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# Effects of Feed Moisture Content, Soybean Ratio and Barrel Temperature on Physical and Functional Properties of Extruded Maize-Soybean Flour Blends

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**Abstract**

The effects moisture content, temperature and soybean ratio on expanded product characteristics of extruded maize-soybean blends were studied. Response surface methodology was used to study the effects of extrusion conditions on extrudate properties taking barrel temperature (BT), feed moisture content (FM) and soybean flour ratio (SR) as factors. Expansion ratio (ER), water absorption index (WAI), water solubility index (WSI), hardness and colour (*b** - (+) yellowness) of the extrudates were determined. BT and FM had significant effects on ER ($p < 0.05$). At low FM levels, ER increased with BT. It was observed that both FM and BT significantly affected WAI and WSI. WAI increased as FM increased. Increasing FM to 20% resulted in a decrease in WSI, beyond which an increase was observed. Hardness increased significantly as feed moisture content increased. High SR content significantly increased the extrudate hardness. FM had no significant effect on colour. Colour increased as the SR and BT increased. Significant regression models explained the effects of SR, FM, and BT on all response variables. All of the response variables' $R^2$, were higher than 0.89.

**Keywords**: Maize, Soybean, moisture content, extrusion.

## Introduction

Global maize production amounts to an annual average of 1,162 million tonnes (OECD/FAO 2021). In Sub-Saharan Africa, maize (*Zea mays*) accounts for up to 40% of cereal production (FAOSTAT 2016). Globally, it is the third most consumed cereal after wheat and rice (FAO 2020). In Uganda, it provides over 40% of the calories consumed in rural and urban areas (NAADS 2020). It is thus readily available in Uganda and is most commonly consumed in roasted form, steamed or used in porridges and maize meal (*posho*) (Muyanja et al. 2020). The porridge is mainly used as complementary food for infants. Maize meal and porridge are commonly served in schools, hospitals and prisons among others. However, despite having a high starch content of about 70%, maize grain is low in protein (about 11%) and essential amino acids; lysine and tryptophan (mamatha et al. 2017). On the other hand, soybean (*Glycine max*) contains about 40% protein and 20% oil; making it one of the most nutritious plant foods in the world (Kure et al. 1998, Tukamuhabwa and Obua 2015). Its amino acid profile is similar to that of animal protein which gives its protein a superior biological value compared to other plant-based proteins (García et al. 1998). Soybeans are also high in calcium, iron, vitamins, phosphorus and fibre (Olaoye et al. 2006). Therefore, given its nutritional superiority, optimum blending of maize flour with soybean flour can result in more nutritious composite flour (Tukamuhabwa and Obua 2015) suitable production for different food products such as porridge and snacks. The presence of antinutritional factors such as protease inhibitors, lectins, phytates, and tannins limits the utilization of soybean despite its health-promoting components (Bajpai et al. 2005).

Various processing techniques, such as popping, roasting, baking, and extrusion cooking, can be used in the development of instant and convenient food products. Extrusion cooking is a feasible alternative for manufacturing water reconstitutable foods for blended flours (Pathania et al. 2013) as well as puffed snack products. Extrusion processing is a high temperature/short time technology that offers numerous advantages including versatility, high productivity, low operating costs, energy efficiency and high quality of resulting products (Milán-Carrillo et al. 2012). The extrusion process involves interaction among flour characteristics, such as moisture content and chemical composition, as well as processing parameters, including temperature, screw speed, feed rate and screw configuration (Gulati et al. 2016).

Extrusion processing affects the physical attributes, sensory properties and the nutritional quality of food products. Extrusion processing has been reported to increase starch and protein digestibility (Diaz et al. 2013). It also breaks down mineral-antinutrients complexes by hydrolysis thereby increasing the mineral availability in the soybean extrudates, altering vitamins, and eliminating anti-nutrient factors such as phytic acid and trypsin inhibitor activity which modifies the nutritional properties of the extrudates (Singh et al. 2007, Sundarrajan 2014). Flour moisture content affects both degree of cooking and shear of starch which has major impact on expansion volume (Thymi et al. 2005, Oke et al. 2013, Kaur et al. 2022). Also, a number of studies have been carried out on temperature and screw speed since they are easily varied extrusion parameters and have significant effects on physical changes on the flour mixture while inside the extruder barrel (Altan et al. 2009). The material composition (such as the presence of protein, starch, fibre, and moisture) and the processing parameters during extrusion determine the physical and functional attributes of the product (water solubility index, water absorption index, bulk density, expansion, texture, and so on). Thus, the aim of this work was to determine the effects of flour moisture content, barrel temperature and soybean ratio on physical and functional properties of extruded maize-soybean flour blend.

## Materials and Methods

### Preparation of maize and soybean flour

Commercially dried maize grain and soybeans were obtained from Nakasero Market, Kampala, Uganda. Maize and soybean were milled into flour using a commercial mill (30B, Changzhou Erbang Drying Equipment Co. Ltd, China), blended, then packaged in polyethylene bags and stored for 24 hours at 4 °C before extrusion and further analysis.

### Experimental design

Maize and soybean flour blends were prepared with plain maize flour used as a control. The effects of three extrusion factors: barrel temperature (BT) at third zone (90–150 °C), feed moisture content (FM) (10–20%) and soybean flour ratio (SR) (0–30%), on the maize-soybean flour extrudate properties were studied while keeping other factors such as feed rate, screw speed and configuration constant. The levels of these factors were determined based on preliminary extrusion trials. Central composite design (CCD) was selected as the most suitable experimental design for building a second order (quadratic) model for the response variables without needing to use a complete three-level factorial experiment. The material characteristics and the extrusion conditions were independent variables for the production of extrudates and varied over three levels as shown in Table 1.

**Table 1:** Central composite design with the observed responses for physical characteristics of maize-soybean extrudates

| | Variables | | | | Coded | | | Product responses | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Run | BT (°C) | FM (%) | SR (%) | Actual BT (°C) | BT | MC | SR | WAI (g g-1) | WSI (%) | Colour b* | H (N) | ER |
| 1 | 105 | 12.5 | 7.5 | 110 | -1 | -1 | -1 | 7.43 | 37.21 | 0.30 | 50.37 | 13.53 |
| 2 | 105 | 12.5 | 22.5 | 107 | -1 | -1 | +1 | 4.37 | 30.80 | 1.47 | 61.68 | 12.36 |
| 3 | 105 | 17.5 | 7.5 | 109 | -1 | +1 | -1 | 6.18 | 20.50 | 0.33 | 82.14 | 8.72 |
| 4 | 105 | 17.5 | 22.5 | 104 | -1 | +1 | +1 | 4.63 | 17.26 | 1.60 | 95.84 | 6.15 |
| 5 | 120 | 15 | 15 | 129 | 0 | 0 | 0 | 5.64 | 23.15 | 1.27 | 74.37 | 11.64 |
| 6 | 120 | 15 | 15 | 121 | 0 | 0 | 0 | 5.64 | 24.25 | 1.23 | 74.32 | 11.79 |
| 7 | 120 | 15 | 15 | 122 | 0 | 0 | 0 | 5.68 | 23.33 | 1.23 | 74.32 | 11.78 |
| 8 | 120 | 15 | 15 | 127 | 0 | 0 | 0 | 5.58 | 24.19 | 1.33 | 74.83 | 11.68 |
| 9 | 135 | 12.5 | 7.5 | 141 | +1 | -1 | -1 | 9.20 | 41.47 | 0.37 | 40.15 | 12.80 |
| 10 | 135 | 12.5 | 22.5 | 138 | +1 | -1 | +1 | 4.65 | 34.45 | 1.93 | 51.38 | 13.16 |
| 11 | 135 | 17.5 | 7.5 | 146 | +1 | +1 | -1 | 7.21 | 39.40 | 0.37 | 78.67 | 10.36 |
| 12 | 135 | 17.5 | 22.5 | 148 | +1 | +1 | +1 | 5.12 | 18.81 | 1.97 | 84.80 | 5.93 |
| 13 | 150 | 15 | 15 | 155 | +1.682 | 0 | 0 | 6.21 | 22.52 | 0.52 | 48.2 | 7.15 |
| 14 | 90 | 15 | 15 | 95 | -1.682 | 0 | 0 | 5.52 | 19.04 | 1.21 | 72.9 | 10.12 |
| 15 | 120 | 20 | 15 | 128 | 0 | +1.682 | 0 | 4.18 | 25.89 | 0.25 | 80.1 | 8.94 |
| 16 | 120 | 10 | 15 | 121 | 0 | -1.682 | 0 | 5.72 | 28.59 | 0.32 | 77.8 | 16.21 |
| 17 | 120 | 15 | 30 | 129 | 0 | 0 | +1.682 | 5.02 | 31.86 | 0.29 | 91.1 | 5.25 |
| 18 | 120 | 15 | 0 | 123 | 0 | 0 | -1.682 | 6.06 | 34.52 | 1.38 | 68.2 | 12.18 |

FM = feed moisture content (%, wet basis); BT = barrel temperature; SR = soybean flour ratio in feed; ER = expansion ratio; WAI = water absorption index; WSI = water solubility index; H = hardness; *b** = yellowness (+) of ground extrudates.

**Extrusion process**

A co-rotary and intermeshing twin-screw extruder (Double screw inflation food machine DP70-III, Jinan Eagle Machine Co. Ltd), with 7 cm screw diameter, 141.7 cm screw length, and 4 mm diameter die opening, was used. The extruder barrel had three temperature zones with those of the first two zones maintained at 60 $^o$C and 90 $^o$C, respectively. The temperatures of the last zone were set according to the experimental design. The extruder feeding frequency of 30 Hz and cutting frequency of 50 Hz were kept constant. The temperature of the last two zones was also higher than set value and needed constant observation because this usually occurs due to frictional heat generated during extrusion. Preliminary experiments were conducted to determine the range of extrusion conditions that produced extrudates with an unburnt appearance and no clogging in the extruder barrel.

The moisture content of a 5 kg batch of the maize-soybean flour mixture representing a corresponding experimental run was adjusted as per the experimental design. The moistened flour mixtures were then sealed in polyethylene bags for storage and then fed into the extruder barrel when needed. The extrudates for each experimental condition were air-dried (25 °C) before further analyses. All treatments and analyses were performed in triplicate.

**Evaluation of product characteristics**

**Expansion ratio**

The expansion ratio (ER) of the extrudates was determined as described by Brennan et al. (2008). It was calculated by measuring the radial diameter at three positions along the length of randomly selected extrudates using a vernier caliper with 0.01 mm accuracy (Neiko 01407A Electronic Digital Caliper; Neiko Tools US, LaPorte, IN). The radial diameter was then divided by the extruder die diameter. The average of ten readings was reported for each extrusion setting.

**Water absorption and water solubility indices**

The water absorption index (WAI) and water solubility index (WSI) were measured using the method by Singh and Singh (2003) and Sahu and Patel (2021). Ground extrudates (2.5 g) were suspended in 30 mL of potable water at room temperature (~25 $^o$C) for 30 min with intermittent stirring. This was followed by centrifugation at 3000 g for 10 min. The supernatant was decanted into a tarred evaporating dish. The WSI was calculated as percent weight of dry solids in the supernatant to the original weight of sample (Equation 1). The WAI was the weight of gel obtained after removal of the supernatant per unit weight of original dry solids (Equation 2).

$$\text{WAI (g/g)} = \frac{\text{Weight of wet gel} - \text{Dry weight of extrudate}}{\text{Dry weight of extrudate}} \quad (1)$$

$$\text{WSI (\%)} = \frac{\text{Weight of dry solid in the supernatant}}{\text{Dry weight of extrudate}} \times 100 \quad (2)$$

**Hardness**

Hardness was determined using a penetrometer (AFG series, T.W.L. Force Systems, Stubbington, United Kingdom). The probe was attached onto the penetrometer and then the gauge fitted onto the stand. The penetrometer was allowed to stabilize for 20 min and it was then zeroed by pressing the reset button. Each sample was placed in between the probe and the stand using a lever. The probe was then gently lowered to press against the maize-soybean extrudate and the reading on the gauge was recorded in degrees. The value obtained was then converted to mm (1$^o$ = 0.01 mm) using a conversion table supplied with the penetrometer. The higher the degrees obtained, the softer the sample. The tests were conducted in a compression mode (Meng et al. 2010). Ten measurements were performed for each extrusion condition and their average value was recorded.

**Colour of ground extrudates ($b$*)**

The colour of the ground extrudates was measured using a Lovibond CAM-System 500 (The Tintometer Ltd., UK). The CIE-Lab scale was used for evaluation of $b$* for (+) yellowness. An average of ten readings was reported for each sample.

**Data analysis**

Responses, that is, expansion ratio (ER), water absorption index (WAI), water solubility index (WSI), colour of ground extrudates ($b$*) and hardness (H) obtained from the proposed experimental design were subjected to regression analysis in order to assess the effects of feed moisture content (FM), barrel temperature (BT) and soybean ratio (SR). A second-order polynomial equation was used to express the responses as a function of the independent variable, which is given in Equation (3).

$$y_i = b_0 + \sum_{i=1}^{\infty} b_i x_i + \sum_{i=1}^{\infty} b_{ii} x_i^2 + \sum_{i=1}^{\infty}\sum_{i=1}^{\infty} b_{ij} x_i x_j \quad (3)$$

Where: $y_i$ is predicted response, $x_i$ ($i$ = 1, 2, 3) are independent variables (FM, SR and BT), respectively. Whereas $b_o$, $b_i$, $b_{ii}$ and $b_{ij}$ are coefficients for intercept, linear quadratic and interactive effects, respectively.

The response surface methodology was applied to fit the experimental data for each response using the R 3.2.5 (R Core Team 2016) statistical package and 3D response surface plots were generated. Data were subjected to analysis of variance to examine the statistical significance of the terms. The adequacy of each regression model for the responses was checked by correlation coefficient, $R^2$ and P-value. In addition, significance of lack of fit term was used to judge the adequacy of model of fit.

**Results and Discussion**

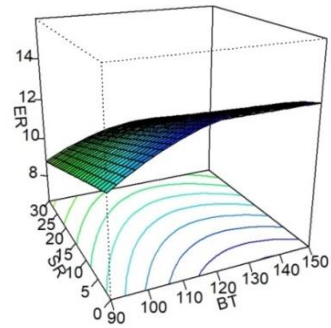
**Influence of extrusion parameters on product characteristics**

***Expansion ratio***

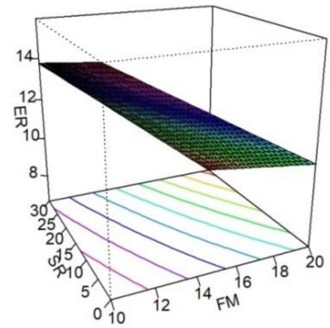
The effects of barrel temperature (BT), feed moisture content (FM) and soybean ratio (SR) on expansion ratio of the extrudates are shown in Figure 1. The ER was lowest and highest at 30% and 0% SR, respectively in the maize-soybean blend mix (Figure 1a). At low feed moisture levels, ER increased with BT before it reached a critical level and then declined (Figure 1b). Table 2 shows the regression coefficients for each response surface equation and model fit parameters. The ER of the maize-soybean blend extrudates ranged from 5.25 to 16.21 with the highest expansion observed at the lowest moisture condition (10%). The linear regression coefficients, quadratic coefficient of BT and interaction terms of SR with BT and FM were significant ($p < 0.05$).

The product with the highest ER (16.21) was produced at low moisture (10%) and intermediate temperature (121 °C). The increase in moisture content of feed causes a decline in the expansion of extrudates. Oke et al. (2013) and Kaur et al. (2022) explained that a decrease in moisture induces drag forces which increases pressure on the die and results in more expansion of the extruded product.

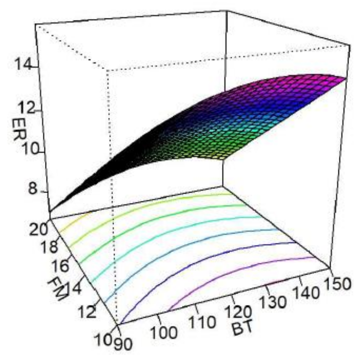
The shearing effect of the screw causes the starch to gelatinize hence favouring expansion (Chinnaswamy and Hanna 1988a). Studies have also shown that as moisture content increases, the melt elasticity of starch reduces and prevents it from expanding (Ilo et al. 1999, Ding et al. 2006, Diaz et al. 2015). Devi et al. (2013) reported that the decrease in ER is attributed with increase in SR (Figure 1a) to increasing protein content. Yağcı and Göğüş (2008) attributed this decrease in ER to the dilution effect of soybean on starch which affects the extent to which starch gelatinizes hence, affecting the rheological properties of the melted food material.




**(a)**




**(b)**




**(c)**

**Figure 1:** Response surface graphs illustrating the effects of (**a**) barrel temperature and soybean ratio, (**b**), feed moisture content and soybean flour ratio and (**c**) barrel temperature and feed moisture content, on the expansion ratio of the extrudates.

**Table 2:** Regression coefficients for each response surface equation and model fit parameters

| **Effect** | **ER** | **WAI (g g$^{-1}$)** | **WSI (%)** | **H (N)** | ***b**** |
|---|---|---|---|---|---|
| (Intercept) | -1.37 | 13.27 | 138.2 | -62.16 | -3.36 |
| BT | 0.33** | -0.093*** | -1.63*** | 1.50*** | 0.063*** |
| FM | -0.42*** | -0.109** | -2.19*** | 2.92** | 0.015 $^{NS}$ |
| SR | 0.09* | -0.13*** | 0.55** | 0.68** | 0.019*** |
| BT x FM | -0.0009 $^{NS}$ | -0.00044* | 0.0105*** | 0.005** | -0.0001 $^{NS}$ |
| BT x SR | -0.0008** | -0.00057** | -0.005** | -0.0021* | 0.0002*** |
| FM x SR | -0.0062*** | 0.0066*** | -0.0173** | - 0.0045$^{NS}$ | 0.0002 $^{NS}$ |
| BT$^2$ | -0.0012*** | 0.00051*** | 0.007* | -0.007** | -0.0003** |
| FM$^2$ | -0.00022$^{NS}$ | -0.0006$^{NS}$ | -0.01* | -0.0008* | 0.09$^{NS}$ |
| SR$^2$ | -0.000032$^{NS}$ | -0.10009$^{NS}$ | -0.09$^{NS}$ | -1.02$^{NS}$ | -0.035$^{NS}$ |
| $R^2$ | 0.980 | 0.993 | 0.950 | 0.996 | 0.992 |
| Adjusted $R^2$ | 0.975 | 0.992 | 0.937 | 0.996 | 0.989 |

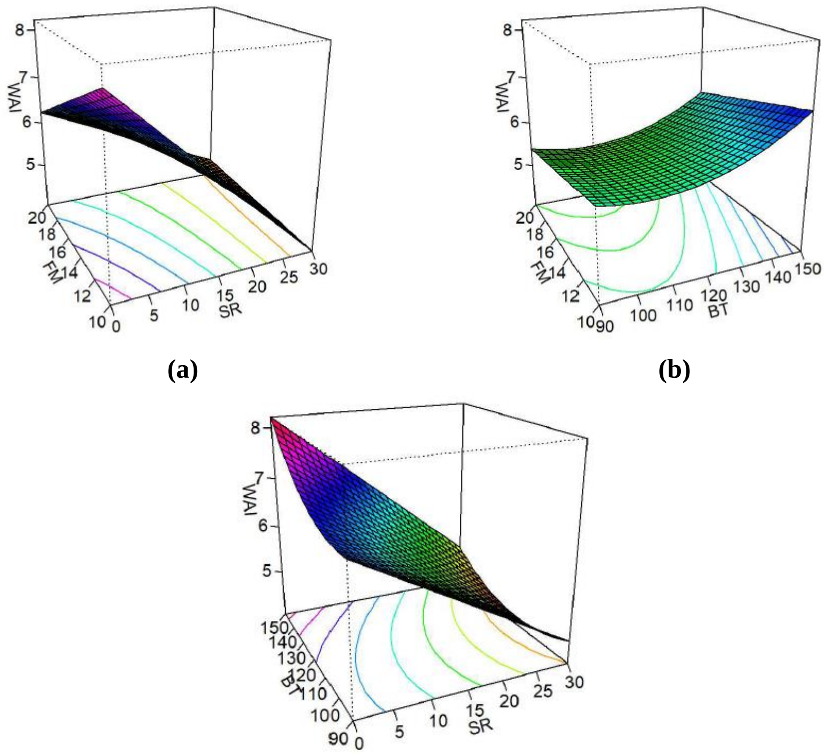
H = hardness; ER = expansion ratio; BT = barrel temperature; FM = feed moisture content; SR = soybean flour; WAI = water absorption index; WSI = water solubility index; *b** = colour of ground extrudates (+) yellowness; NS = not significant. * Significant at 10% ($p < 0.1$); ** significant at 5% ($p < 0.05$); *** significant at 1% ($p < 0.01$).

The observed increase in ER with BT at low FM (Figure 1b) could be explained by dextrinization of starch and weakening of starch structure (Dogan and Karwe 2003). In a similar study, Camire and King (1991) suggested that water might be more tightly bound by the non-starch polysaccharides in fibre which hinders water loss at the die, hence reducing expansion unlike protein and starch.

***Water absorption and water solubility indices***

Figures 2 and 3 summarize the effects of barrel temperature (BT), feed moisture content (FM) and soybean ratio (SR) on the WAI and WSI of the extrudates, respectively. The WAI decreased significantly as SR increased (Figure 2a and 2c). From the scaled estimates, it was observed that both moisture and temperature contributed to a substantial portion of the variation in WAI and WSI. As FM increased, WAI showed an increasing trend, while with increasing SR there was an initial increase in WAI and then a decrease (Figure 2a). Lower FM had the highest WSI. An increase in FM was also associated with a significant increase in WSI ($p < 0.05$).

It was also noted that the quadratic effect of a combination of moisture content and barrel temperature was the main contributing factor for change in WSI. As shown in Table 2, the WAI values obtained for the maize-soybean blend extrudates ranged from 4.3 to 9.20 g $g^{-1}$, while WSI ranged from 17.26 to 41.47%. The linear and quadratic effects of BT had significant effects on both WAI and WSI (Table 2), while the linear effects of SR and FM and the interaction between variables also had significant effects on both WAI and WSI.




(c)

**Figure 2:** Response surface graphs illustrating the effects of (**a**) feed moisture content and soybean ratio, (**b**) feed moisture content and barrel temperature, and (**c**) barrel temperature and soybean flour ratio on the water absorption index (WAI) of the extrudates.

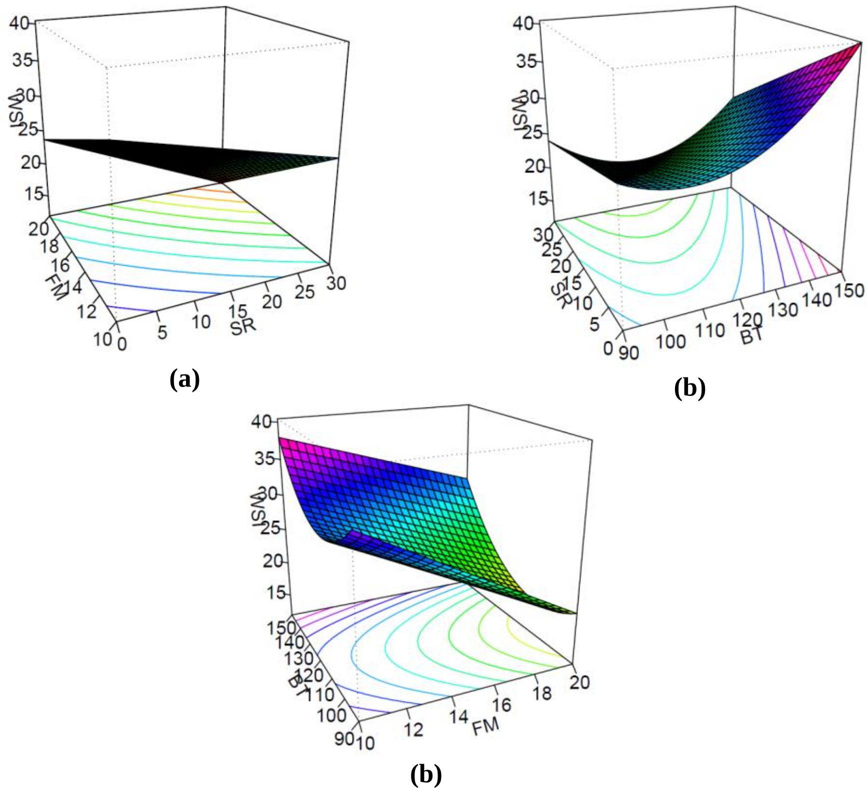



**Figure 3:** Response surface graphs illustrating the effects of (**a**) feed moisture content and soybean ratio, (**b**) barrel temperature and soybean ratio, and (**c**) feed moisture content and barrel temperature on the water solubility index (WSI) of the extrudates.

WAI and WSI are important measures during extrusion cooking and are related to the degree of starch conversion or damage (De Mesa et al. 2009). The significant decrease in WAI as SR increased (Figure 2a and 2c) could be due to reduction in the starch content (Kumar et al. 2015). Soybean addition decreases the starch content hence affecting the extent of starch gelatinization in the extruder hence reduction of water absorption capacity. A similar effect was reported by Chakraborty et al. (2011) when they added non-starch components in the millet-legume blend. In this study, screw speed was fixed but a substantial portion of the variation in WAI has been attributed to it. However, screw speed is not considered an important contributor to changes in WSI.

However, the trends of various extrusion parameters on WSI were similar to extruded rice (Ding et al. 2005). The dramatic influence of FM and BT on WAI was in agreement with Ding et al. (2005) and Yağcı and Göğüş (2008). Increasing FM and BT promotes internal mixing and uniform heating, which enhances starch plasticizing and increases WAI (Lawton et al. 1972). On the other hand, excessive temperature or low moisture content significantly decreases the WAI which can be explained by prevalence of plasticizing over crystallisation (Ding et al. 2006). WSI was maximum at lower moisture content; increasing moisture content to 20% resulted in a significant decrease in WSI (Figure 3). Further increase in FM resulted in increase in WSI. This can be explained by greater shear degradation of starch at lower moistures making starch fragments more soluble in water (Yağcı and Göğüş 2008), while high moisture can have plasticizing effect on starch granules, thus preventing them from degradation by shear (Hagenimana et al. 2006).

***Hardness***

The effects of BT, FM and SR on hardness of the extrudates are shown in Figure 4. The BT, FM and SR had significant effects on extrudate hardness (Table 2). In Figure 4b, hardness increased significantly with increase in feed moisture content ($p < 0.05$). BT decreased hardness with a highly significant quadratic effect at $p < 0.05$ (Table 2 and Figures 4a & 4c). The SR had a significant effect on hardness at $p < 0.05$ (Table 2). An increase in soybean content led to an increase in hardness of the extrudates (Figure 4).

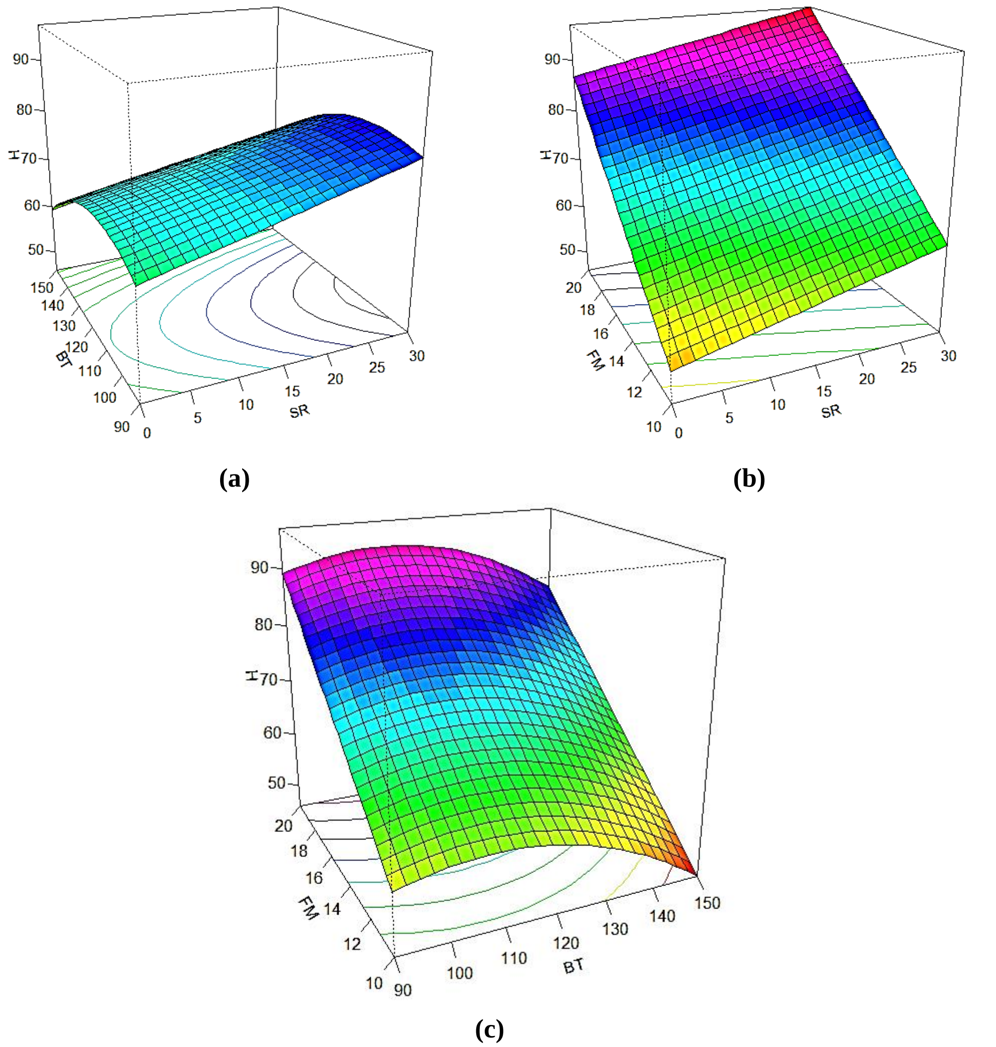



**Figure 4:** Response surface graphs illustrating the effects of (**a**) barrel temperature and soybean ratio, (**b**) feed moisture content and soybean ratio, and (**c**) feed moisture content and barrel temperature on the hardness (H) of the extrudates.

Seth et al. (2015) and Pardhi et al. (2019) have reported similar findings. They attributed this to the reduction in expansion as a result of increase in moisture content. Researchers have studied the relationship between hardness and moisture content extensively (Sebio and Chang 2000, Kumar et al. 2010, Chiu et al. 2013). They noted an increase in hardness with increase in moisture content.

Increasing BT decreased hardness of the extrudates (Table 2 and Figure 4a) possibly due to the enhanced degree of superheating of water in the extruder. This encourages bubble formation, as well as lowers the melt viscosity within the extruder, resulting in low density extrudates with small and thin cell walls, lowering the hardness (Sangnark 2015). The increased hardness of the extrudates with increased SR is reported elsewhere (Chinnaswamy and Hanna 1988b, Coulter and Lorenz 1991, Lue et al. 1991, Devi et al. 2013, Tobias-Espinoza et al. 2019). These authors associated the incorporation of protein or dietary fibre sources to harder extrudates which is consistent.

***Colour of extrudates* (*b**)**

Colour is one of the most important characteristics of extruded products since it shows extent of thermal treatment. Changes in colour can be used as an indicator of extent of browning reactions for example caramelization, maillard reaction and degree of cooking plus pigment degradation that take place during extrusion cooking (Serge et al. 2011). Yellowness values ($b^*$) of the ground extrudates ranged from 0.25 to 1.97. Barrel temperature and soybean ratio had significant effects ($p < 0.05$) on yellowness (Table 2). FM content had no significant effect on yellowness of the extrudates.

Yellowness increased as the soybean ratio and barrel temperature increased. Studies have shown that increase in $b^*$ value can be due to Maillard reactions between amino acids and reducing sugars in the blended flour during extrusion cooking (Falade and Omiwale 2015, Djeukeu et al. 2017). Notably, the moisture levels at specific soybean ratios exhibited significant differences ($p < 0.05$) in yellowness ($b^*$). It has also been suggested that when the screw speed increases, the shearing impact within the barrel increases, favouring the formation of coloured compounds.

**Conclusion**

The effects of barrel temperature, feed moisture content and soybean flour ratio, on maize-soybean flour extrudates were studied while keeping other factors such as feed rate and screw speed constant. Functional and physical properties of the extrudates such as expansion ratio, water absorption index, water solubility index, hardness and colour were significantly affected by the changes in feed composition, moisture content and also barrel temperature. Barrel temperature and feed moisture content had significant effects on expansion ratio, water absorption index, water solubility index and hardness. Barrel temperature and soybean ratio had significant effects on colour of the extrudates. Feed moisture content had no significant effect on colour of the extrudates.

**Competing Interests**

The authors declare that there are no competing interests.

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