (Table 7) below.

Table 7. Data for functional properties of the extruded product.

Run	F-1 BT (°C)	F-2 BR (%)	F-3 FMC (%)	R-1 WAI	R-2 WSI	R-3 WHC
1	200	10:90	16	5.73 ± 0.27	6.54 ± 0.32	3.43 ± 0.25
2	200	50:50	16	8.17 ± 0.04	9.22 ± 0.74	6.32 ± 0.09
3	180	10:90	13	4.77 ± 0.52	6.41 ± 0.29	3.94 ± 0.14
4	180	10:90	19	6.02 ± 0.41	7.02 ± 0.62	5.18 ± 0.53
5	180	50:50	13	7.06 ± 0.14	9.54 ± 0.49	6.32 ± 0.45
6	160	30:70	13	4.78 ± 0.45	6.72 ± 0.36	6.63 ± 0.06
7	160	50:50	16	7.08 ± 0.23	11.74 ± 0.24	7.83 ± 0.74
8	160	10:90	16	4.76 ± 0.42	10.36 ± 0.22	2.64 ± 0.33
9	180	30:70	16	6.20 ± 0.28	9.51 ± 0.52	5.23 ± 0.12
10	160	30:70	19	5.69 ± 0.27	8.89 ± 0.36	4.57 ± 0.27
11	180	30:70	16	6.20 ± 0.21	9.50 ± 0.52	5.23 ± 0.12
12	200	30:70	19	4.96 ± 0.31	7.98 ± 0.25	3.864 ± 0.21
13	180	30:70	16	6.20 ± 0.21	9.50 ± 0.52	5.23 ± 0.12
14	180	50:50	19	8.23 ± 0.47	11.36 ± 0.26	8.83 ± 0.37
15	200	30:70	13	4.11 ± 0.54	9.38 ± 0.78	5.01 ± 0.55
16	180	30:70	16	6.30 ± 0.26	8.10 ± 0.33	5.43 ± 0.11
17	180	30:70	16	6.41 ± 0.35	9.31 ± 0.21	5.12 ± 0.52

Where: *WAI - water absorbing index, WSI - water solubility index and WHC - water holding capacity; F - Factor; R - Response. Values are triplicate means ± SD*

Studied water absorption index, water absorption capacity, oil absorption capacity, and emulsifying capacity in the extrusion process of normal bean cultivars flour. The influence of process variables on functional properties have been shown to be generally significant in all these studies [20]. In this work similar finding were obtained.

The texture analysis by compression test of extruded foods are mainly composed mainly cereals, starch, and vegetable proteins. The major role of these ingredients is to give structure, texture, mouth feel, bulk and many other characteristics desired for specific finished products [21].The compression tests (or Texture analyzing) were performed at room temperature (25 °C) using cylindrical probe TA-XT (stable micro systems, surrey, England). The samples were compressed between two parallel plates of 10 cm diameter each, at a crosshead speed of 5 mm/min, with a 100 N load cell. Force and deformation were recorded and gives the values range from 0.4 to 0.80 N/mm^2 for 17 samples.

Crispness of extrudate was affected by extrusion temperature and material characteristics. Feed moisture content decreased crispness of extrudate. Hardness of the samples was found to be affected by feed moisture content, extrusion temperature and blend ratio ($p < 0.001$). When lentil level increased, the force of deformation increased as show from the (Table 8) below. The temperature rise also resulted to softer products.

Table 8. Texture analysis results for sample extrudate

Run	BT (°C)	BR (%)	FMC (%)	Breaking strength/texture value (N/mm^2)
1	180	50:50	13	0.75 ± 0.11
2	180	10:90	13	0.80 ± 0.14
3	160	10:90	16	0.78 ± 1.55
4	180	50:50	19	0.47 ± 1.40
5	180	10:90	19	0.54 ± 2.07
6	160	50:50	16	0.73 ± 0.16
7	160	30:70	19	0.62 ± 1.40
8	180	30:70	16	0.40 ± 1.32
9	200	50:50	16	0.53 ± 0.54
10	160	30:70	13	0.75 ± 2.22
11	180	30:70	16	0.35 ± 1.11
12	200	10:90	16	0.38 ± 0.11
13	180	30:70	16	0.37 ± 1.50
14	200	30:70	19	0.51 ± 2.01
15	180	30:70	16	0.42 ± 1.62
16	200	30:70	13	0.44 ± 1.52
17	180	30:70	16	0.46 ± 0.78

The optimization was to get maximum expansion ratio, *WAI, WSI, WHC*, specific length and minimum bulk density as much as possible. Under these conditions the optimum response values were found out within the boundaries of the experimental region following the method of ridge analysis [22]. The values showed that for verification of models optimum temperature, feed moisture, and blend ratios could be taken as 181.97 °C, 15.82% and 47.8:52.2% lentil-corn blends, respectively, for all the six responses (Table 9). Since moisture content had less effect on expansion ratio and bulk density as compared to that on hardness, 16% moisture content was assumed to be the optimum for these responses. At these optimum values the model was tested

Table 9. Optimum conditions for all responses in the experiment.

Barrel temp.	Blend ratio	Feed moisture content	Bulk density	Expansion ratio	Specific length	WAI	WSI	WHI	Desirability	Remark
181.97	47.76%	15.82	0.42	1.38	2.91	7.94	10.15	6.87	0.74	Selected

3.4 Effects on Sensory Evaluation

Regarding to sensory analysis; as shown (Table 10) below, It was found that lentil content had significant effect on all the characteristics of product in visual color, appearance, flavor and crispiness, whereas feed moisture had only significant effect on appearance and texture but it can be maximized with increase in food additives. However, the operating conditions at 50:50% lentil-corn blend ratio content 180 °C barrel temperature and 19% feed moisture had higher preference in overall acceptability than other conditions according to the recipes formulation.

There was significant difference between the overall acceptability of the extrudate ($p < 0.05$). Generally more accepted extrudate for overall acceptability were those extrudate that had relatively higher scores for color or appearance, taste or flavor, mouth feel and crispiness. Lentil flour addition significantly affected over all acceptability ($p < 0.05$). The 50:50% lentil-corn blend extrudate were most accepted. As discussed above, the corn used for this study had lower protein content than several

Table 10. Sensory analysis of extruded snack products.

Blend ratio and operating conditions				*Panelist score			
Run	BT (^{0}C)	BR (%)	FMC (%)	Color	Flavor	Crispiness	Overall acc.
1	180	50:50	13	7.00 ± 0.71	7.25 ± 0.40	7.5 ± 1.12	7.00 ± 0.00
2	180	10:90	13	3.4 ± 0.4	6.00 ± 1.41	7.20 ± 1.16	5.20 ± 1.16
3	160	10:90	16	6.5 ± 1.87	7.00 ± 1.41	7.25 ± 1.64	6.50 ± 1.73
4	180	50:50	19	4.67 ± 2.40	5.67 ± 1.40	7.22 ± 0.92	8.24 ± 2.10
5	180	10:90	19	5.80 ± 1.47	7.20 ± 1.56	7.20 ± 1.47	6.40 ± 1.36
6	160	50:50	16	8.33 ± 0.46	7.67 ± 0.74	8.83 ± 0.37	7.83 ± 0.90
7	160	30:70	19	5.20 ± 2.40	4.80 ± 2.10	6.00 ± 1.41	4.80 ± 1.72
8	180	30:70	16	5.80 ± 1.10	7.3 ± 0.50	7.0 ± 0.60	6.20 ± 0.40
9	200	50:50	16	7.33 ± 0.47	7.67 ± 0.47	8.17 ± 1.07	7.17 ± 0.69
10	160	30:70	13	6.5 ± 1.12	5.25 ± 2.17	5.25 ± 0.43	4.75 ± 1.48
11	200	30:70	19	5.50 ± 1.12	7.25 ± 0.43	7.75 ± 0.80	6.75 ± 0.83
12	180	30:70	16	5.80 ± 1.10	7.3 ± 0.50	7.00 ± 0.60	6.20 ± 0.40
13	200	30:70	13	6.80 ± 1.10	5.50 ± 2.13	6.40 ± 0.41	4.7 ± 1.46
14	180	30:70	16	5.80 ± 1.10	7.3 ± 0.50	7.01 ± 0.60	6.20 ± 0.40
15	200	10:90	16	4.33 ± 1.87	5.67 ± 1.88	6.16 ± 0.90	5.66 ± 1.11
16	180	30:70	16	5.67 ± 1.20	7.01 ± 0.33	6.82 ± 0.55	6.81 ± 0.35
17	180	30:70	16	5.70 ± 0.89	6.91 ± 0.22	7.36 ± 0.41	7.10 ± 0.26

*BT - barrel temperature (^{o}C), FMC - feed moisture content (%), SS - screw speed (rpm) and n - number of panelist**Samples were evaluated in rod form.

cereals and moderate amount of lentil flour addition was needed to improve sensory properties associated with protein content. The barrel temperature, feed moisture and blend ratio had significantly affected overall acceptability of extrudate ($p < 0.05$).

4 Conclusıons

This study was conducted to investigate the effect of blend ratio and operating conditions (feed moisture and barrel temperature) on the physicochemical, functional and sensory properties of extruded product from corn and lentil flour. Extrusion tests were conducted using co-rotating twin screw extruder at three levels of blend ratio [10:90 (LF:MF), 30:70(LF:MF), and 50:50(LF:MF)], feed moisture [13,16 and 19%] and barrel temperature [160,180 and 200 °C] using Design-Expert 7.

Blend ratio, temperature and feed moisture content were found to have significant effects on the product properties. Lentil blending increased protein, total ash and fiber content of the product but reduced fat and carbohydrate content of the extrudate. Blend ratio was the most dominant factor affecting physical, functional and sensory properties of extruded products. Increased lentil proportion affected diametric expansion ratio, WSI, WAI, WHC, bulk density and hardness positively. On the other hand, the effects of addition of lower lentil levels were positive while higher levels were negative on specific length. The effect of feed moisture content was observed on WSI, WAI, specific length and bulk density of products was positive and negatively affects expansion ratio. Barrel temperature significantly affected bulk density negatively.

It is interesting to mention here that extrusion at feed moisture (16%) and high temperature (180 °C) was good to produce puffed product from 50:50% corn and lentil blend using 9 mm die size and reduced residence time. Sample extruded at barrel temperature of 180 °C had the highest product moisture (9.34%). In this study, a decreasing trend of product moisture content from 9.34% to 8.55% and 8.16% for barrel temperature of 180 °C, 200 °C and 160 °C were observed respectively. Products extruded at 160 °C showed lower product moisture (8.16%). This was due to moderate bulk density and lower feed moister content retains the lowest moisture puffing.

This product had a mean value (at least for three measurements) of specific length of 2.44 cm/g, expansion ratio of 1.28, bulk density of 0.44 g/cm^3, WAI of 6.01%, WSI of 8.95%and WHC of 5.34%. The sensory scores (a mean value of 22 panelists) for color, flavor, crispness and overall acceptability were also 5.92, 6.58, 7.06 and 6.24 respectively on nine-point hedonic scale.

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