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Optimization of Process Variables to Develop Teff-Amaranth Based Extrudates

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Abstract: ***Response Surface Methodology was adopted to study the effect of barrel temperature, screw speed, feed moisture content and blend ratio to optimize the physical properties (expansion ratio, bulk density and specific length) and functional properties (water absorption index and water solubility index) during extrusion process to develop teff-amaranth based extrudates using twin screw co-rotating extruder. Kuncho teff grains with voucher numbers DZ-C1-387 which was harvested in DebreZeit Agricultural Research Center in 2011/12 and white amaranth which was collected from Konso commercial market were used for production the extrudates. On the basis of extruded product quality, the extrusion process variables were feed moisture (12, 18, and 24%), teff - amaranth blend ratio (90:10, 85:15 and 80:20%), barrel temperature (110, 130 and 150°C) and screw speed (120, 140 and 160 rpm) through a die of opening about 9.00mm. the physical properties, functional properties of all the extruded products were evaluated. The maximum expansion ratio (3.0789), maximum water absorption index (8.728g/g) and minimum bulk density (0.1614g/cm^3) values of the extrudates were observed at 130 ^{0}C, 140 rpm, 15% feed moisture content and 85:15 blend ratio. The the maximum specific length (3.6193cm/g) was obtained at 150 ^{0}C, 160 rpm, 15% feed moisture content and 80:20 blend ratio and the maximum water solubility index (22.217%) was obtained at 150 ^{0}C,120 rpm, 15 feed moisture content and 80:20 blend ratio. In this study, promising results were obtained for the development of teff- amaranth based extrudates and process optimization studies.***

Keywords: Teff, Amaranth, Extrusion, Extrudates, Optimization, Response Surface Methodology

1. Introduction

Amaranth is easy to grow, nutrient rich and underutilized pseudo-cereal that can play an important role in actions against hunger and malnutrition that occur due to low rainfall conditions (Shimelis and Martha, 2012). Amaranth grows rapidly and has a high tolerance to arid conditions and poor soils where traditional cereals cannot be grown. The amaranth plant is also attractive since it adapts itself to a large number of environments, grows with vigor, produces large amounts of biomass, and resists drought, heat, and pests (Teutonico *et al.,* 1985). Amaranth has been touted as a miracle grain, a super grain, and the grain of the future (Monica *et al.,* 2011).

Because it is easy to digest, amaranth is traditionally given to those who are recovering from an illness or a fasting period. Amaranth grain has continued to be an under-exploited crop with a promising economic value due to the variety of uses it can have and the benefits it can provide to producers, processors, and consumers (Pedersen *et al.,* 1987). The amaranth grains contain large amounts of dietary fiber, iron, calcium, lysine, methionine and cysteine, combined with a fine balance of amino acids, making them an excellent source of high quality, balanced protein**,** which is more complete than the protein found in most grains (Bressani *et al.,* 1987; Monica *et al.,* 2011).

Amaranth grain is a pseudo-cereal and gluten-free used in breakfast cereals, pancakes, soup, breads, cookies, gluten-free foods, extruded snacks and as an ingredient in confections (Shimelis and Martha, 2012). South Americans parch or cook it for a gruel or porridge, or mill it to produce light-colored flour. As a snack, the grain is popped and tastes like nutty-flavored popcorn. It can also be mixed with honey (Chávez-Jáuregui *et al.,* 2000). Ljubica *et al.,* (2009) have reported that amaranth flour can be used to partially replace regular corn flour for extruded snack manufacturing. Xaene *et al.,* (2008) also reported that mixture of instant whole amaranth and rice can be used to produce extruded flours to be used in formulations of beverages and According to Rosa *et al.,* (2010), extruded snacks can be manufactured from defatted amaranth flours.

Teff (*Eragrostis Teff*) is an intriguing grain, ancient, minute in size, and packed with nutrition and it is believed to have originated in Ethiopia between 4000 and 1000 before Christ (BC) (Stallknecht, 1993). Teff is one of the major indigenous Ethiopian cereals producing in large scale and it is mainly used for making popular pancake-like local bread called *injera*. During 2009-2010, it was estimated that 3.2 million tons of teff was produced on 2.6 million hectares of land **(**CSA, 2010). This is equivalent to 21% and 28% of the total cereal production and acreage in the country, respectively, making teff the leading crop among cereals and other annual crops and by 2011-2012, it was estimated that 3.5 million tons of teff was produced on 2.73 million hectares of land **(**CSA, 2012).

Replacement of part of teff flour with non-teff ingredients for the production of extruded products had been reported by Sirawdink and Ramaswamy (2011) and they reported that 20% Teff, 60% corn, and 20% SPI was selected as the best formulation to yield a protein rich extruded product with desirable attributes. Laike *et al.,* (2010) had studied the physical and sensory properties of an teff extruded product (DZ 01-99 and 196, red and white coloured, respectively) and they concluded that increased temperature, reduced feed moisture and a higher screw speed showed a significantly ($p < 0.01$) higher radial expansion, reduced bulk density and less compression resistance of extrudates.

Extrusion cooking is applicable in the manufacture of breakfast cereals, pasta, meat analogs, filled snack products, confectioneries, bread, pasta products, pet foods, and breakfast cereals are a few examples of the conventional uses of extruders in the food industry and pet food and it permits better utilization of available cereal grains, as well as vegetable and animal proteins, in manufacturing cost-effective and nutritionally balanced diets with unique and improved characteristics (Guy, 2001; Harper, 1991). According to Filli *et al.*,*(*2010), to achieve enzyme denaturation, anti-nutrient inhibition, microbial inactivation, general product acceptability e.t.c, extrusion cooking presents the best option. Extrudates are microbiologically safe and can be stored for long periods because of low moisture content (Fellows, 2009). Therefore, in this study, extrusion process variable were optimized to develop teff-amaranth based extrudates.

2. Materials and Methods

2.1 Flour preparation and blend formulation

Teff grain was obtained from DebreZeit Agricultural Research Center (DZARC). Two cultivars namely, kuncho teff with voucher number DZ-C1-387 and red teff with voucher number DZ-01-99, grown at DZARC in 2011/12 cropping year were used for the study. The selection of teff varieties were based on grain color and yield. Amaranth (black, pale-white and white coloured) varieties which were harvested in the year 2011/12 were collected from Konso Commercial market.

2.1.1 Teff flour preparation

Teff samples were cleaned manually to remove damaged grains, stones, dusts, light materials, glumes, stalks, undersized and immature grains and other extraneous materials. About 20 kilograms of kuncho Teff (DZ-C1-387) and 20 kilograms of red Teff (DZ-01-99) were cleaned, milled and ground into fine flour using small- scale commercial mill. Following grinding, the flour was sifted to pass through 710 μm test sieve (Laike *et al.*, 2010; Sirawdink and Ramaswamy, 2011), and sealed in poly ethylene plastic bags, and stored at room temperature.

2.1.2 Amaranth flour preparation

The amaranth samples obtained from Konso Commercial Market were cleaned manually to remove damaged grains, stones, dusts, light materials, glumes, stalks, undersized and immature grains and other extraneous materials. About 10 kilogram of black, 10 kilogram pale-white and 20 kilogram of white coloured cleaned amaranth was milled and ground into fine flour using small-scaled commercial mill. Following milling and grinding, the flour was sifted to pass through 710 μm test sieve (Monica *et al.*, 2011; Chávez-Jáuregui *et al.*, 2000) and the sieved flour was sealed in air tight poly ethylene plastic bags, and stored at 5^0c (Monica *et al.*, 2011) for further laboratory analysis and till extrusion cooking was conducted.

2.1.3 Flour blend formulation

According to Sirawdink and Ramaswamy, (2011); Chavez-Jauregui *et al.*, (2000);Ilo and Liu, (1999) and preliminary tests of the extrusion cooking process, three blends of Teff and Amaranth flours (BR_1, BR_2 and BR_3) were developed by blending at three levels (table 2.1).

Table 2.1: Flour blend formulation

Blend proportion	Code
90%Teff and 10%Amaranth	BR_1
85% Teff and 15%Amaranth	BR_2
80% Teff and 20%Amaranth	BR_3

The three blends were mixed together in a ribbon blender (*Model AB, Alvan blanch Type, England*) for 20 minutes and it was packed in plastic bags (polyethylene bags) and stored at room temperature till extrusion was conducted.

2.2 Extrusion Process

Extrusion was performed on a pilot scale co-rotating twin screw food extruder (model Clextral, BC-21 N^0 124, Firminy, France) at Bahir Dar University, School of Chemical and Food Process Engineering. Prior to extrusion, the raw materials were well mixed (blended) according to the recipes (table 2.1) before addition into the feeding hopper of the extruder.

The barrel of the extruder had a smooth 300 mm length and it consists of three modules each 100 mm long fitted with 25mm diameter screws. The barrel temperature was fixed in zone 1 and 2 at 70°C. The temperature of zone 3, which was located just before the die, was an independent variable in the study and varied at 110, 130 and 150°C. Twin screw volumetric feeder (type KMV- KT20) delivered the raw material into the extruder inlet. While operating, water at ambient temperature was injected into the extruder via an inlet port by a positive displacement pump (DKM-Clextral, France).

The moisture content of the material was adjusted by varying the water injection rate of the pump to give a moisture content of 25, 20 and 15% in the mixes for a constant material feed rate. Screw speed was set at 120, 140 and 160 rpm. The selected moisture, temperature and speed levels were chosen from pre-test experiments. The end of the extruder was caped with a die plate, which held a die having four circular openings of 9 mm diameter. Samples were subjected to extrusion test at all combinations of the processing conditions. During extrusion the samples were extruded as cylindrical shape.

Extruded samples were collected when the extrusion process parameters reached steady state, i.e. when there were no visible drift in torque and die pressure (Garber *et al.*, 1997). The extruded products were placed on a table and allowed to cool for 30 minutes at room temperature (Ibanoglu *et al.*, 2005) for the measurement of weight, length and diameter. Samples were collected and sealed in plastic bags after equilibration for 24 hours at ambient condition.

2.3 Physical Properties

2.3.1 Degree of expansion(E_R)

The expansion ratio (diametric), E_R was determined as the ratio of the diameter of the extrudates to the diameter of the die hole (Mason and Hoseney, 1986).

$$E_R = \left(\frac{D_e}{D_d}\right)$$

Where:

- D_e = diameter of the extrudates(cm)
- D_d = diameter of the die whole(cm)
- E_R = expansion ratio of the extrudates

2.3.2 Specific length, L_{sp}

The Specific length, L_{sp} (cm) of the extrudates was calculated as the ratio of length of extrudates to unit weight (g) of the extrudate (Fan *et al.*, 1996).

$$L_{sp} = \left(\frac{L_e}{M_e}\right)$$

Where:

- L_{sp} = specific length of the extrudates (cm/g)
- L_e = length of extrudates(cm) and
- M_e = mass of extrudates in (g).

2.3.3 Bulk density, B_{den}

Bulk density, B_{den} of the extrudates was calculated as the ratio of weight of extrudates to the volume of extrudates (Mason Hoseney, 1986)assuming that the product has a cylindrical shape.

$$B_{den}\ (g/cm^3) = \left[\frac{4M}{\pi D_e^2 * L_e}\right]$$

Where:

- B_{den} = bulk density (g/cm^3)
- D_e = diameter of extrudate (cm)
- L_e = length of extrudates (cm) and
- M= weight of the extrudate (g)

2.4 Functional properties

WAI and WSI were determined according to the method developed for cereals (Stojceska *et al.*, 2008). The ground extrudate was suspended in water at room temperature for 30 min, gently stirred during this period, and then centrifuged at 3000 g for 15 min. The supernatant was decanted into an evaporating dish of known weight. The WAI was the weight of gel obtained after removal of the supernatant per unit weight of original dry solids. The WSI was the weight of dry solids in the supernatant expressed as a percentage of the original weight of sample.

$$\text{WAI} = \left[\frac{W_s}{W_0}\right] * 100$$

Where:

- W_s = weight of sediment (g) and
- W_o = weight of sample (g)
- WAI = Water Absorption Index (%)

$$\text{WSI} = \left[\frac{W_r}{W_0}\right] * 100$$

Where:

- W_r = weight of residual after evaporation(g)
- W_o = weight of the initial sample (g) and
- WSI = Water Solubility Index (%)

2.4 Experimental design and statistical data analysis

Response surface methodology (RSM) was adopted in the design of experimental combinations (Giovanni, 1983; Montgomery, 2002). This Experiment was designed to search the Optimum Process Variables to develop teff–amaranth based extrudates using extrusion cooking processing according to Central composite design of face centered method (Montgomery, 2001).

Table 2.2: Coded levels of the variables

Factors	Coded Levels		
	-1	0	+1
FMC (%)	15	20	25
BT(^{0}c)	110	130	150
SS(rpm)	120	140	160
BR (%)	90T:10A	85T:15A	80T:20A

Where; BT - barrel temperature, FM – feed moisture content, BR- blending ratio, A- amaranth and T- teff and -1, 0, and +1 are coded for lower, middle and upper levels, respectively

RSM design expert stat-Ease software version 7.0 was used to determine the optimum extrusion variables. Face centered Central Composite Design (CCD) for a four factor (blend ratio, feed moisture content, barrel temperature and screw speed) and three level combinations with a total number of 30 runs were used to conduct this study. Means Comparisons was performed using one-way analysis of variance (ANOVA) for all data at each processing stage. Comparisons for each data were carried out using Student's t test at α= 0.05, to see whether the actual difference in each value means is greater than the difference that would be significant. All statistical mean comparison analyses were performed using JMP™ Version 5 (SAS Institute Inc., Cary, NC, USA)

Response of variables was represented by:

$$Y = \beta_0 + \beta_1 A + \beta_2 B + \beta_3 C + \beta_4 D + \beta_{12} AB + \beta_{13} AC + \beta_{14} AD + \beta_{23} BC + \beta_{24} BD + \beta_{34} CD + \beta_{11} A^2 + \beta_{22} B^2 + \beta_{33} C^2 + \beta_{44} D^2 + \epsilon$$

Where:

- Y -the response function
- β_o - constant
- β_{ij} - are regression coefficients (i-1, 2, 3,4 and j-1, 2, 3,4)
- A - Barrel Temperature (^{0}C)
- B - Screw Speed (rpm)
- C - Feed Moisture (%)
- D - Blend Ratio (%)
- ϵ _ Random error

3. Results and Discussion

The significant influence of processing variables was studied to evaluate their effects on the quality (bulk density, expansion ratio, specific length, water absorption index and water solubility index, and sensory quality attributes) of teff-amaranth based extrudates.

3.1 Physical Properties of Extrudates

For the production of teff-amaranth based extrudates, physical properties like expansion ratio, bulk density and specific length are the most important product characteristics; this can vary considerably depending on the processing conditions (Rosa *et al.*, 2010 and Jose, 2011).

3.1.1 Expansion ratio

the expansion of extrudates of cereals depend on the degree of gelatinization which was also determined by process temperature, screw speed and moisture content of the feed material (Ilo *et al.*,1999; Guha, 2003). Quadratic model was suggested by the design program for this response to test for its adequacy and to describe its variation with the independent variables. The Model F-value of 14.78 (table3.2) implies the model was significant. Values of "Prob > F" less than 0.0500 indicated that the model terms were significant. In this case C, D, AB, AC, C^2 and D^2 were significant model terms. The R^2 and Adjusted R^2 values of the model were 0.9324 and 0.8693, respectively (table 3.2). By Multiple regression model of E_R versus FMC, BR, BT, and SS; the following fitted model was obtained:

$$E_R = +2.86 + 0.011*A + 0.016*B - 0.12*C - 0.057*D - 0.050*A*B - 0.035*A*C - 8.375E\ 004*A*D - 9.125E\text{-}003*B*C - 0.025*B*D + 0.022*C*D - 0.063*A^2 - 0.045*B^2 + 0.081*C^2 - 0.095*D^2 \quad (3.1)$$

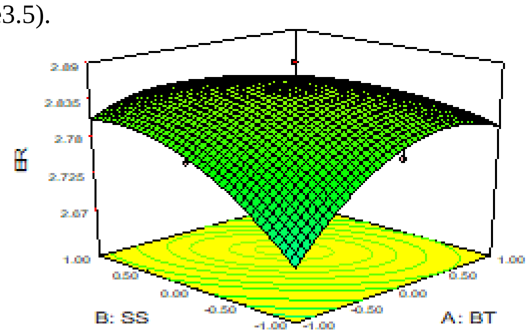
Where; A:Barrel Temperature(^{O}C), B:Screw Speed(rpm), C: Feed Moisture Content(%), D: Blend Ratio(%), AB: Barrel Temperature Screw Speed, AC: Barrel Temperature*Moisture Content of Feed, AD: Barrel Temperature* Blend Ratio, BC: Screw Speed*Moisture Content of Feed, BD: Screw Speed* Blend Ratio and CD: Moisture Content of Feed* Blend Ratio, respectively.*

From equation (3.1), the coefficients of A and B were positive, where as the coefficients of C and D were negative.Therefore, increase in barrel temperature and screw speed may increase E_R; whereas, increase in feed moisture content and amaranth proportion in the feed may reduce E_R. The coefficients of A^2, B^2 and D^2 were negative therefore they will show negative quadratic effect on E_R where as the coefficient of C^2 was positive, so it will show positive quadratic effect (table3.2).

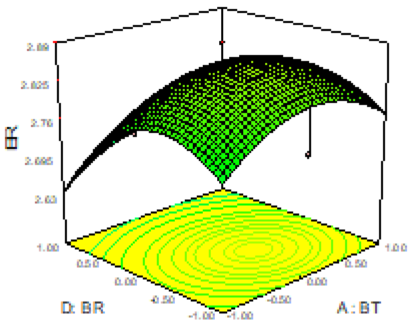
The expansion process can be described as nucleation in the die, extrudates swelling immediately beyond the die, followed by bubble growth and collapse (Ljubica *et al.*, 2009). In this study, E_R was ranged from 2.5427 to 3.0789 g/cm^3 with an average value of 2.8108 g/cm^3 (table3.1). The maximum E_R obtained at coded point (0, 0,-1,0) was about 1.22 times more than the minimum E_R obtained at the coded point of (-1,-1,1,1). 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 110°C to 130°C, E_R was increased from 2.5427 to 3.0789 g/cm^3 and decreased to slightly at and beyond 150^{o}C. On increase temperature, gelatinization of starch was more and rose in E_R, which was confirmed by Mercier and Feillet, (1975), extrudates viscosity decreased withincreased temperature. Moreover, the degree of superheating of water in the extruder would increase at higher temperatures, also leading to greaterexpansion (Jose, 2011). Ding *et al.*, (2006), also reported that the viscosity of feed material decreased as barrel temperature increased which results in better expansion. Feed moisture has been identified as the main factor affecting extrudates expansion (Guy, 2001). E_R was decreased with increasing feed moisture content which was in good agreement with the findings of Ding *et al.*, (2006), and Sirawdink and Ramaswamy (2011) who reported E_R increased with increased barrel temperature and reduced feed moisture content.

For most of the treatments increasing screw speed from 120 to 160 rpm significantly ($p<0.05$) increased E_R of the extrudates. Singh *et al.*, (2007) reported that increasing screw speed improved expansion and reduced bulk density of extrudates during extrusion of soybean protein and corn starch. Similar results were observed in extruding teff flour (Laike *et al.*, 2010) and teff, corn and soybean flour mixtures (Sirawdink and Ramaswamy, 2011).

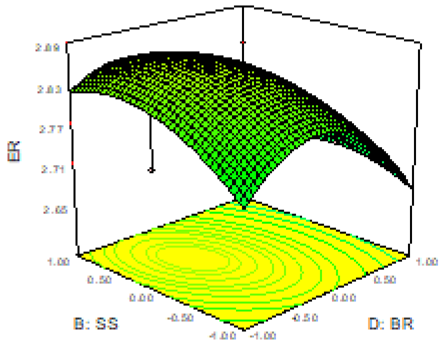
As it can be seen from the figures, increase amaranth proportion in feed composition resulted in decreased in E_R of the extrudate which was in good agreement with Chessari*et al.*, (2001) and Fan *et al*.,(1996). The interaction effect of the process variables showed that the highest E_R was observed at 15% feed moisture content, 130°C barrel temperature, 140 rpm screw speed and 85:15 blend ratio (table3.5).



(a)



(b)



(c)

Figure 3.1: Response surface plots for expansion ratio as a function of (a) SS and BT (b) BR and BT and (c) SS and BR keeping all other processing parameters constant.

3.1.2 Bulk density of the extrudates

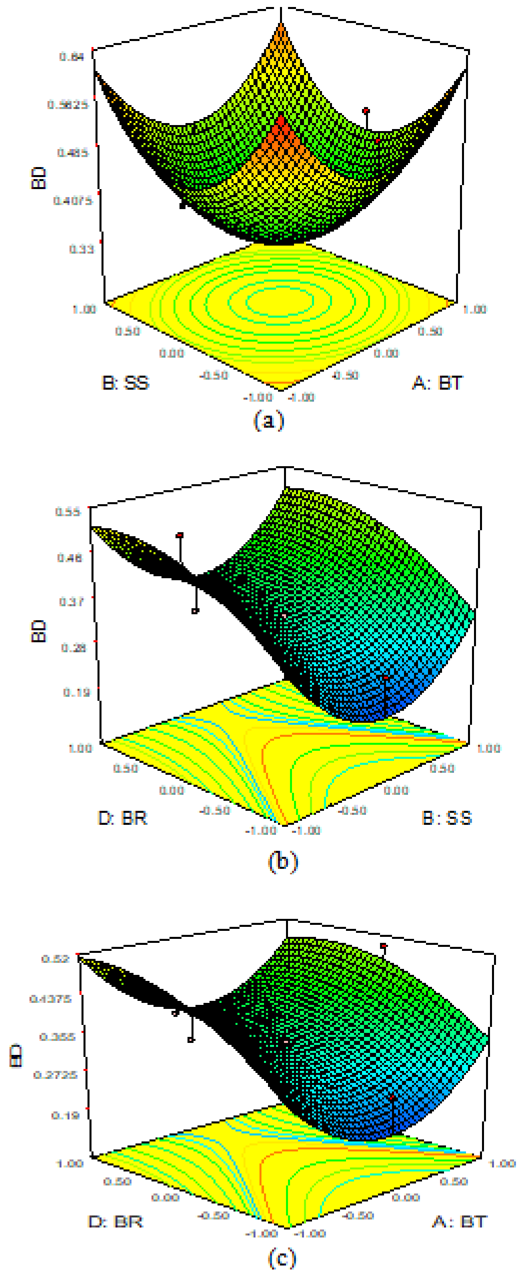
Bulk density is one of the most significant response variables in the production of extrudates. The Model F-value of 18.58 implies the model was significant and the R^2 value of 0.9455 was in reasonable agreement with the Adj R^2 of 0.8946 (table3.2). In this case C, D, BC, CD, A^2, B^2, C^2, D^2 were significant model terms. The following response model was selected for representing the variation of bulk density with respect to the processing variables for further analysis.

From equation 3.2 and table 3.2, it was evident that the coefficients of A and B were negative, but the coefficients of C and D were positive. Therefore, increase in barrel temperature and screw speed may reduce the bulk density, whereasincrease in feed moisture content and amaranth proportion in the feed may increase the bulk density of the extrudates. The coefficients of A^2 and B^2 were positive; therefore, they may show positive quadratic effect on bulk density and the coefficients of C^2 and D^2 were negaitive, thus they may show negative quadratic effects.

$$BD = +0.34 - 3.794E\text{-}003*A - 5.722E\text{-}003*B + 0.072*C + 0.081*D + 5.413E\text{-}003*A*B - 8.487E\text{-}003*A*C - 0.014*A*D - 0.028*B*C + 6.500E\text{-}004*B*D - 0.044*C*D + 0.13*A^2 + 0.15*B^2 - 0.11*C^2 - 0.057*D^2 \quad (3.2)$$

The maximum bulk density (0.6454g/cm^3) of extrudates at coded point (-1, -1, +1,+1) was about 3.99 times more than the minimum bulk density (0.1614g/cm^3) at coded points (0, 0,-1,0) and the average value was 0.4034g/cm^3(table 3.1). According to Mercier and Fiellet, (1975) and Jose, (2011), density of extrudates decreased with increasing in barrel temperature due to starch gelatinization. Increased gelatinization increases the volume of extrudates; consequently bulk density was decreased as observed in this study.

At high temperature the vapor pressure of the free moisture is also greater which would cause an increased rate of moisture flashing and puffing up on exit from the die (Frame, 1994 and Jose, 2011) and this could result in a decreased bulk density as well. As observed in this research work, increasing in barrel temperature, the bulk density was decreased until it reached its optimum value and then increased with increased in barrel temperature. As the temperature was increased from 110 to 130^{0}C the bulk density decreased from 0.6454 to 0.1614g/cm^3 (table3.1) which was in good agreement with Gamel, (2005), who reported that there was decrease in bulk density of the blend snack extrudates as the barrel temperature increased. This means that the melt has lower viscosity and hence, a high pressure is available, causing increase in expansion and decrease the bulk density .It was also observed that bulk density of the extrudates was decreased with decreasing feed moisture content and amaranth proportion in the blend feed. As the moisture content increased from 15 to 25% the bulk density was increased from 0.1614 to 0.6454g/cm^3. Laike *et al.*, (2010) reported that increasing feed moisture content resulted in increased bulk density.



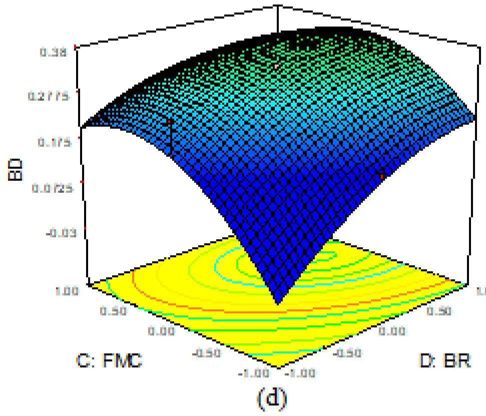


Figure 3.2: Response surface plots for bulk density as functions of (a) SS and BT (b) BR and SS (c) BR and BT and (d) FMC and BR keeping all other processing parameters constant.

3.1.3 Specific length of the extrudates, L_{sp}

The Model F-value of 20.60 implies the model was significant (table 3.6). Values of "Prob > F" less than 0.0500 indicated that the model terms were significant. In this case A, B, C, D, AD, BD, C^2, D^2 were significant model terms (table 3.5). The second degree polynomial model for L_{SP} versus MCF, BR, BT, and SS was estimated as follows:

$$L_{sp} = +1.45 + 0.53*A + 0.11*B - 0.13*C + 0.21*D + 0.047*A*B + 0.074*A*C + 0.35*A*D + 0.044*B*C + 0.25*B*D - 0.039*C*D - 0.070*A^2 + 0.019*B^2 + 0.34*C^2 + 0.28*D^2 \qquad (3.3)$$

From Equation (3.3), the coefficients of A, B and D were positive, where as the coefficient of C was negative.Therefore, increase in temperature, screw speed and amaranth proportion in the feed may increase L_{sp}; whereas increase in feed moisture content may reduce L_{sp} of extrudates. The coefficient of A^2 was negative, therefore it will show negative quadratic effect on L_{sp} of the extrudates. The coefficients of B^2, C^2 and D^2 were positive so they will show positive quadratic effect on L_{sp} of the extrudates. L_{sp} of the extrudates was ranged from 0.717429 to 3.61932 cm/g with an average value of 1.80. The maximum L_{sp} obtained at coded point (+1,+1,-1,+1) was about 5.05 times more than the minimum L_{sp} at the coded point of (-1,0,0,0). Specific length was increased from 0.7174 to 3.61932 *cm/g* as temperature increased from 110 to 150^0 C (table 3.1). According to Riaz, (2000), the extrudates longitudinal expansion and melt viscosity were inversely related and he reported that a longer specific length was due to an increase in product temperature which reduced the melt viscosity which is in good agreement with the results of this study. Chessari, (2001) found that product temperature increased with increasing screw speed, due to the fact that with increasing screw speed more SME input to the system happens thereby increasing the product temperature and increasing the feed rate enhances the feed contact with the hot extruder barrel. According to Mercier*et al.*, (1989) and Jose, (2011), semi-crystalline amylose-lipid complex formation generates a rigid matrix that is less elastic. Because radial expansion is normally favored by the elastic properties of the melt, the loss of elasticity due to formation of amylose-lipid complex may explain the decrease in radial expansion, and consequently the increase in longitudinal expansion. This work confirmed the same effect for higher amaranth proportions in that increasing amaranth added more oil to the teff and the specific length was increased. The decrease in specific length for lower amaranth proportion may be because the amylose-lipid complex formation was insignificant to increase specific length.

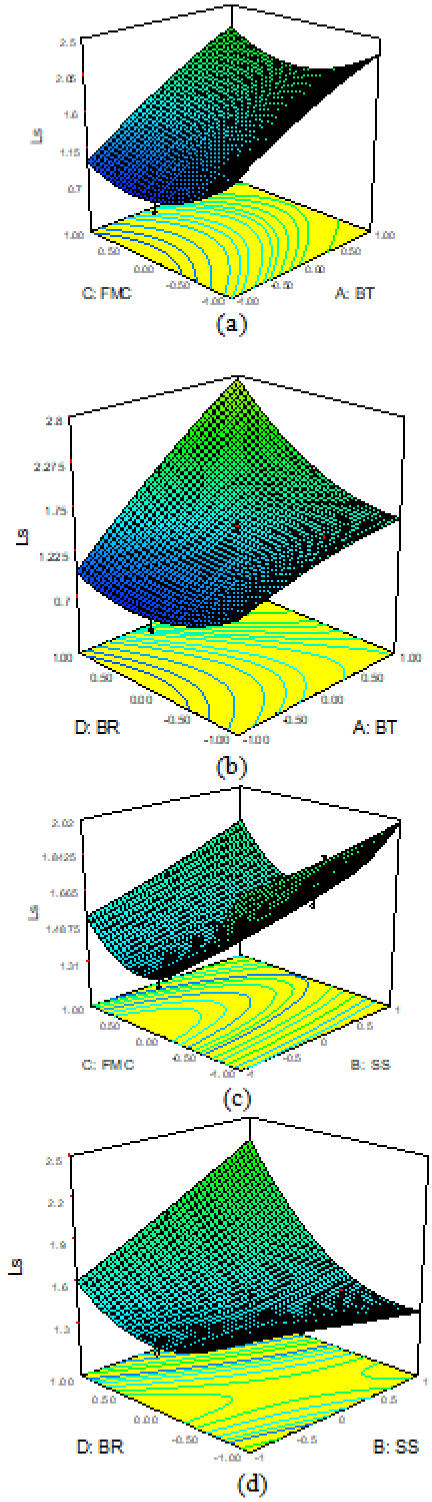


Figure 3.3: Response surface plots for specific length as function of (a) BT and FMC (b) BT and BR (c) SS and FMC (d) BR and BR keeping other processing parameters constant.

3.2 Functional Properties of Extrudates

Water absorption index (WAI), an indicator of the ability of flour to absorb water, depends on the availability of hydrophilic groups which bind water molecules and on the gel-forming capacity of macromolecules. WAI is the measure of the swelling power of the starch (Harper, 1989 and Anderson *et al.,* 1996). Water solubility index (WSI), on the other hand, expresses the percentage of dry matter recovered after the supernatant is evaporated from the water absorption determination (Anderson *et al.,* 1996). WSI measures the amount of soluble polysaccharides released from the starch component after extrusion (Ding *et al.,* 2006). WAI and WSI characterizes how the products will interact with water and are often important in predicting how the extrudates materials may behave if further processed.

3.2.1 Water Absorption Index, *WAI*

The Model F-value of 28.50 signifies that the model was significant ($P < 0.05$). Values of "Prob > F" less than 0.0500 indicated that the model terms were significant. In this case A, B, C, D, AB, AC, AD, BC, BD, CD, A^2, B^2, C^2 were significant model terms. R^2 (0.9638) and Adjusted R^2 (0.9300) were in reasonable agreement (table3.2). The Adequate Precision value of 23.099implied that the model could be used for prediction purposes (Montgomery, 2002) and the following response model was selected for representing the variation of *WAI* with respect to the process variables.

$$WAI = +7.07 + 0.53*A + 0.39*B - 0.32*C + 0.48*D - 0.19*A*B + 0.39*A*C - 0.19*A*D + 0.25*B*C - 0.23*B*D - 0.43*C*D - 1.39*A^2 - 1.15*B^2 + 0.95*C^2 + 0.071*D^2 \quad (3.4)$$

The coefficients of A, B and D were positive, but the coefficient of C was negative; thereforeincrease in temperature, screw speed and blend ratio may increase *WAI*, whereas increase in feed moisture content may decrease *WAI* of the extrudates. The coefficients of A^2 and B^2 were negative therefore; they will show negative quadratic effect on WAI of the extrudates. The coefficients of C^2 and D^2 were positive therefore they will show positive quadratic effect on WAI of the extrudates (Equation 3.4). WAI of the extrudates varied in the range of 3.007 to 8.728g/g with an average value of 6.16 g/g. The maximum *WAI* at coded point (0, 0, -1, 0) was about 2.9 times more than the minimum *WAI* at the coded point of (-1,-1,+1,-1) (table 3.1). The flour mixture and its extrudates showed *WAI* values of 1.69 g/g solid and 8.728g/g solid respectively. This indicates that WAI value of the extrudate was relatively higher than that of the formulated flour mixture. This also shows that there was starch gelatinization during extrusion cooking. Protein denaturation, starch gelatinization and, swelling of crude fiber, which occur during extrusion could all be responsible for increasing *WAI* value of extrudates (Riaz, 2000 and Jose, 2011). The increase in *WAI* observed might have been caused probably a more open structure was formed during extrusion which could allow water penetration and retention in the product (Mercier *et al.*, 1989).

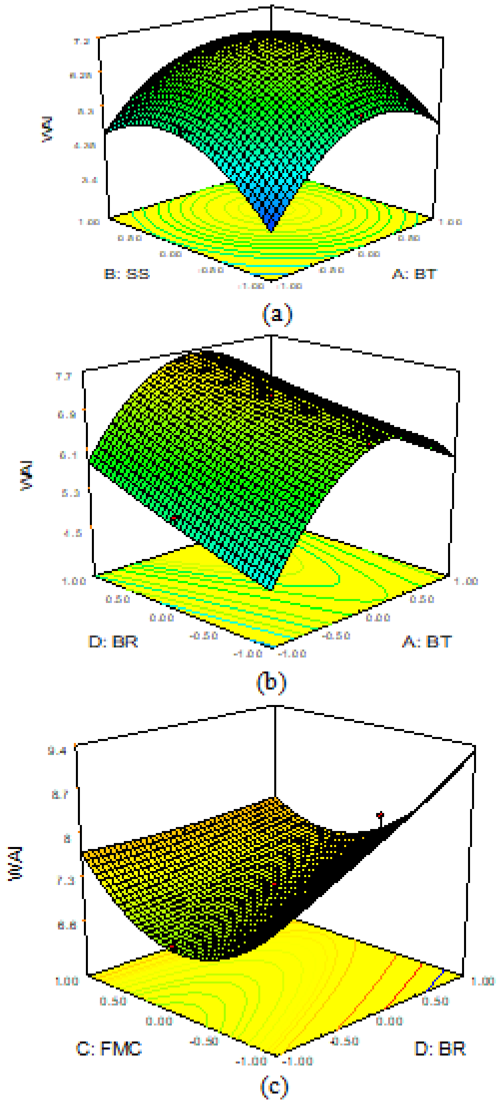


Figure 3.4: Response surface plots for WAI as functions of (a) SS and BT (b) BR and BT and (c) FMC and BR, keeping all processing parameters constant.

During extrusion starch gelatinization will takes place, and *WAI* is an index of gelatinization, since native starch does not absorb water at room temperature (Anderson *et al.*, 1996). As shown in figure 3.4a and b, initially, there was increasing in WAI with increase in barrel temperature and increase of amaranth proportion in the feed, but after obtaining the maximum value, there was a decrease in WAI with further increase in barrel temperature which was in good agreement with the work findings of Mercier *et al.*, (1989). In some cases higher increasing of the temperature will cause the decrease in the WAI. Mercier *et al.*,(1989) reported increasing extrusion temperature from 150 to180^{0}C decreased the WAI, which was probably due to an increase in starch degradation. The effect of barrel temperature on WAI observed in this experiment was not completely in agreement with Ding *et al.*, (2006), who found that *WAI* decreased with increasing the die temperature.

3.2.2 Water Solubility Index, *WSI*

The Model F-value of 26.38 indicates that the model was significant ($P < 0.05$).R^2 (0.9610) and Adjusted R^2 (0.9245) were in reasonable agreement (table3.6). Moreover, the adequate precision (20.576) is greater than 4, indicating a good fit of experimental data and the acceptability of the model for prediction purposes (Montgomery, 2002). Considering these criteria, the following response model was selected for representing the variation of *WSI* for further analysis:

$$WSI = +18.87 + 0.57*A - 0.24*B - 0.23*C + 1.43*D - 0.22*A*B - 0.19*A*C + 0.50*A*D - 0.023*B*C - 0.16*B*D - 0.20*C*D + 0.17*A^2 - 0.45*B^2 - 0.45*C^2 - 0.029*D^2 \quad (3.5)$$

The coefficients of A and D were positive. Therefore, increase in temperature and feed proportion of amaranth in the feed may increase the *WSI* of the extrudates. The coefficients of B and C were negative, therefore increase in screw speed and feed moisture content may decrease *WSI* of the extrudates (Equation 3.1 and table 3.2).

WSI of the extrudates was ranged from 16.359 to 22.217% with an average value of 18.42 % (table 3.5). the maximum *WSI* of the extrudates at coded point (+1,-1,-1,+1) was about 1.36 times more than the minimum *WSI* at the coded point of (-1,+1,+1,-1)(table 3.1). The WSI value is related to the presence of soluble molecules, which has been related to dextrinization (Jorge *et al.*, 2012 and Anderson *et al.*, 1996). An increase in *WSI* therefore shows macromolecular degradation with intensity of extrusion condition (Jose, 2011). Consequently, the WSI increased because starch granules were then more soluble in water (Smith, 1992) and large amount of soluble materials are released during extrusion cooking process.

The barrel temperature and feed proportion (amount of amaranth in the feed) were the most significant independent variables. As can be seen from fig. 3.5, there was slight decrease in water solubility index with increase in screw speed which was in good agreement with Ding *et al.*, (2006) who reported that there was no significant effect of screw speed on the WSI. However, results of effect of temperature on WSI (fig. 3.5) were in good agreement with the Ding *et al.*, (2006) and Laike *et al.*, (2012); which showed increase in WSI with increase in die temperature. Results of WSI were also in agreement with Mercier and Feillet, (1975) who found that WSI increased with increase in temperature at the feed moisture of 18.2%. With the increase in the feed proportion of amaranth, there was increase in WSI (Fig. 3.5) which was somilar to the work findings of Laike *et al.*, (2010).

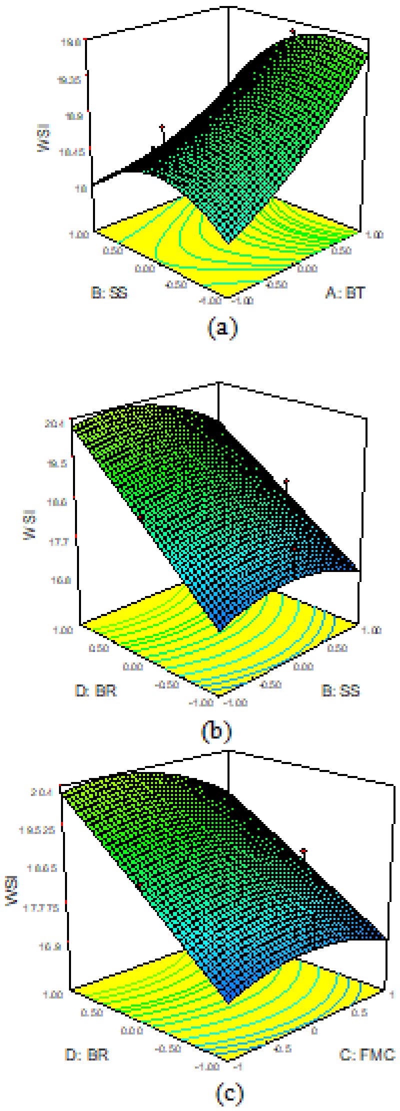


Figure 3.5: Response surface plots for WSI as functions of (a) BT and SS (b) SS and BR and (c) BR and FMC keeping all other parameters constant

Table 3.1: Response variables of extrudates as functions of independent variables

S/N	Coded independent variables				Actual dependent (response) variables				
	A	B	C	D	$B_{den}(g/cm^3)$	$L_{Sp}(cm/g)$	$E_R(mm/mm)$	*WAI(%)*	*WSI(%)*
1	-1	-1	-1	-1	0.2268±0.012^{r}	1.7459±0.019^{ghi}	2.7978±0.082^{h}	3.816±0.08^{o}	16.515±0.11^{kl}
2	1	-1	-1	-1	0.2258±0.065^{r}	2.2193±0.117^{d}	2.9874±0.099^{b}	5.247±0.10^{kl}	16.898±0.79^{j}
3	-1	1	-1	-1	0.2256±0.113^{r}	1.7541±0.018^{ghi}	2.9873±0.053^{b}	5.304±0.10^{k}	16.525±0.82^{kl}
4	1	1	-1	-1	0.2858±0.065^{p}	1.7273±0.068^{hi}	2.9848±0.076^{c}	5.192±0.17^{l}	16.645±0.09^{jkl}
5	-1	-1	1	-1	0.4898±0.104^{h}	1.7924±0.032^{fgh}	2.6361±0.048^{t}	3.01±0.29^{p}	16.679±0.07^{jk}
6	1	-1	1	-1	0.4878±0.061^{h}	1.9592±0.017^{e}	2.6353±0.069^{t}	5.561±0.07^{j}	16.637±0.05^{jkl}
7	-1	1	1	-1	0.4635±0.093^{j}	1.1481±0.083^{l}	2.7458±0.078^{n}	5.104±0.08^{m}	16.359±0.08^{l}
8	1	1	1	-1	0.4568±0.075^{k}	1.9398±0.069^{ef}	2.6764±0.070^{r}	7.275±0.08^{b}	16.580±0.12^{kl}
9	-1	-1	-1	1	0.4785±0.016^{i}	1.5293±0.0148^{j}	2.6687±0.107^{s}	6.639±0.11^{e}	18.564±0.19^{fgh}
10	1	-1	-1	1	0.4568±0.036^{k}	2.8565±0.171^{b}	2.8547±0.095^{g}	6.912±0.14^{d}	22.217±0.08^{a}
11	-1	1	-1	1	0.5675±0.079^{b}	1.7795±0.027^{fghi}	2.7651±0.089^{l}	6.847±0.10^{d}	18.624±0.76^{fgh}
12	1	1	-1	1	0.5384±0.076^{e}	3.6193±0.107^{a}	2.7856±0.074^{j}	6.645±0.06^{ef}	20.647±0.15^{b}
13	-1	-1	1	1	0.6454±0.058^{a}	0.7345±0.045^{m}	2.5427±0.095^{u}	4.101±0.07^{n}	18.374±0.18^{h}
14	1	-1	1	1	0.5673±0.029^{b}	2.5926±0.102^{c}	2.6795±0.083^{q}	5.847±0.08^{h}	20.797±0.17^{b}

15	-1	1	1	1	0.5473±0.081^{c}	1.6264±0.089^{ij}	2.6897±0.112^{p}	5.183±0.17^{ml}	18.437±0.16^{gh}
16	1	1	1	1	0.5067±0.082^{f}	3.6046±0.025^{a}	2.5499±0.057^{v}	6.358±0.16^{g}	18.981±0.19^{e}
17	-1	0	0	0	0.4468±0.055^{l}	0.7174±0.061^{m}	2.7789±0.081^{k}	5.294±0.07^{k}	18.789±0.12^{ef}
18	1	0	0	0	0.4975±0.060^{g}	1.8906±0.103^{efg}	2.7576±0.087^{m}	5.783±0.09^{hi}	19.676±0.11^{d}
19	0	-1	0	0	0.5439±0.072^{d}	1.3171±0.092^{k}	2.7847±0.103^{j}	5.697±0.08^{i}	18.785±0.10^{ef}
20	0	1	0	0	0.4275±0.065^{m}	1.4683±0.071^{jk}	2.7894±0.075^{i}	5.869±0.13^{h}	17.829±0.07^{i}
21	0	0	-1	0	0.1614±0.008^{s}	1.9376±0.081^{ef}	3.0789±0.071^{a}	8.728±0.17^{a}	18.782±0.13^{ef}
22	0	0	1	0	0.2891±0.070^{o}	1.5007±0.049^{j}	2.7472±0.138^{n}	7.047±0.10^{c}	18.424±0.08^{gh}
23	0	0	0	-1	0.2772±0.096^{q}	1.7576±0.035^{ghi}	2.7456±0.094^{n}	6.729±0.08^{e}	18.065±0.15^{i}
24	0	0	0	1	0.2864±0.056^{op}	1.5548±0.019^{j}	2.7285±0.096^{o}	7.278±0.11^{b}	19.989±0.11^{c}
25	0	0	0	0	0.3365±0.061^{n}	1.5337±0.171^{j}	2.8897±0.124^{de}	7.189±0.10^{b}	18.691±0.01^{efg}
26	0	0	0	0	0.3375±0.072^{n}	1.5346±0.021^{j}	2.8887±0.085^{de}	7.199±0.09^{b}	18.683±0.12^{efg}
27	0	0	0	0	0.3381±0.043^{n}	1.5329±0.017^{j}	2.8879±0.078^{de}	7.186±0.09^{b}	18.696±0.09^{efg}
28	0	0	0	0	0.3378±0.060^{n}	1.5351±0.019^{j}	2.8908±0.175^{de}	7.194±0.10^{b}	18.676±0.08^{efg}
29	0	0	0	0	0.3369±0.062^{n}	1.5332±0.026^{j}	2.8899±0.105^{de}	7.187±0.12^{b}	18.689±0.12^{efg}
30	0	0	0	0	0.3385±0.059^{n}	1.5341±0.028^{j}	2.8901±0.086^{de}	7.189±0.11^{b}	18.678±0.09^{efg}

Where; A:Barrel temperature(^{0}C), B:Screw speed(rpm), C:feed moisture content(%) and D: blend ratio(%) , B_{den}= bulk density, E_R =expansion ratio, L_{Sp}=specific length, WAI = water absorption index, WSI = water solubility index, Values within the same column with different letters are significantly different ($p< 0.05$) and were means of three determinations.

Table 3.2: Regression coefficients of second order polynomial and their significance for E_R, D_{bulk}, L_{sp}, *WAI and WSI*

Coeff.	Expansion ratio (mm/mm)			Bulk density (g/cm^3)			Specific length(cm/g)			Water Absorption Index (%)			Water Solubility Index (%)		
	Coeff. value	F	P	Coeff. value	F	P	Coeff. value	F	P	Coeff. value	F	P	Coeff. value	F	P
B_0	0.51	14.78	< 0.0001	0.43	18.58	< 0.0001	11.72	20.60	< 0.0001	42.51	28.50	< 0.0001	54.65	26.38	<0.0001
A	2.202	0.89	0.3603	2.592E-004	0.16	0.6990	5.10	125.52	< 0.0001	5.04	47.31	< 0.0001	5.82	39.32	<0.0001
B	4.579	1.85	0.1937	5.894E-004	0.35	0.5610	0.20	5.04	0.0402	2.68	25.19	0.0002	1.01	6.84	0.0195
C	0.25	99.78	< 0.0001	0.092	55.19	< 0.0001	0.29	7.05	0.0180	1.90	17.83	0.0007	0.96	6.46	0.0226
D	0.059	23.93	0.0002	0.12	70.55	< 0.0001	0.83	20.31	0.0004	4.09	38.35	< 0.0001	36.72	248.07	<0.0001
AB	0.040	16.29	0.0011	4.687E-004	0.28	0.6038	0.036	0.88	0.3623	0.55	5.18	0.0379	0.76	5.13	0.0387
AC	0.020	8.12	0.0122	1.153E-003	0.69	0.4188	0.087	2.15	0.1635	2.45	22.96	0.0002	0.56	3.79	0.0705
AD	1.122	4.537	0.9472	3.025E-003	1.81	0.1980	1.96	48.21	< 0.0001	0.58	5.46	0.0337	3.97	26.80	0.0001
BC	1.332	0.54	0.4743	0.012	7.44	0.0156	0.032	0.78	0.3920	1.02	9.53	0.0075	8.281	0.056	0.8162
BD	9.653	3.90	0.0669	6.760E-006	4.054	0.9501	1.03	25.41	0.0001	0.86	8.07	0.0124	0.43	2.91	0.1085
CD	7.718	3.12	0.0977	0.031	18.81	0.0006	0.024	0.59	0.4544	3.01	28.27	< 0.0001	0.63	4.25	0.0571
A^2	0.010	4.22	0.0579	0.046	27.73	< 0.0001	0.013	0.31	0.5838	5.03	47.26	< 0.0001	0.079	0.53	0.4766
B^2	5.165	2.09	0.1690	0.056	33.64	< 0.0001	8.884	0.022	0.8844	3.42	32.14	< 0.0001	0.52	3.49	0.0814
C^2	0.017	6.93	0.0188	0.033	19.94	0.0005	0.31	7.59	0.0147	2.36	22.18	0.0003	0.52	3.54	0.0796
D^2	0.023	9.38	0.0079	8.343E-003	5.00	0.0409	0.21	5.07	0.0397	0.013	0.12	0.7311	2.183	0.015	0.9050
R^2	0.9324				0.9455			0.9506			0.9638			0.9610	
Adjd. R^2	0.8693				0.8946			0.9044			0.9300			0.9245	
Adeq. Prec.	16.078				16.206			19.753			23.099			20.576	
Lack of fit	0.000				0.000			0.002			0.000			0.001	

4. Conclusion

Designed experiments were conducted following Response Surface Methodology (RSM) for the extrusion process to produce teff-amaranth based extrudates using co-rotating twin screw food extruder. The RSM was found to be effective technique to investigate the optimum values of expansion ratio, bulk density, specific length, water absorption index and water solubility index of the extrudates. From the results, it is observed that amaranth could be incorporated to the extrudates up to 15%.

Teff-amaranth extrudates production has potential of increased provision of food especially in the aviation industry, refugee camps, food aids, for areas prone to protein energy malnutrition and those living in war torn famine ravaged areas of Africa. This product could make a great contribution to food supply in Africa including Ethiopia especially to mitigate the problem of famine. This study represents the first investigation using teff-amaranth flour to determine physical property (expansion ratio, bulk density, specific length) and functional property (WAI and WSI) to investigate the optimum values. Therefore, promising results were obtained for the development of teff- amaranth based extrudates to produce at commercial level.

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