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Predictive Modeling of Functional and Physical Properties of Extrusion Cooked Ready-To-Eat Corn Meal

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ABSTRACT

Cornmeal is the product of corn-based food processed or pre-cooked through extrusion to produce a ready-to-eat breakfast. The quality of the meal depends on the extrusion cooking factors and process variables. The study focused on the effects of screw speed (SS: 100-120 rpm), barrel temperature (BT: 170-190℃), feed rate (FR: 40-60 rpm), and moisture content (MC: 20-25%) on: water absorption index (WAI), water solubility index (WSI), bulk density (BD) and expansion ratio (ER) to predict functional and physical properties of extruded corn meal. Brabender single-screw laboratory-scale extruder was used to process corn flour into ready-to-eat corn meal. JMP Pro 16 was used for experimental design, which was conducted in triplicate using: Central composite response surface methodology. Design Expert 13 and MATLAB 2020b were used respectively for data analysis and visualization. The main, interaction and quadratic effects of SS, BT, FR, and MC were evaluated on WAI, WSI, BD and ER. The significance level was established at $p \leq 0.05$. A second-degree polynomial equation was fitted for each response variable as a function of extrusion cooking process factors. Adequate precision/R-Square values for WAI, WSI, BD, and ER respectively were 25.92/0.97, 11.69/0.99, 10.00/0.94, and 22.51/0.99, which measured each model's degree of fitness. These values proved that each model have good predictability and was fitted for prediction purposes.

Keywords: Corn, Extrusion, Functional, Physical, Properties

INTRODUCTION

Extrusion cooking technology is a thermo-mechanical, short-time process. It is unique and crucial for food processing and product development (Danbaba *et al*, 2019). Its applications cover a very wide range of products, which include pasta, noodles and other food process and development.

Extrusion cooking technique possesses a number of properties; energy efficient, environmentally friendly, low or zero effluent, prolific, increase protein digestibility, versatility and adaptability, which make it generally suitable and acceptable in food manufacturing settings (Okunola, *et al.*, 2023). However, researchers have employed this technology to produce arrays of ready-to-eat meals (RTEM) using both single and double screw extruders (Jakkanwar *et al*., 2018, Hegazy *et al*., 2017, Patil *et al*., 2016 and Danbaba *et al*., 2015). The modern lifestyle and time-saving needs have increased consumers demand for extrusion cooked of ready-to-eat corn meal products (Pasqualone *et al*., 2020). Extruded products are on high demand, cherished and valued by many consumers for some of the following reasons, namely: Customization, variety, quality, consistency, enhanced, functionality, cost-effectiveness and sustainability. The consumers' increasing demand has necessarily increase production and the need to further study process factors' influence on extrudate properties for better process and product handling. Corn is commonly used in extrusion processing to produce various food products for the following benefits: High starch content, good source of nutritional values, corn is economical for large scale production, and it has good extrusion cooking properties. (Agrivi, 2024). Moreover, corn has industrial applications and most food processing industries used it as raw material. And in terms of technological consideration, corn produces high quality products than wheat (Tomasz *et al.*, 2015., Moscicki 2011). Among cereal group, with the exception of rice, corn has superior starch content ranged between 71.0 – 74.0%db and gelatinization temperature range 62 – 72°C (Caldwell *et al*, 2016). Using a single screw extruder, Jakkanwar *et al*., (2018) evaluated and reported that bulk density (BD) and hardness (HD) increased with increase in feed moisture content (FMC) and barrel temperature (BT), however, expansion ratio (ER), water absorption index (WAI), water solubility index (WSI), and overall acceptance (OA) decreased. Singh, *et al*., (2014) studied the influence of feed moisture content (FMC), screw speed (SS), and BT on (SME), (HD), (BD), (WSI) and (WAI) of potato-based snack using a twin-screw extruder; he established that FMC influenced all product responses. However, SS and BT had no influence on the specific mechanical energy (SME), WSI and hardness (HD) of the product. Increasing FMC increases BD, WAI, and hardness, while it decreases SME and WSI. The BD, WAI, and hardness of the snacks reduced as the SS increases. But, the SME, BD, WAI, and HD decrease as the BT increases, but the WSI also increases.

Okunola *et al*., 2023 reported the effects of extrusion cooking process factors on WSI, WAI, BD and ER of the extruded snack using regression analysis. Okunola *et al*., 2023 used regression analysis in the reported work which lacked statistical values such as p-value, R-Square and Adequate precision. This research work has these statistical values. However, the report indicated that MC and SS had negative effect on ER of the extrudate, while BT had positive influence, as increase in BT increases ER. However, MC had positive influence on BD while BT and SS had negative effects. The result further observed that WAI increased with an increase in MC, BT, and SS. But WSI decreased with an increase in MC, BT, and SS. While BT influenced the ER of the extrudate. Therefore, the objective of this study is to model the functional and physical properties of ready-to-eat corn meal for prediction purposes. In food processing industries, Emprical modeling has the following advantages: Minimizes material wastage, shortens time needed for management to take decision and reduces costs of repeating and running experiment.

MATERIALS AND METHODS

The experiments were conducted using the commercial corn flour meal (CFM) product of Stapro Industry Nigeria Limited, Lagos. It was a candidate raw material because it possesses superior quality in terms of its starch content (Moscicki, 2011). The CFM was prepared by weighing 250g for each sample.

The initial moisture content of 7.09 % (w.b.) of CFM was determined using the standard 1666-1973(E) (ISO 1985) oven drying method (This indicated the initial moisture content of the corn flour and (ISO) Standard used). Laboratory distillation water was used to increase the moisture content to the desired levels of 20.00, 22.50, and 25.00% (w.b.), which were calculated using the (Li, 2016) and (Sacilik *et al.*, 2003) methods.

$$Q = \frac{W_i(M_f - M_i)}{(100 - M_i)} \qquad (1)$$

Where:

Q, represents the quantity of water required

W_i, represents sample initial mass (kg),

M_i, represents sample initial moisture content (%w.b) and

M_f, represents sample final moisture content (%w.b)

Tempering was done by keeping the moistened samples separately in a metallized zip-lock pack, stored at 4°C (Mulugeta 2018) The conditioned sample was extrusion-cooked using a laboratory-scale Brabender single-screw extruder (Model Kompakt E-19/25 D Brabender Duisburg, Germany) at preset process variables. The length-to-screw diameter (15D), compression ratio 3:1, and die opening (6 mm) were constant parameters.

Experimental Design and Data Analysis

Table 1 depicts actual and coded operational and processing variables, featuring engineering and design values. The experimental design was done using the response surface methodology. Each factor was evaluated randomly at three (3) different levels (coded values: -1, 0, +1). The experiment was run in triplicate at each level and the average value recorded. To avoid unexplained variability in the observed responses and to minimize the effects of extraneous factors, the experiment was randomized (Kaur *et al*., 2014, Nath and Chattopadhyay, 2007). Prepared samples were extrusion-cooked at the designed independent variables as shown in Table 2: SS (100, 110, and 120rpm), BT (170, 180, and 190°C), FR (40, 50, and 60 rpm), and NC (20.25 and 25%). The following were the dependent variables: Water Absorption Index (WAI), Water Solubility Index (WSI), Bulk Density (BD) and Expansion Ratio (ER). Models developed for prediction purposes for each of the responses were analyzed by evaluating the validity of the model with Adequate precision and R-Square. Response is described as a quadratic polynomial equation written as a function of independent variables in terms of linear, quadratic, and their interactions; see equation (2).

$$\begin{aligned} Y_i = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 \\ + \beta_{11} X_1^2 + \beta_{22} X_2^2 + \beta_{33} X_3^2 \\ + \beta_{44} X_4^2 + \beta_{12} X_1 X_2 \\ + \beta_{13} X_1 X_3 + \beta_{14} X_1 X_4 \\ + \beta_{23} X_2 X_3 + \beta_{34} X_3 X_4 \\ + \varepsilon \qquad (2) \end{aligned}$$

Where:

Y_i represents interested response,

β_0 represents interception coefficient;

β_i, β_{ii}, and β_{ij} represent linear, quadratic and interaction coefficients,

X_i represents independent variables

$\mathcal{E}$, represents random error.

The water absorption index (Y_{WAI}), water solubility index (Y_{WSI}), bulk density (Y_{BD}) and expansion ratio (Y_{ER}), and were the four responses of the designed experiments. Data was analyzed to evaluate the effects of operational and process variables on extrudates functional and physical properties.

Functional Properties

Water Absorption Index (WAI)

WAI was estimated by measuring 2.5g of ground extrudate sample, which was dispersed in 25g of distilled water using a magnetic stirrer for 30minutes at laboratory temperature and centrifuged at 3000rpm for 15minutes. The supernatant was obtained. This liquid was carefully poured into a tarred evaporating dish and evaporated in a dryer chamber at 110°C. WAI was calculated by taking the weight of gel obtained after the removal of supernatant liquid per gram of solid according to (Kanojia and Singh, 2016, Patil *et al*., 2005 and Nidhi *et al*., 2019). WAI can be estimated using equation (3) below:

$$WAI = \frac{W_{sedt}}{W_{dry}} \quad (3)$$

Where:
WAI: represents WAI
W_{sedt} (g): represents sediment weight and
W_{dry} (g): represents Weight of dry solid.

Water Solubility Index (WSI)

WSI was evaluated by weighting a ground extrudate sample of 200µm particles dissolved in 25g of distilled water. Ground samples were dispersed in water by a magnetic stirrer for 30 minutes at laboratory temperature and centrifuged at 3000rpm for 15minutes. The supernatant liquid was carefully decanted into a weighed evaporating dish and dried in an air-conventional dryer at 110°C. The weight of the solute was expressed as a percentage of the original dry sample, according to (Chinnaswamy and Hanna, 1988; Liu *et al*., 2000 and Mason and Hoseney 1986), using equation (4) below.

$$WSI(\%) = \frac{W_{dist}(g) * 100}{W_{dry}(g)} \quad (4)$$

Where:
WSI (%): represents WSI
W_{disl} (g): represents dissolved solid weight, and W_{dry} (g): represents dry solid weight.

Physical Properties

Bulk Density (BD)

Extrudate BD was determined using the (Sawant, *et al*., 2013) method. Ten (10) pieces of extrudate were randomly selected as representatives of each experimental run. The diameter and length of the pieces were measured using a digital vernier caliper, and the average of the measurements was recorded. Extrudate pieces were weighed using an electronic Metller weighing balance with 0.001g accuracy. BD was calculated using equation (5), and extrudates were assumed to be cylindrical in shape.

$$\rho_{bulk}(gcm^{-3}) = \frac{4W}{\pi d^2 l} \quad (5)$$

Where:
ρ_{bulk}: represents Bulk density (gcm^{-3})
W: represents weight in grams of extrudate
d: represents extrudate diameter (cm) and
l: represents extrudate length (cm).

Expansion Ratio (ER)

According to (Nidhi *et al*., 2019, Kanojia and Singh 2016, Patil *et al*., 2016, and (Chinnaswamy and Hanna, 1988), Diameters of seven (7) randomly selected segments of each extrudate sample were measured from each experimental run using a digital Vernier calliper and the average value of the measurement. ER is determined as a ratio of the average cross-sectional area of extrudates to the cross-sectional area of the die-nozzle using equation (6) below

$$ER = \frac{D_{ex}}{D_{dn}} \quad (6)$$

Where:
ER: represents extrudate expansion ratio
D_{ex}: represents extrudate diameter (mm) and
D_{dn} - represents die-nozzle diameter (mm).

RESULTS AND DISCUSSION

The obtained data is presented in Table 2 below and analyzed by multiple regression and a second-order quadratic polynomial equation fitted to the experimental data with coded values of independent variables and interpreted using model parameters, visualized with 3-D and linear graphs.

Water absorption index (WAI)

The functional property that defines the volume of granule polymer starch in water is WAI (Kaur *et al*., 2014). The WAI of ready-to-eat corn meal extrusion cooked as influenced by SS, BT, FR, and MC is presented in Table 2. WAI values ranged from 4.25 to 6.80; this trend in value is the result of different extrusion conditions. The minimum WAI 4.25 value occurred at MC of 20.00%, BT of 170°C, SS of 110rpm, and FR of 50rpm. Maximum WAI of 6.80 occurred at 20.00% MC, BT of 190°C, SS of 120rpm, and FR of 60rpm. These implied that BT, SS, and FR had a positive effect on WAI. The observed trend was contrary to what was reported by (Kaur *et al*., 2014), which was attributed to an increase in the percentage of sugar in the product. An increase in SS from 100 to 120 rpm increased WAI by 18%. When FR increased from 40 to 60g/min, WAI increased by 9.3%, while increasing MC from 20 to 25% decreased WAI by less than 1%, this was in agreement with (Mulugeta, 2018) who reported decrease in WAI as MC increased. The decrease in WAI however negligible, could be due to other material inherent properties. Water absorption index (WAI) is a result of the availability of hydrophilic substances that bind molecules of water and has been used to estimate the suitability, bulkiness, and consistency of the product (Mulugeta, 2018). Increasing BT from 170 to 190°C increased WAI by 60%. An increase in WAI caused starch degradation or gelatinization as BT increased (Hernandez-Diaz *et al*., 2007) reported a similar trend. The regression model for WAI is given as stated in equation (7).

$$WAI = 5.41 + 0.5*SS + 0.53*BT + 0.1*FR + 0.1*MC + 0.38*SS*BT - 0.21*SS*FR \; 0.13*SS*MC - 0.47*BT*FR - 0.53*BT*MC + 0.17*FR*MC + 0.09*SS^2 - 0.31*BT^2 + 0.12*FR^2 + 0.22*MC^2 \quad (7)$$

The WAI-coded prediction model equation written in equation (7) is useful to predict the relative impact of the process variables by comparing their coefficients. In equation (7), it can be deduced that BT (0.529) has a greater impact than SS (0.473) on WAI. The WAI of the product indicated the level of starch content and the extent of inherent starch gelatinization (Tiwari and Jha, 2017). Low MC levels were directly related to puffing and usually resulted in extruded products with a hard and coarse texture, but high MC levels were linked to soft extruded and dense products (Nath and Chattopadhyay, 2007).

From the Summary of Fit for WAI Table 3, the value of (R-Square = 0.99) indicated that the model has the capability to explain up to 99.9% of the variation in the. Table 4 shows the WAI analysis of variance. A quadratic second-order polynomial was predicted for WAI, and its significance coefficients were determined using the F-test and P-value. The model's 47.60 F-value indicated that the model was good and significant. It was only a 0.02% chance that an F-value of this magnitude could occur because of noise. From Table 4, the interactive terms that have significant effects on WAI include SS*BT, BT*FR, and BT*MC (the p-values are 0.0252, 0.0011 and 0.0017, respectively). The quadratic terms that have a significant effect on WAI are BT2 and MC2. Table 5 showed coefficients in terms of coded factors for WAI. The positive coefficient at linear terms SS (0.4731), BT (0.5288), FR (0.0991), and MC (0.0561) showed there is an increase in response with an increase in level of the given term. The negative quadratic term SS^2 (-0.0448) indicated that the maximum value of WAI was present at the center of the design space, while the positive second-order BT2 (-0.3052) term shows the minimum value of WAI (Liu *et al*., 2000). Table 6 displays the model-predicted values and actual measurement values of WAI.

Figures 1a and 1b display the effects of FR and BT on WAI and FR and BT on WAI. The figures showed the effects of varying two process variables on WAI, while the other two process variables were kept constant. In Figure 1a, increasing FR and BT increases WAI. This could be due to starch degradation. Figure 1b displayed a similar increase in WAI when FR and MC increased. Figure 1c shows the interaction between SS and BT, while Figure 1d depicts the effect of varying SS and MC together. In Figure 1c, increasing SS and BT increases WAI; WAI increases when SS and MC increase. The interaction between SS and FR is as shown in Figure 1e. Increasing SS with FR causes WAI to increase. Figure 1f shows the graph of actual WAI plotted together with WAI model predicted values; there was little disparity between the WAI model predicted values and the actual measurement.

Water solubility index (WSI)

Functional property of product extrusion cooked that measures the amount of free polysaccharide or polysaccharide released from starch granule in excess water is WSI (Kaur *et al.*, 2014). After the extrusion cooking process, the extrudate's WSI determines the quantity of soluble starch components released into the supernatant water. A high WSI indicates good starch digestibility as a result of the extent of gelatinization and dextrinization. The data on the influence of extrusion cooking process conditions on products' WSI is presented in Table 2. Minimum WSI of 0.20% occurred at SS of 120rpm, BT of 180°C, FR of 60rpm, and MC of 25%. Maximum WSI of 0.78% occurred at SS of 120 rpm, BT of 190°C, FR of 60g/min, and MC of 20%.

Increasing SS from 100 to 120rpm increased WSI by 69.56%. When BT was increased from 180 to 190°C, WSI increased from 0.46 to 0.78% see Table 2. Kaur *et al.*, 2014) reported a similar trend. The high temperature and shearing action of the mixture in the extruder chamber resulted in starch degradation and protein denaturation. Decreasing MC increases WSI by 69.56%. These phenomena were similar to those reported previously (Mulugeta, 2018). Raw starch is insoluble in water, but when degradation occurred as a result of extrusion process conditions (high temperature, screw speed, moisture content), starch is converted and becomes more soluble (Caldwell, *et al*, 2016).

Tables 3 and 4 showed the WSI summary of the fit table and the analysis of variance table, respectively. Table 3 revealed that the WSI coefficient of determination, R-Square, was 0.97. This implies that the WSI model has the ability to explain 97% of data variation and that the model is good for prediction purposes. An adequate prediction value measures the response signal-to-noise ratio. A ratio value greater than 4 is required. The WSI model had an adequate prediction ratio of 11.687, which implied an adequate response signal- to-noise ratio.

This model can be used to navigate the experimental design space. The analysis of variance in Table 4 F-value of 12.03 proved that the model is good and significant. An F- value of this size has a 0.6 percent probability of occurring due to noise. Table 5 displays the WSI coefficients for coded variables. A rise in response was observed with an increase in the level of the selected term, as evidenced by the linear term positive coefficient at BT (0.093) and FR (0.0048).

The negative quadratic term SS^2 (-0.0448) suggests that the center point is where the WSI maximum value is found, but the minimum value of the WSI is implied by the positive quadratic BT^2 (0.063) term. Table 6 presents the model-predicted values and the measured values of WSI. The regression equation for the water solubility index model is given in equation (8). This by comparing the coefficients of the various components, the coded equation can be used to determine the relative impact of the elements.

WSI = 0.47 - 0.011*SS + 0.09*BT + 0.005*FR - 0.17*MC - 0.16*SS*BT + 0.08*SS*FR + 0.015*SS*MC + 0.08*BT*FR -0.02*BT*MC-0.09*FR*MC - 0.045*SS^2 + 0.06*BT^2 - 0.04*FR^2 - 0.04*MC^2 (8)

From equation (8), it can be inferred that MC (0.2) has a greater positive impact than BT (0.12) while FR (-0.02) and SS (-0.01) have a negative impact on WSI.

Figure 2a shows the surface response of WSI to factors BT and FR. Increasing BT together with FR increases WSI. Figure (2b) also showed a similar trend of increase when both SS and BT increased. The same trend was observed in Figure 2c. However, in Figure 2d, it was observed that increasing SS (120rpm) and MC (25%) decreased WSI. While Figure 2e showed that decreasing SS (100rpm) and increasing FR (60g/min) cause WSI (0.60%) to increase. Figure 2f shows the graph of WSI model predicted values plotted together with the actual value. The two graphs show little or no disparities, which attests to the good predictability of the WSI mode.

Bulk Density (BD)

Table 2 showed the facts regarding the extrusion cooking processing conditions for bulk density (BD). According to Table 2, BD had a mean value of 0.83 gcm^{-3} and varied from 0.67 to 0.92gcm^{-3}. At barrel temperature (BT) of 170°C, screw speed (SS) of 110 rpm, moisture content (MC) of 20%, and feed rate (FR) of 50 rpm, the minimum BD of 0.67 gcm^{-3} was achieved. At BT of 180 °C, SS of 110 rpm, MC of 22.50%, and FR of 50 rpm, the maximum BD of 0.92 gcm^{-3} was reached. From Table 2, increasing MC from 20 to 25% caused a 37% BD increase. When BT increased from 170°C to 190°C, BD increased by 17.5%. This might be due to an increase in MC because, with increasing BT, BD should decrease. However, at higher temperatures, the BD increased because of the high moisture content. Increasing FR from 40rpm to 60rpm caused BD to increase by 18.18%. These results are in agreement with those published in (Mulugeta 2018). Tables 3 and 4 show the BD Summary of Fit Table and Analysis of Variance Table, respectively. Table 3 indicates that the BD model is good with a good regression coefficient of determination (R-Square = 0.94).

This proved that BD can explain 94% of the variation in the data. BD An adequate prediction value of 10.00 is a good measure of signal-to-noise ratio, since a ratio larger than four is preferred. The BD Model's 5.63 F-value suggests the model is significant, according to Analysis of Variance Table 4. The likelihood that noise might cause an F-value this high is 3.35%. From Coefficients in Terms of Coded Bulk Density (BD) Model Table 5, increasing SS and MC cause BD to increase. Interactive (BT*FR, BT*MC, and FR*MC) and quadratic (BT^2) terms have a significant effect on BD. This result is in agreement with previously reported publications: Mulugeta (2018), and Tiwari and Jha (2017).

Table 6 presents data for predicted model values and actual measured values of BD. The graph of the BD model predicted value plotted together with the measured BD had negligible disparity. The discrepancies mostly occurred in experiments 1, 8, and 20

(Figure 3f). However, the model predicts well and can be used for that purpose.

The equation provided the quadratic model that was derived from the regression analysis for BD in terms of the coded levels of the components (9).

BD = 0.9 + 0.04*SS - 0.001*BT - 0.01*FR + 0.03*MC - 0.1*SS*BT - 0.0003*SS*FR + 0.007*SS*MC + 0.071*BT*FR - 0.10*BT*MC - 0.10*FR*MC + 0.03*SS^2 - 0.05*BT^2 - 0.04*FR^2 + 0.05*MC^2 (9)

Figure 3a shows the quadratic interactive effect of FR and BT on BD. Increasing FR and BT increases BD, which is expected because of the high material volume. Another reason could be due to high temperature, the melt emerges from the die nozzle, expanding and gaining volume more than the extrudates that depart at a low temperature (Sushil, 2016). Figure 3b depicts the quadratic response surface effect of FR and MC on BD. Increasing interaction between FR and MC increases the BD. This is because high MC decreases

the volume of extruded cooking products. This effect of increasing BD when FR and MC increased and BD reduced when BT increased was reported by Adeyemi-Peluola and Idowu (2014). Figure 3c shows that decreasing SS and increasing BT decrease BD. Figure 3d illustrates the effects of interactions between SS and MC on BD. As decreasing SS and increasing MC increase BD, the product has a high BD because of its high moisture content. The interactions of SS and FR had little effect on BD.

Expansion Ratio (ER)

Table 2 displayed the data regarding the impact of process parameters on the product expansion ratio (ER). At barrel temperature (BT) of 180 °C, screw speed (SS) of 100rpm, moisture content (MC) of 25.00%, and feed rate (FR) of 50 rpm, the minimum ER of 2.11 was reached. A maximum of 2.67 occurred at BT of 190 °C, SS of 120 rpm, MC of 20.00%, and FR of 60rpm. The varying extrusion circumstances may be the cause of this trend in values. Table 2 demonstrated that the ER had a mean value of 2.36 and varied from 2.11 to 2.67. Increasing SS from 100 rpm to 120 rpm increased ER by 2%. When BT was increased from 170 °C to 190°C, ER increased by 8.3%. This might be due to the escape of entrapped steam in the structure. The result disagreed with Mulugeta (2018), who reported decrease in ER when BT increased. The increase in ER was as expected because increase in temperature results to increase in volume of gelatinized starch product (Caldwell, *et al*, 2016; Sushil, K. S 2016). MC had a negative effect on ER. Increasing MC from 20% to 25% decreased ER by 16%. An increase in feed moisture caused low vapour pressure in the melt, which lowers the sectional expansion index and lessens moisture flashing. (SEI) (Kaur *et al.*, 2014). This observation of decreasing ER when MC increased was also reported by Mulugeta (2018). Tables 3 and 4 showed the ER Summary of Fit Table and Analysis of Variance Table, respectively. Table 3 revealed the ER coefficient of determination (R-Square = 0.99). It implied that the ER model has the ability to explain 99.9% of the data variation. An adequate prediction value of 22.51 from this (Table 3) indicated a high signal-to-noise ratio; this also further confirmed that the model is good and can be used for prediction purposes. From the analysis of variance in Table 3, the model's 40.69 F-value suggests the importance of the model. An F-value this large could only be the result of noise in 0.03 percent of cases. The equation provides the regression equation for the ER model (10). Equation 10, which is coded, can be utilized to compare the coefficients of the components and determine their respective impacts.

ER = 2.35 + 0.04*SS + 0.07*BT + 0.002*FR - 0.21*MC - 0.03*SS*BT + 0.03*SS*FR + 0.005*SS*MC - 0.0163171*BT*FR - 0.01*BT*MC - 0.1*FR*MC + 0.02*SS^2 - 0.03*BT^2 - 0.002*FR^2 - 0.03*MC^2 (10)

From equation (10), it can be inferred that BT (0.075) has a greater positive impact on ER than SS (0.0316), while FR (-0.0014) and MC (-0.208) have a negative impact, respectively. Table 5 showed coefficients in terms of coded factors for ER. This (Table 3) revealed that linear terms with a positive coefficient implies a rise in ER correlated with elevated levels of specific terms SS (0.048), BT (0.067), and FR (0.002). While MC (-0.21) with a negative coefficient indicates a decrease in ER when MC increases, negative quadratic terms in Table 5 (BT^2 (-0.034), FR^2 (-0.0021), and MC^2 (0.029) showed that, whereas in positive quadratic, the maximum value of ER occurred at the central point. SS^2 (0.024) gave the minimum value of ER. From Table 6, Figure 4f was drawn, which showed the graph of the ER model predicted value plotted together with the actual value of ER. The two graphs seamlessly fit together. This indicates that the model has the capacity to predict well and can be used for that purpose. The surface diagram showing how BT and FR affect ER is shown in Figure 4a. The interaction reveals the linear effect that BT and FR had on ER. Figure 4a revealed that increasing BT increases ER, while increasing FR has no effect on ER. BT had a positive linear effect on ER as the viscosity decreased. This reduced viscosity effect affects bubble growth during extrusion cooking (Kaur *et al*., 2014). Figure 4b also showed linear surface response plots of the effects of BT and MC on ER. This figure revealed the value of ER = 2.60 when BT = 190°C and MC = 20.25%. Figure 4b also indicated the values of ER (2.26), BT (170), and MC (22.89%). The value of ER was increased to 2.54 when the BT was 190°C and the SS was 120rpm. This increase may be attributed to high gelatinization and the rate of damage to the starch. Similar research findings were published by Fillil, *et al*, (2013) and Neelam, *et al*, (2006). Figure 4c revealed that the optimum value of ER was 2.54 when SS and BT were 120rpm and 190°C and 2.20 when SS and BT were 100 rpm and 170 °C, respectively. As SS and BR increased, ER also increased. The optimum values of ER were 2.12 when SS and MC were 120rpm and 24.74%, respectively, and 2.61 when SS and MC were 120rpm and 20.26% (Figure 4d). This increase in ER of the extrusion cooking product as a result of the increase in BT was also reported by (Sushil, 2016). The optimum value of ER when SS interacted with FR was 2.50 when SS and FR were 120 rpm and 51.58 rpm, respectively. While the ER was 2.15 when the SS was 100 rpm and the FR was 49.47 rpm.

CONCLUSION

The use of corn meal flour in the extrusion cooking procedure with a Brabender single-screw laboratory scale extruder was employed to investigate the production of ready-to-eat break-fast meal. The Models' Adequate precision values (25.92, 11.69, 10.00 and 22.51) with R-Square values (97%, 99%, 94% and 99%) for response variables (WAI, WSI, BD and ER) respectively demonstrated the capabilities of the models to predict the effects of extrusion cooking process variables (SS, BT, FR and MC). These are crucial for production and product development to eliminate or reduce corn post-harvest losses. The use of constructed models is recommended for prediction purposes because of their strong predictability, as demonstrated by the statistical analysis of their parameters.

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Table 1. Actual and coded of extrusion cooking process variables values for ready-to-eat breakfast from corn meal flour

Operational Variable	Actual	Coded	Actual	Coded	Actual	Coded
Barrel Temp. (℃)	170	-1	180	0	190	1
Screw Speed (rpm)	100	-1	110	0	120	1
Feed rate (rpm)	40	-1	50	0	60	1
Moisture (%)	20	-1	22.5	0	25	1

Table 2. Effect of operation and process variables on WAI, WSI, BD and ER

Run	SS (rpm)	BT (℃)	FR (rpm)	MC (%)	WAI	WSI (%)	BD (g/cm^3)	ER
1	110	170	60	25.0	5.60 ± 0.03	0.25 ± 0.03	0.86 ± 0.03	2.13 ± 0.01
2	110	180	50	22.5	5.30 ± 0.02	0.30 ± 0.02	0.86 ± 0.02	2.28 ± 0.04
3	120	180	60	20.0	6.60 ± 0.04	0.36 ± 0.05	0.87 ± 0.01	2.45 ± 0.06
4	110	190	40	25.0	5.87 ± 0.01	0.78 ± 0.01	0.84 ± 0.04	2.58 ± 0.01
5	120	190	60	25.0	5.50 ± 0.02	0.45 ± 0.03	0.84 ± 0.05	2.35 ± 0.03
6	120	170	60	22.5	5.35 ± 0.01	0.58 ± 0.04	0.86 ± 0.01	2.55 ± 0.05
7	100	190	60	20.0	5.67 ± 0.03	0.37 ± 0.06	0.86 ± 0.06	2.19 ± 0.02
8	120	180	50	22.5	5.51 ± 0.05	0.45 ± 0.07	0.92 ± 0.07	2.35 ± 0.04
9	120	170	40	20.0	6.21 ± 0.03	0.58 ± 0.03	0.86 ± 0.01	2.57 ± 0.07
10	110	170	40	22.5	4.51 ± 0.07	0.50 ± 0.03	0.85 ± 0.03	2.30 ± 0.02
11	120	180	40	25.0	4.80 ± 0.01	0.46 ± 0.01	0.83 ± 0.04	2.37 ± 0.04
12	100	190	50	25.0	6.80 ± 0.04	0.78 ± 0.02	0.87 ± 0.05	2.67 ± 0.01
13	110	180	50	20.0	5.52 ± 0.02	0.21 ± 0.04	0.86 ± 0.02	2.11 ± 0.06
14	100	170	60	22.5	5.55 ± 0.01	0.57 ± 0.05	0.80 ± 0.05	2.52 ± 0.05
15	100	190	40	22.5	6.32 ± 0.03	0.20 ± 0.02	0.80 ± 0.01	2.15 ± 0.02
16	110	190	60	22.5	5.51 ± 0.05	0.45 ± 0.05	0.86 ± 0.05	2.35 ± 0.05
17	110	180	50	22.5	4.50 ± 0.02	0.29 ± 0.03	0.76 ± 0.03	2.17 ± 0.04
18	110	180	50	22.5	4.84 ± 0.01	0.70 ± 0.05	0.75 ± 0.01	2.35 ± 0.01
19	120	170	50	25.0	4.25 ± 0.05	0.55 ± 0.06	0.67 ± 0.02	2.44 ± 0.02
20	100	170	50	20.0	5.61 ± 0.06	0.71 ± 0.07	0.80 ± 0.05	2.37 ± 0.07

SS - Screw speed (rpm); WAI- Water absorption index (dimensionless)
BT- Barrel temperature (℃); WSI - Water solubility index (%)
FR- Feed rate (rpm); BD - Bulk density (g/cm^3)
MC- Moisture content (%); ER - Expansion ratio (dimensionless)

Table 3. Summary of model statistics for the extruded corn flour breakfast

Parameters	WAI	WSI (%)	BD (gcm^{-3})	ER
Std. Dev.	0.11	0.06	0.03	0.03
Mean	5.49	0.48	0.83	2.36
R-squared	0.99	0.97	0.94	0.99
Adj-R^2	0.97	0.89	0.77	0.97
Adeq-precision	25.92	11.69	10.00	22.51
C.V%	2.08	12.50	3.16	1.25
Lack of fit	NS	NS	NS	NS

Table 4. ANOVA for WAI, WSI, BD and ER Models

Source	WAI		WSI (%)		BD (gcm^{-3})		ER	
	F-value	P-value	F-value	P-value	F-value	P-value	F-value	P-value
Model	47.60	0.0002	12.03	0.0062	5.63	0.0335	40.69	0.0003
A	115.74	0.0001	0.2448	0.6417	18.81	0.0075	13.59	0.0142
B	131.52	<0.0001	14.97	0.0118	0.0112	0.9197	31.31	0.0025
C	4.75	0.0812	0.0403	0.8488	0.4436	0.5349	0.0404	0.8486
D	1.60	0.2617	55.13	0.0007	8.64	0.0323	325.99	< 0.0001
AB	9.97	0.0251	6.32	0.0536	2.77	0.1567	1.04	0.3540
AC	4.31	0.0926	2.45	0.1783	0.0003	0.9872	1.18	0.3265
AD	3.38	0.1254	0.1649	0.7015	0.1560	0.7092	0.0827	0.7853
BC	45.88	0.0011	5.61	0.0641	20.18	0.0064	0.8471	0.3996
BD	37.60	0.0017	0.1822	0.6872	25.56	0.0039	0.2012	0.6725
CD	1.47	0.2797	1.69	0.2503	10.51	0.0229	2.40	0.1820
A^2	1.48	0.2778	1.25	0.3148	2.55	0.1710	1.44	0.2833
B^2	28.85	0.0030	4.51	0.0870	16.78	0.0094	5.41	0.0675
C^2	1.18	0.3261	0.5043	0.5093	1.94	0.2229	0.0054	0.9441
D^2	7.55	0.0404	0.7535	0.4251	5.78	0.0614	1.89	0.2274

A – SS (rpm); WSI – Water solubility index (%)
B – BT (℃); BD – Bulk density (g/cm^3)
C – FR (rpm); ER – Expansion ratio (dimensionless)
D – MC (%)

Table 5. Coefficient in terms of Coded Factors for WAI, WSI, BD and ER Models

Factor	Coefficient Estimate			
	WAI	WSI (%)	BD (gcm^{-3})	ER
Intercept	5.41	0.47	0.88	2.35
A	0.47	-0.01	0.04	0.04
B	0.53	0.09	-0.00	0.07
C	0.10	0.01	-0.01	0.00
D	0.10	-0.17	0.03	-0.21
AB	0.38	-0.16	-0.05	-0.03
AC	-0.21	0.08	-0.00	0.03
AD	-0.13	0.02	0.01	0.01
BC	-0.47	0.08	-0.07	-0.02
BD	-0.53	-0.02	-0.10	-0.01
CD	0.17	-0.09	-0.10	-0.06
A^2	0.09	-0.05	0.03	0.02
B^2	-0.31	0.06	-0.05	-0.03
C^2	0.12	-0.04	-0.04	-0.00
D^2	0.22	-0.04	-0.05	-0.03

A – SS (rpm); WAI – Water absorption index (dimensionless)
B – BT (°C); WSI – Water solubility index (%)
C – FR (rpm); BD – Bulk density (g/cm^3)
D – MC (%); ER – Expansion ratio (dimensionless)

Table 6. Actual and predicted values of WAI, WSI, BD and ER response variables

Run	WAI		WSI (%)		BD (g/cm^3)		ER	
	Actual	Predicted	Actual	Predicted	Actual	Predicted	Actual	Predicted
1	5.60	5.68	0.25	0.27	0.86	0.87	2.13	2.12
2	5.30	5.26	0.30	0.32	0.86	0.86	2.28	2.270
3	6.60	6.57	0.36	0.42	0.87	0.86	2.45	2.42
4	5.87	5.88	0.78	0.78	0.84	0.83	2.58	2.58
5	5.50	5.62	0.45	0.44	0.84	0.84	2.35	2.35
6	5.35	5.33	0.58	0.57	0.86	0.86	2.55	2.54
7	5.67	5.70	0.37	0.37	0.86	0.86	2.19	2.21
8	5.51	5.41	0.45	0.47	0.92	0.88	2.35	2.35
9	6.21	6.27	0.58	0.54	0.86	0.88	2.57	2.59
10	4.51	4.53	0.50	0.50	0.85	0.85	2.30	2.30
11	4.80	4.83	0.46	0.48	0.83	0.84	2.37	2.36
12	6.80	6.78	0.78	0.78	0.87	0.86	2.67	2.67
13	5.52	5.44	0.21	0.22	0.86	0.85	2.11	2.09
14	5.55	5.57	0.57	0.61	0.80	0.81	2.52	2.53
15	6.32	6.29	0.20	0.18	0.80	0.80	2.15	2.16
16	5.51	5.43	0.45	0.43	0.86	0.86	2.35	2.35
17	4.50	4.57	0.29	0.25	0.76	0.77	2.17	2.20
18	4.84	4.84	0.70	0.72	0.75	0.75	2.35	2.35
19	4.25	4.21	0.55	0.56	0.67	0.66	2.44	2.42
20	5.61	5.63	0.71	0.63	0.80	0.83	2.37	2.38

WAI – Water absorption index (dimensionless)
WSI – Water solubility index (%)
BD – Bulk density (g/cm^3)
ER – Expansion ratio (dimensionless)

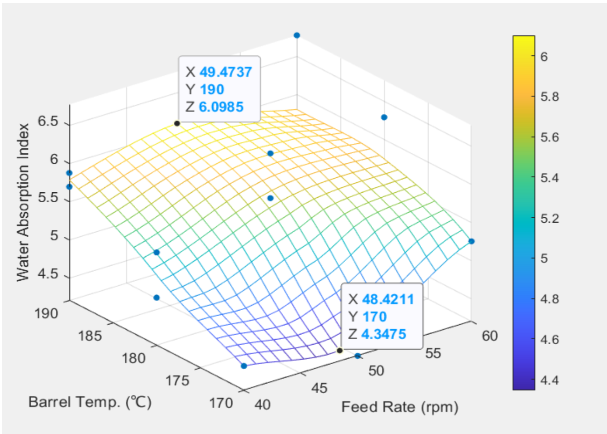

Fig. 1a. WAI as a function of feed rate and barrel temperature.

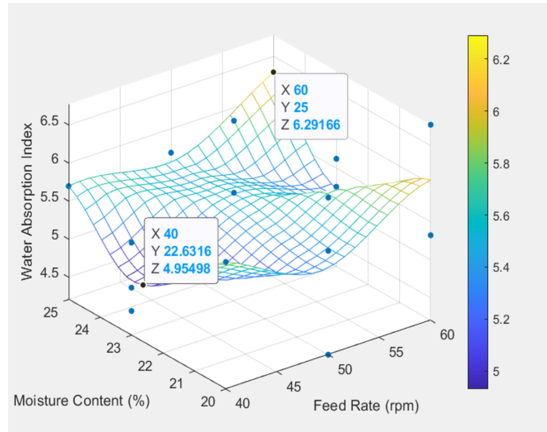

Fig. 1b. WAI as a function of feed rate and moisture content.

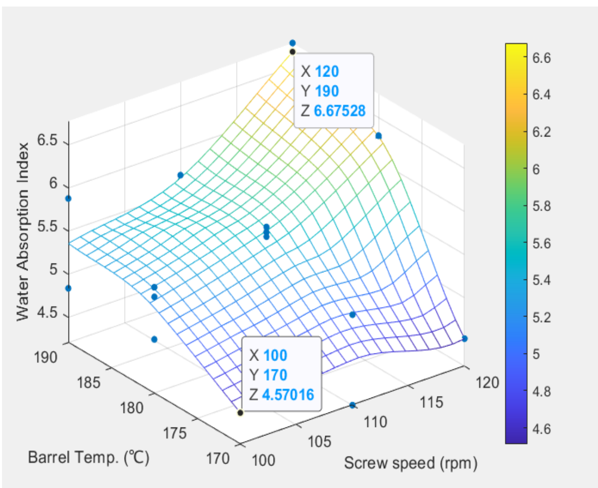

Fig. 1c. WAI as a function of screw speed and barrel temperature.

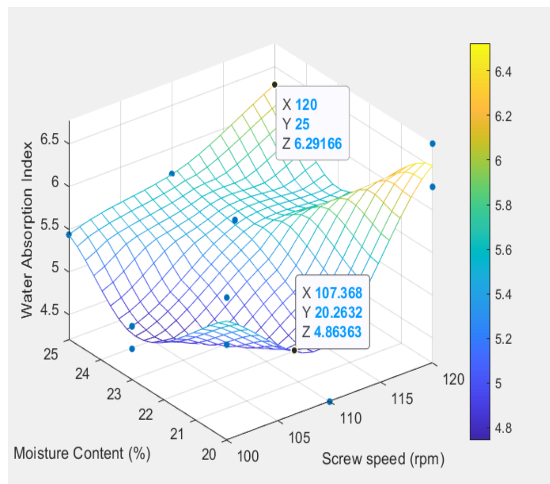

Fig. 1d. WAI as a function of screw speed and moisture content.

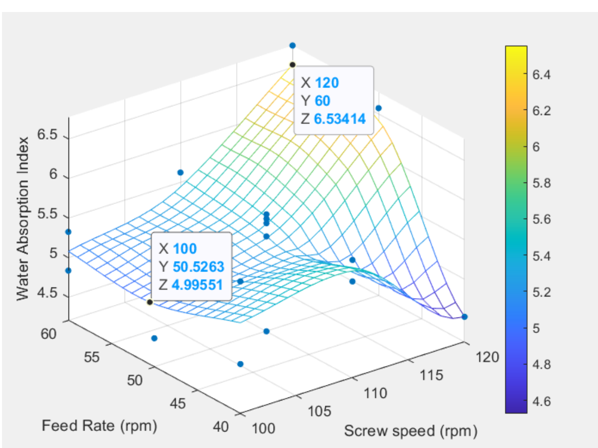

Fig. 1e. WAI as a function of screw speed and feed rate.

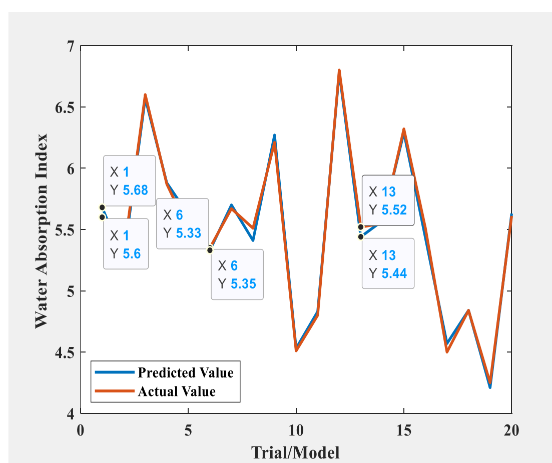

Fig. 1f. WAI model predicted value compared with actual value.

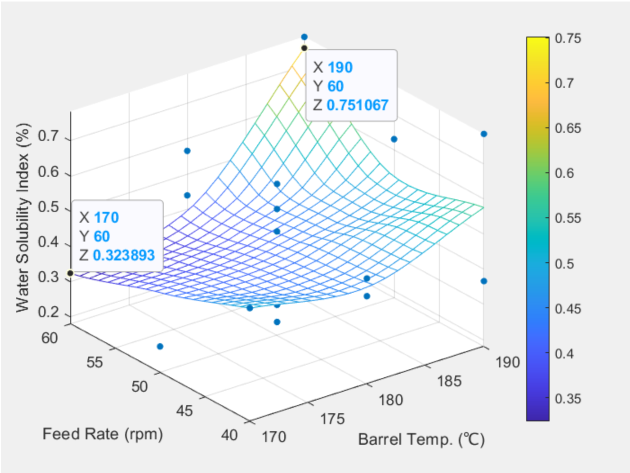

Fig. 2a. WSI as a function of barrel temperature and feed rate.

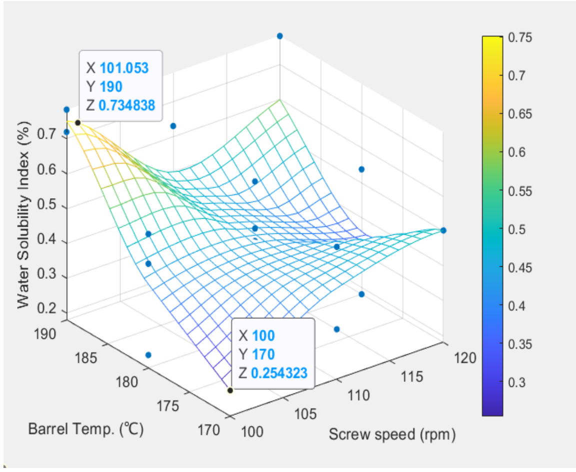

Fig. 2b. WSI as a function of screw speed and barrel temperature.

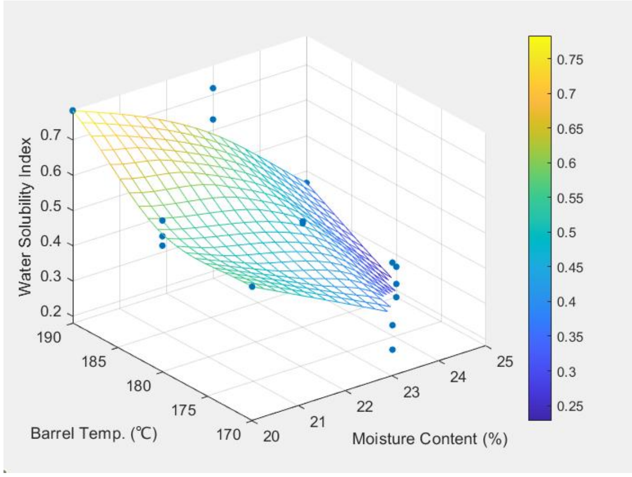

Fig. 2c. WSI as a function of moisture content and barrel temperature.

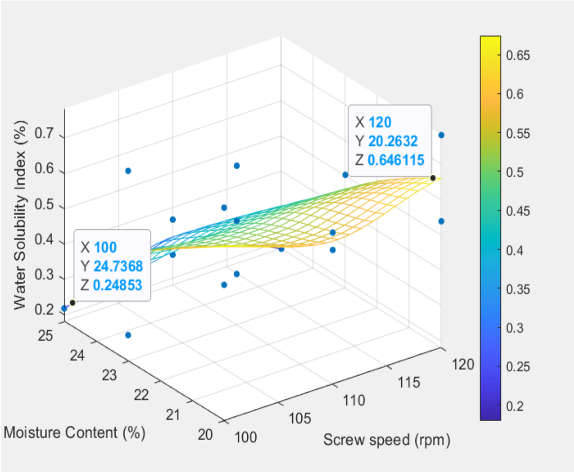

Fig. 2d. WSI as a function of screw speed and moisture content.

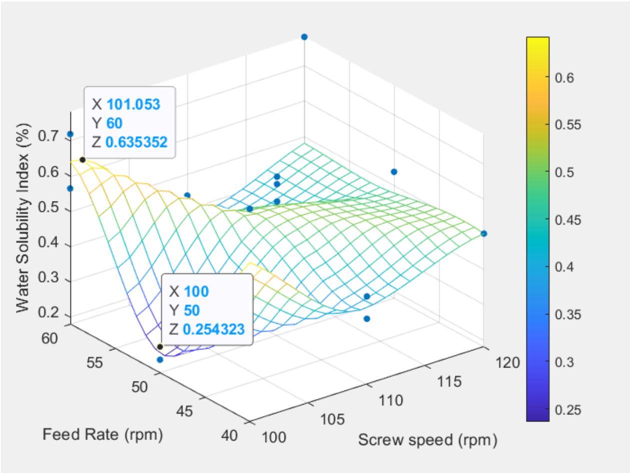

Fig. 2e. WSI as a function of screw speed and feed rate.

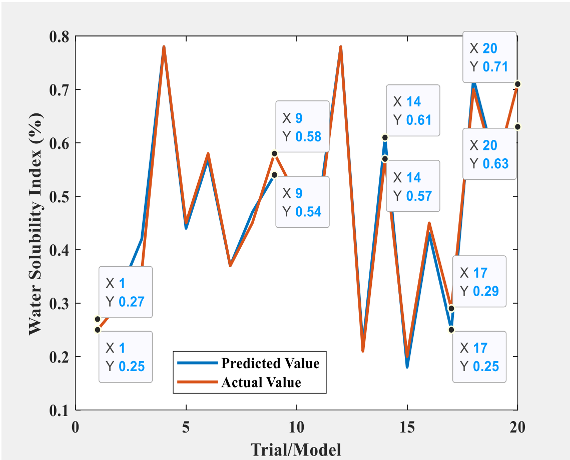

Fig. 2f. WSI model predicted value compared with actual value.

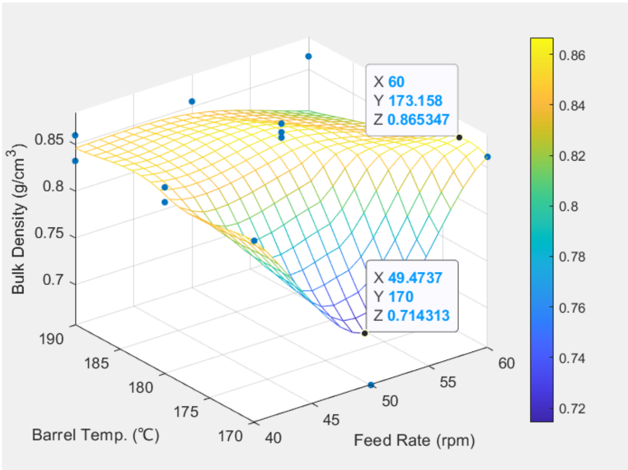

Fig. 3a. BD as a function of feed rate and barrel temperature.

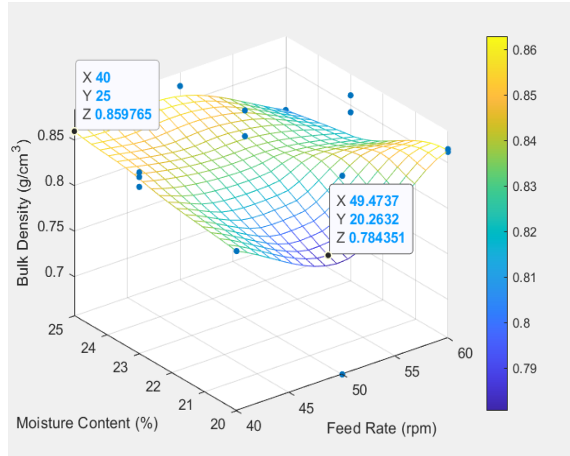

Fig. 3b. BD as a function of feed rate and moisture content.

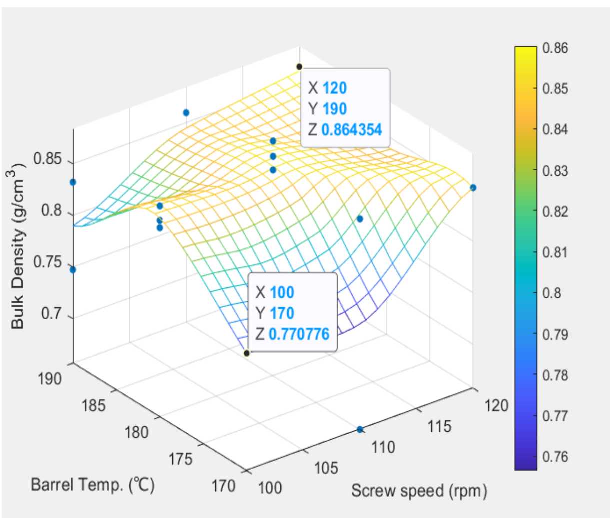

Fig. 3c. BD as a function of screw speed and barrel temperature.

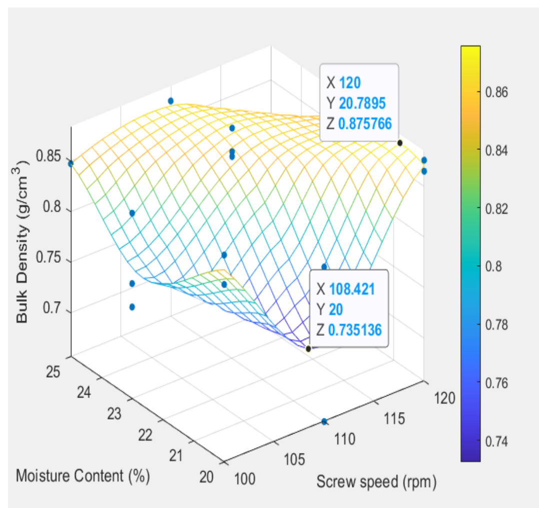

Fig. 3d. BD as a function of screw speed and moisture content.

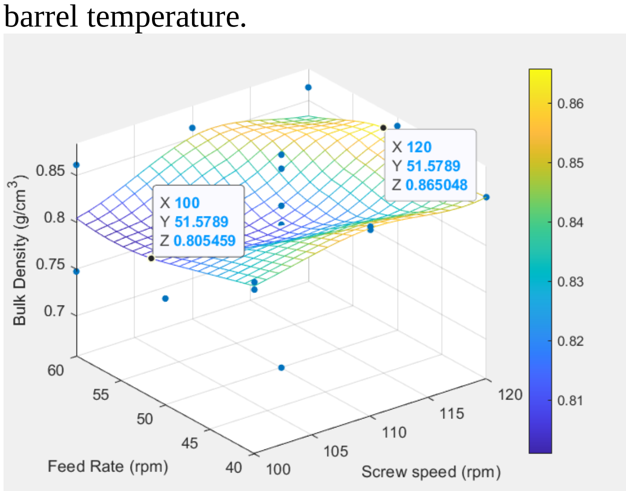

Fig. 3e. BD as a function of screw speed and feed rate.

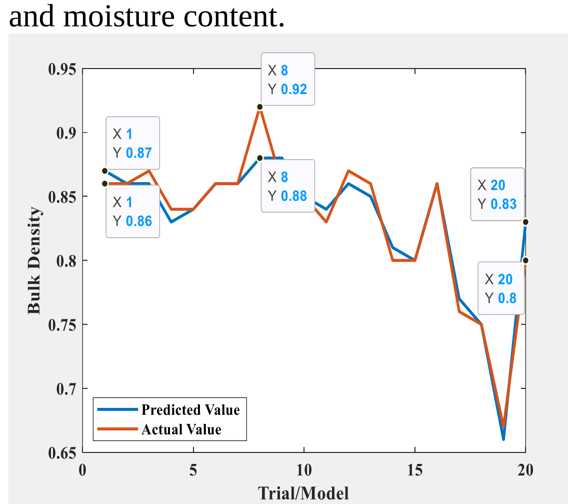

Fig. 3f. BD model predicted value compared with actual value.

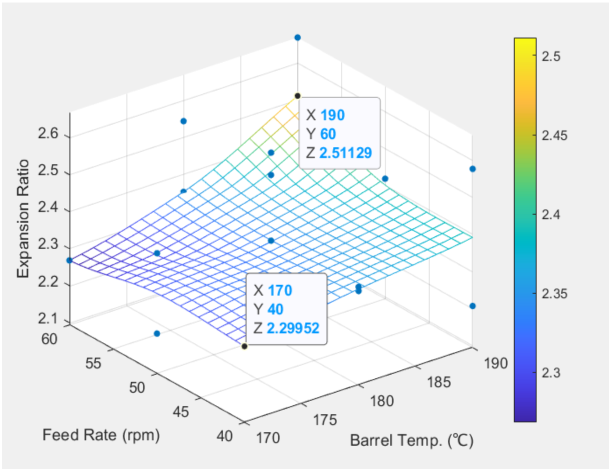

Fig. 4a: ER as a function of feed rate and barrel temperature.

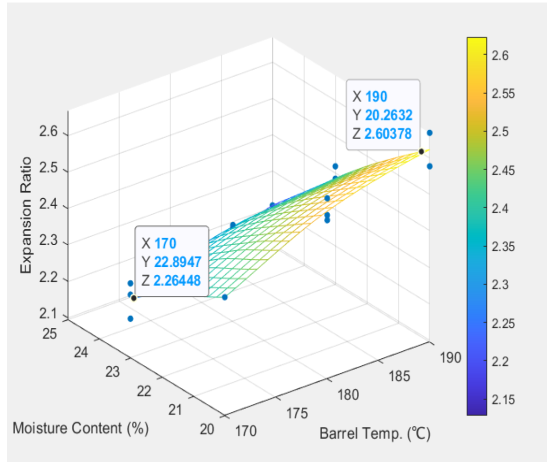

Fig. 4b: ER as a function of barrel temperature and moisture content.

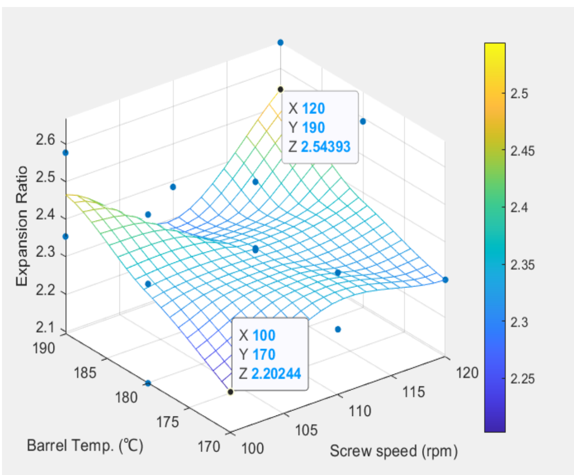

Fig. 4c: ER as a function of screw speed and barrel temperature.

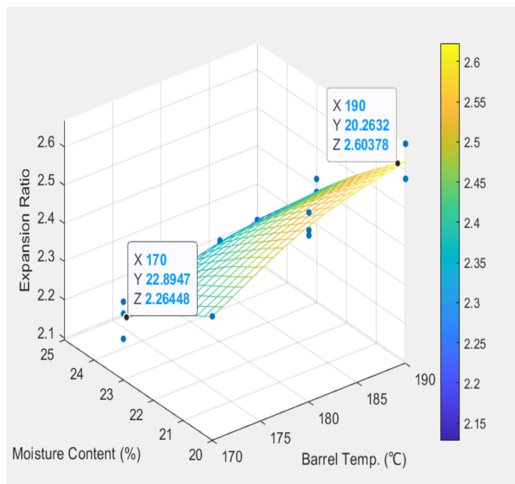

Fig. 4d: ER as a function of barrel temperature and moisture content.

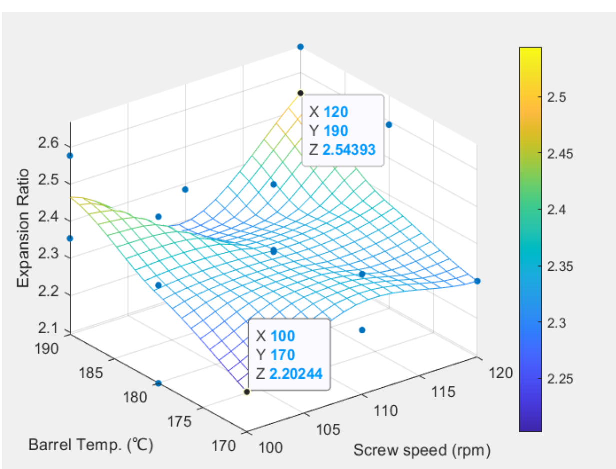

Fig. 4e: ER as a function of screw speed and barrel temperature.

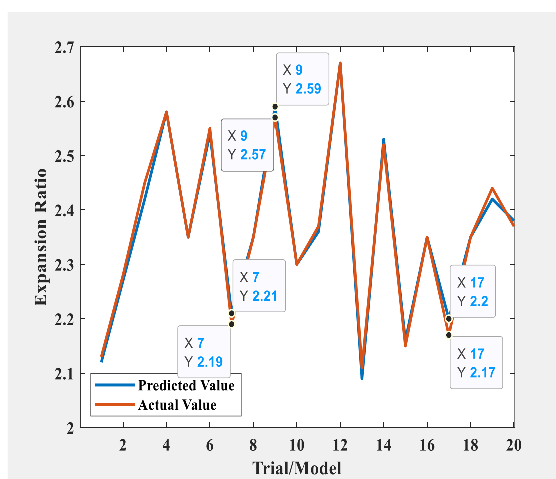

Fig. 4f: ER model predicted value compared with actual value.