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Development of breakfast cereal based on quality protein maize by twin screw extrusion process for improved nutrition

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Abstract
This research study was mainly focused on the development of optimized conditions to produce nutritious breakfast cereals from QPM and NM. Central composite rotatable design (CCRD) and response surface methodology (RSM) were used to design experiments and to study the effect of independent variables on dependent variables. Significance of fitted model ($p \leq 0.01$, $p \leq 0.05$) was described by conducting ANOVA. The coefficient of the determination (R^2) and lack-of-fit was observed to be greater than 80% and non-significant, respectively. Increase in feed moisture results in reduced SME, WAI and increased dispersibility. Increase in screw speed positively affects SME, WAI and dispersibility. While decrease in SME, BD and dispersibility of the porridge (NM and QPM) was noted as barrel temperature increases. From the overlay plots, observed optimum extrusion conditions to produce instant porridge from NM and QPM were feed moisture 14-14.87%, 14.86-16.66 % and barrel temperature 137.472-175ºC, 125-144.496ºC at 475 rpm screw speed, respectively.

Keywords: quality protein maize, water solubility index, dispersibility, response surface methodology, optimization

Introduction
Cereals are most important part of human diet because they provide energy and nutrient intake of humans (Julien *et al*. 2016) [18]. Maize also known as Queen of cereals, ranks third after wheat and rice. It provides about half of the proteins in the human diet of developing countries. From the nutritional point of view, maize kernel contains carbohydrates, proteins and fats in the range of 69.6–74.5%, 7.7–13.6 %, 3.2-7.7% fats, respectively. But, there protein is deficient in mainly Lysine and Tryptophan with moderate deficiency of Ile which contributes to the development of diseases like pellagra or florid kwashiorkor (Bressani *et al*. 1990) [7]. These deficiencies have been sorted through development of quality protein maize (maize hybrid) in which lysine and tryptophan levels is twice than that of the normal corn (Rodriguez *et al*. 2006; Ruiz-Ruiz *et al*. 2008; Carrillo *et al*. 2007) [32, 33, 8].
Quality protein maize is nutritionally superior and is in importance for food and nutritional security purpose as well as to prepare quality feed for piggery, poultry and animal sector (Prasanna *et al*. 2001) [31]. The percentage of lysine content in quality protein maize varied between 0.33-0.54 which is 46 percent higher than normal maize. QPM also contain 66% more tryptophan (0.08%) than normal maize. These two amino acids allow the body to manufacture complete protein (Tiwari *et al*. 2013) [38]. Thus, Maize becomes a potential source of protein for humans and animals. It holds great promise for increasing production of protein rich products. As protein energy malnutrition (PEM) problem continues to worsen in the phase of limited protein sources, the effective use of readily available and inexpensive protein sources has become a major area of research in recent years (Plahar *et al*. 2003) [30]. Traditional snacks were based on cereals such as maize, rice and wheat which are deficient in protein content and fortified with pulse protein to increase nutritious value of foods.
Porridge is a traditional food but its growing popularity has made it a healthy food worldwide. It is eaten as breakfast cereal and prepared by boiling cereals such as oats, cracked wheat, corn or other cereals in water or milk with or without the addition of sugar or salt. However, with the development of food processing technologies, a new version of porridge as "ready-made" breakfast cereals is manufactured (Fast 1987; Mandge *et al*. 2014) [12, 20].
Extrusion process is used worldwide for the production and modification or improvement of quality of various products. Extrusion cooking is popular technique with high versatility and efficiency (Altan *et al*. 2008) [1]. A food extruder is a high temperature and short processing time bioreactor which transform a variety of ingredients into final products and is used by several food industries to produce extruded products such as precooked flour, expanded snacks, pasta

products, breakfast cereals, baby foods, extruded bread, modified starches, texturized protein, expanded snack foods and pet foods from corn meal (Martinez *et al*. 1996; Anderson *et al*. 1969; Ruiz-Ruiz *et al*. 2008) [33, 21, 4]. Extrusion of starchy material results in starch gelatinization, protein denaturation and complexes formation between starch, lipids and proteins (Singh and Smith 1997) [37]. It is also being adapted to process ready-to-eat (RTE) breakfast cereals.

Optimization of independent variables was done using RSM by CCRD experimental design. It determines the relationship between the dependent and independent variables. It is mainly used for optimizing the response and selecting optimum operating conditions to achieve target specifications or customer requirements (Myers and Montgomery 2002) [24].

Extruded products with various shapes, flavours, textures and colours are developed in the food industry (Llo and Berghofer 1999) [17]. The most widely consumed extruded products are made primarily with cereals/grains but they tend to have low protein quality and many other nutrients. Hence, there is an increasing demand for more nutritious and high value food products by consumer (Meng *et al*. 2010, Bisharat *et al*. 2013) [23, 6]. So, the current research study is mainly focuses on the optimization of extrusion parameters for the production of nutritious instant porridge from Quality protein maize (QPM) and Normal maize (NM) using response surface methodology and central composite design.

Material and Method

Raw material

Normal maize (var. PMH-1) and Quality protein maize (var. HQPM-1) was procured from Directorate of seed and Indian institute of Maize research, Punjab Agricultural University, Ludhiana, Punjab, India. Both maize varieties were ground to make maize flour (< 200µ) using laboratory mill (Perten Intruments, Hagersten, Sweden). Sugar was purchased from the local market and added at 15 % level. Sugar was mixed with maize flour using ribbon blender (G L Extrusion systems, New Delhi, India) to ensure proper mixing.

Extrusion

A co-rotating intermeshing twin-screw extruder (Model BC 21, Clextral, Firminy, Cedex, France) with barrel diameter of 25 mm and length to diameter ratio (L/D) 16:1 respectively was used for extrusion (Figure 1). The barrel consist of four barrel zones, housed the twin screws. Twin screws (400mm) consist of segmental elements (5- 50 mm) with decreasing pitch (Figure 2). The temperature of three barrel zones was controlled at 40ºC, 70ºC and 100ºC independently throughout the experiments. However, the temperature of last zone was varied depending upon the experimental design. The die opening with diameter of 5 mm was used. The extruder was powered by motor (8.5 kW) and equipped with torque indicator. Raw material was fed into the extruder inlet by a single screw volumetric feeder (D.S. and M, Modena, Italy). Feed rate was varied corresponding to the screw speed for optimum filling of the extruder barrel. Water was injected into extruder using water pump to maintain moisture content of feed. Extruded samples were cut with die face cutter which consists of four bladed knives and drives at variable speed. The resultant extrudates were dried and packed in polythene bags and laminated pouches. The packed extrudates were stored in airtight containers and kept for further physicochemical analysis.

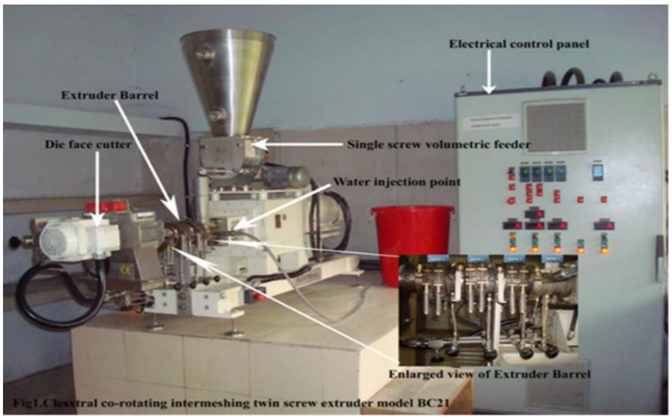

Fig 1: Clextral co rotating intermeshing twin screw extruder BC21

Fig 2: Screw configuration

Experimental design and statistical analysis

Response surface methodology was used to assess the optimum processing conditions for preparation of normal and quality protein maize based instant porridge. Preliminary trials were conducted to determine the levels of extrusion conditions. The optimization of experiments was done using three independent variables and five levels central composite rotatable design (CCRD). Twenty experimental runs with eight factorial points, six center points and six star corner points were used. The independent variables considered in this study were moisture (14-18%), screw speed (400-550 rpm) and barrel temperature (125- 175º C). By using a commercial statistical package, Design expert (version 10.0.7.0, Stat- Ease, Inc., Minncapolis, MN, USA). The effect of extrusion conditions on the product properties such as specific mechanical energy (SME), bulk density (BD), water absorption index (WAI), water solubility index (WSI) and dispersibility (D) of normal maize (NM) and quality protein maize (QPM) based instant porridge was also investigated using RSM. Second order polynomial regression method was validated in order to predict the effect of each variable on product response. To the selected models experimental data was fitted for each of the response functions. The model equation is as follow-

$$Yi = b_0 \pm b_1A \pm b_2B \pm b_3C \pm b_{12}AB \pm b_{13}AC \pm b_{23}BC \pm b_{11}A^2 \pm b_{22}B^2 \pm b_{33}C^2$$

Where, Yi represented the predicted response. Coefficients intercept, Linear, interaction and quadratic effects showed by b0, b_1, b_2, b_3; b_{12}, b_{13}, b_{23} and b_{11}, b_{22}, b_{33}, respectively. A, B and C indicated independent variables as feed moisture, screw speed and barrel temperature, respectively. Analysis of data was evaluated by multiple regression analysis. ANOVA was conducted to analyze the significance and validation of model (Ali *et al.* 2016a) [2]. Adequate precision measures the signal to noise ratio. Ratio greater than 4 for all responses indicates an adequate signal. The results obtained were used to determine the optimum extrusion conditions to prepare NM and QPM based instant porridge. The individual and interaction term effect of each variable was determined. Randomization of the experiments was done to reduce the systematic bias in observed responses due to external factors. Response surface plots were generated and statistical analysis of experiment data was performed.

Product properties

Specific mechanical energy (Wh/kg) was calculated from the percent motor torque and motor power rating (8.5 kW) using the formula given below (Pansawat *et al*. 2008) [27].

$$\text{SME (Wh/kg)} = \frac{\text{Actual screw speed (rpm)}}{\text{Rated screw speed (rpm)}} \times \frac{\text{Per cent motor torque}}{100} \times \frac{\text{Motor power rating (KW)}}{\text{Mass flow rate (kg/h)}} \times 1000$$

Bulk density (BD) of the extrudates was measured as the ratio of weight of sample and volume replaced by the sample in the cylinder (Patil *et al*. 2007) [29]. Density was calculated and expressed as

$$\text{Bulk Density (g/cc)} = \frac{\text{Weight of extrudates}}{\text{Volume displaced by extrudates}}$$

Water absorption index (WAI) and Water solubility index (WSI) of the extrudates was determined by previously described method (Anderson *et al*. 1969) [4]. WAI and WSI were expressed in g/g and percent, respectively by using following formulas:

$$\text{WAI (g/g)} = \frac{\text{Weight of gel}}{\text{Dry solids weight}}$$

$$\text{WSI (per cent)} = \frac{\text{Weight of dissolved solid in supernatant}}{\text{Dry solids weight}} \times 100$$

Dispersibility (D) – To measure dispersibility, 15g of sample was placed in a 100ml measuring cylinder. Volume was made 100 ml by adding water followed by stirring for 1min 30sec. The samples were allowed to settle for 15min. The difference was calculated from the difference obtained by subtraction of volume of the settled particles from 100 and reported in percentage (Nahemiah *et al*. 2016) [25].

Optimization

Extrusion processing parameters were optimized by using a conventional graphical method given in Design expert software, to obtain porridge with acceptable properties. Sensory evaluation was performed and used as criteria for constraints optimization. Range of optimum process variables to develop instant porridge with specified properties was determined from final overlay plots obtained by superimposing the contour plots of all responses. Physical properties of instant porridge developed from NM and QPM are given in Table 1. Analysis of variance, model statistics and regression coefficients for the dependent variables are presented in Table 2 and Table 3.

Table 1: Effect of extrusion conditions on dependent variables

Sr. No.	Feed moisture (%)	Screw speed (rpm)	Barrel Temp (ºC)	SME (Wh/Kg)		BD (g/cc)		WAI (g/g)		WSI (%)		D (%)	
				NM	QPM	NM	QPM	NM	QPM	NM	QPM	NM	QPM
1	14(-1)	400(-1)	125(-1)	87.98	107.15	0.218	0.174	3.58	3.75	29.45	30.27	76.75	73.15
2	18(+1)	400(-1)	125(-1)	88.09	93.89	0.287	0.315	3.38	3.41	26.61	30.61	98.82	86.50
3	14(-1)	550(+1)	125(-1)	124.12	127.09	0.197	0.146	3.62	3.58	26.91	34.41	84.09	82.00
4	18(+1)	550(+1)	125(-1)	104.12	106.59	0.213	0.240	3.59	3.59	27.14	33.81	94.00	83.50
5	14(-1)	400(-1)	175(-1)	93.12	100.85	0.209	0.177	3.76	3.74	32.38	35.91	50.00	76.00
6	18(+1)	400(-1)	175(+1)	82.13	86.68	0.307	0.259	3.49	3.04	30.19	35.82	84.40	71.06
7	14(-1)	550(+1)	175(-1)	115.91	124.61	0.189	0.155	3.74	3.04	28.91	35.82	75.48	71.06
8	18(+1)	550(+1)	175(+1)	84.72	109.62	0.220	0.222	3.64	3.48	29.61	37.81	82.00	79.12
9	12.64 (-1.682)	475(0)	150(0)	115.82	122.41	0.129	0.150	3.52	3.44	33.79	34.58	74.00	86.50
10	19.36 (+1.682)	475(0)	150(0)	89.61	93.74	0.201	0.314	3.30	3.04	30.63	33.22	93.00	85.00
11	16(0)	349 (-1.682)	150(0)	65.13	58.91	0.308	0.231	3.27	3.60	29.01	29.52	95.00	76.02
12	16(0)	601(+1.682)	150(0)	101.14	114.81	0.216	0.21	3.40	3.62	28.81	34.19	95.00	82.00
13	16(0)	475(0)	107.95 (-1.682)	112.31	125.41	0.256	0.234	4.07	3.98	22.32	28.02	86.5	86.00
14	16(0)	475(0)	192.04(+1.682)	101.68	121.89	0.248	0.174	4.26	3.75	27.20	38.61	47.50	74.5
15	16(0)	475(0)	150(0)	105.81	114.79	0.242	0.177	3.50	3.44	30.00	36.72	90.00	96.00
16	16(0)	475(0)	150(0)	107.55	98.77	0.248	0.179	3.47	3.46	26.95	33.47	76.00	92.00
17	16(0)	475(0)	150(0)	106.45	102.86	0.243	0.193	3.48	3.43	27.45	35.43	72.00	94.50
18	16(0)	475(0)	150(0)	107.82	96.73	0.249	0.199	3.52	3.50	26.71	33.42	70.00	90.00
19	16(0)	475(0)	150(0)	107.24	110.67	0.244	0.185	3.50	3.51	28.32	36.41	87.00	95.50
20	16(0)	475(0)	150(0)	106.89	112.54	0.246	0.187	3.51	3.49	29.66	34.56	84.01	91.50

* Coded values are in the parenthesis

Table 2: Analysis of variance for the fit of experimental data to response surface model for normal maize (NM) and quality protein maize (QPM) porridge

Regression	SME		BD		WAI		WSI		D	
	NM	QPM	NM	QPM	NM	QPM	NM	QPM	NM	QPM
Adequate precision	95.12	13.25	47.77	17.89	47.62	24.04	14.06	13.16	10.39	11.00
CV (%)	0.86	6.29	2.31	0.959	0.83	1.59	3.86	4.29	8.79	3.17
R^2	0.998	0.909	0.991	0.923	0.991	0.967	0.890	0.768	0.860	0.934
Adjusted R^2	0.996	0.828	0.983	0.738	0.984	0.938	0.791	0.724	0.734	0.876
Predicted R^2	0.989	0.672	0.938	6.46	0.947	0.786	0.707	0.645	0.513	0.643

Lack of fit	1.68n.s.	0.55n.s.	6.40s	4.10n.s.	4.09n.s.	4.75n.s.	0.25n.s.	1.09n.s.	0.46n.s.	1.42n.s.

s - significant at $p < 0.05$ n.s. - Non significant

Table 3: Regression coefficients for fitted models for normal maize (NM) and quality protein maize (QPM) porridge

Parameters	SME		BD		WAI		WSI		D	
	NM	QPM	NM	QPM	NM	QPM	NM	QPM	NM	QPM
Intercept of Model	106.94	106.03	0.25	0.19	3.50	3.47	28.17	34.18	79.87	93.30
Feed moisture (A)	-7.77**	-8.14**	0.025**	0.048**	-0.071**	-0.15**	-0.69*	-0.12	7.68**	0.22
Screw speed (B)	10.11**	12.69**	-0.026**	-0.014**	0.044**	0.040*	-0.47	1.32**	1.87	2.30**
Barrel temperature (C)	-3.39**	-1.38	-2.529E-004	-0.012**	0.057**	-0.048*	1.40**	2.57**	-9.33**	-2.55**
Feed moisture × screw speed (AB)	-5.04**	-1.01	-0.015**	-7.750E-003	0.043**	0.091**	0.75		-5.00	-1.41
Feed moisture × barrel temperature (AC)	-2.79**	0.58	5.500E-003*	-0.011*	-0.017	-0.086**	0.14		1.12	-3.02**
Screw speed × barrel temperature (BC)	-3.35**	1.76	-1.500E-003	5.500E-003	-0.015	0.061*	-0.25		2.57	1.21
Feed moisture × feed moisture (A^2)	-1.40**	0.89	-0.027**	0.014**	-0.040**	-0.088**	1.48**		1.03	-2.99**
Screw speed × screw speed (B^2)	-8.32**	-6.61**	6.910E-003**	9.897E-003*	-0.067**	0.043*	0.31		5.10*	-5.38**
Barrel temperature × barrel temperature (C^2)	0.11	6.40**	3.374E-003*	4.063E-003	0.23**	0.13**	-1.16**		-4.80*	-4.94**

** Significant at $p < 0.01$; * Significant at $p < 0.05$

Validation of model

The regression models for SME, WAI, WSI, BD and dispersibility were highly significant (Where model terms are significant when values of "Prob > F" less than 0.05) with a strong correlation coefficient (R^2). Non significant lack of fit means all the second-order polynomial models correlated well with the measured data. This model can be used to navigate the design space.

Result and Discussion

Specific Mechanical Energy (SME)

Specific mechanical energy (SME) is an important factor to design engineering as it directly affects the quality of final product. It is also used as a system parameter to model properties of extruded products (Godavarti and Karwe 1997; Harper 1989) [14, 16]. Assessment of the effect of independent variables under various processing conditions on SME was done by using ANOVA. Results given in Table 1 elucidated that SME was varied from 65.13 to 124.12 Wh/kg for NM and 58.91 to 127.09 Wh/kg for QPM based instant porridge, respectively. The regression analysis model for NM showed highly significant linear as well as quadratic effect of the independent variables on SME ($p < 0.01$). However, in case of QPM Feed moisture, screw speed showed highly significant ($P < 0.01$) while barrel temperature non-significantly effects the SME. In both cases NM and QPM porridge, feed moisture and barrel temperature exhibited negative while screw speed showed positive coefficients of the linear terms which indicated that SME decreased with increase in feed moisture and barrel temperature and increased with increase in screw speed. Similar results were also reported by other authors (Zuang *et al*. 2010). Fig 2 and 3 indicates curvilinear nature of feed moisture and barrel temperature on SME of PMH and QPM porridge. Increase in feed moisture and temperature resulting in reduced SME due to lubricating effect and starch gelatinization, respectively (Singh *et al*. 2015) [36]. High barrel temperature also causes solid to viscoelastic flow transformation which mitigate the melt viscosity and SME. The coefficient of variation (CV) which was 0.84 % (NM) and 6.29 % (QPM) exhibited the relative dispersion of the experimental points from prediction model, shown in Table 2. A high coefficient of determination that is R^2 (0.998), adjusted R^2 (0.996) for NM and R^2 (0.909), adjusted R^2 (0.828) shows the strong interaction between the processing parameters. Lack of fit was found to be non significant in both cases NM as well as QPM.

Bulk density (BD)

The observed value of bulk density was ranged from 0.129 to 0.308 g/cc for NM and 0.146- 0.315 g/cc for QPM (Table 1). Analysis of responses was performed by using ANOVA. Predicted model showed values of coefficient of determination (R^2 = 0.991 and adjusted R^2= 0.983) and coefficient of variation (C.V. = 2.31 %) for NM and coefficient of determination (R^2 = 0.959 and adjusted R^2= 0.923) and coefficient of variation (C.V. = 6.46 %) for QPM (Table 2). As evident from the regression coefficients given in (Table 3), it was observed that the BD was significantly affected by the positive linear effect of feed moisture content and negative linear effect of temperature and screw speed ($P<0.01$) in NM and QPM. However, in NM barrel temperature showed non significant effect on bulk density. Response surface plots show the effect of independent variables on BD of porridge. The positive coefficients of the linear terms of feed moisture in Table 3 emphasize that BD arises by increasing the feed moisture while negative coefficients of screw speed and barrel temperature indicated that BD reduced by increasing screw speed and temperature (Fig 3, 4). The interaction between feed moisture and screw speed had significant negative correlation with density in NM at $p< 0.01$ whereas, non significant effect was observed in QPM. The interaction between feed moisture and temperature had significant positive correlation ($p< 0.05$) in NM and QPM (Table 3). This can be explained by the fact that when extrudates comes out from the die, the presence of higher temperature causes super-heated water evaporation from extrudates and results in expansion and lighter weight (Koksel *et al*. 2004) [19]. Increase in feed moisture results in reduction of elasticity and starch gelatinization leading to increased bulk density (Ding *et al*. 2005) [10].

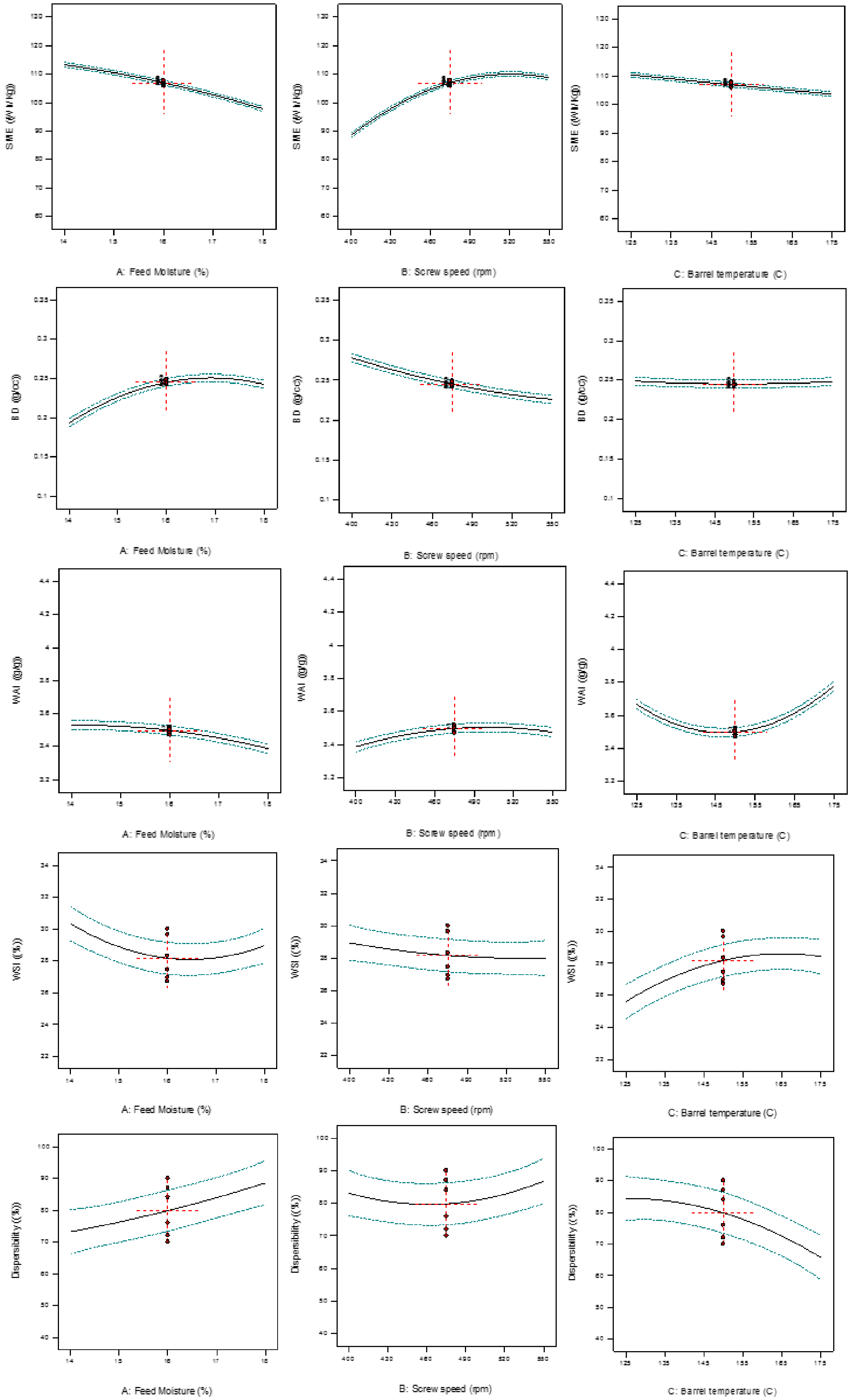

Fig 3: Model graphs depicting the behaviour of SME, BD, WAI, WSI and D at different feed moisture content, screw speed and barrel temperature of NM based instant porridge

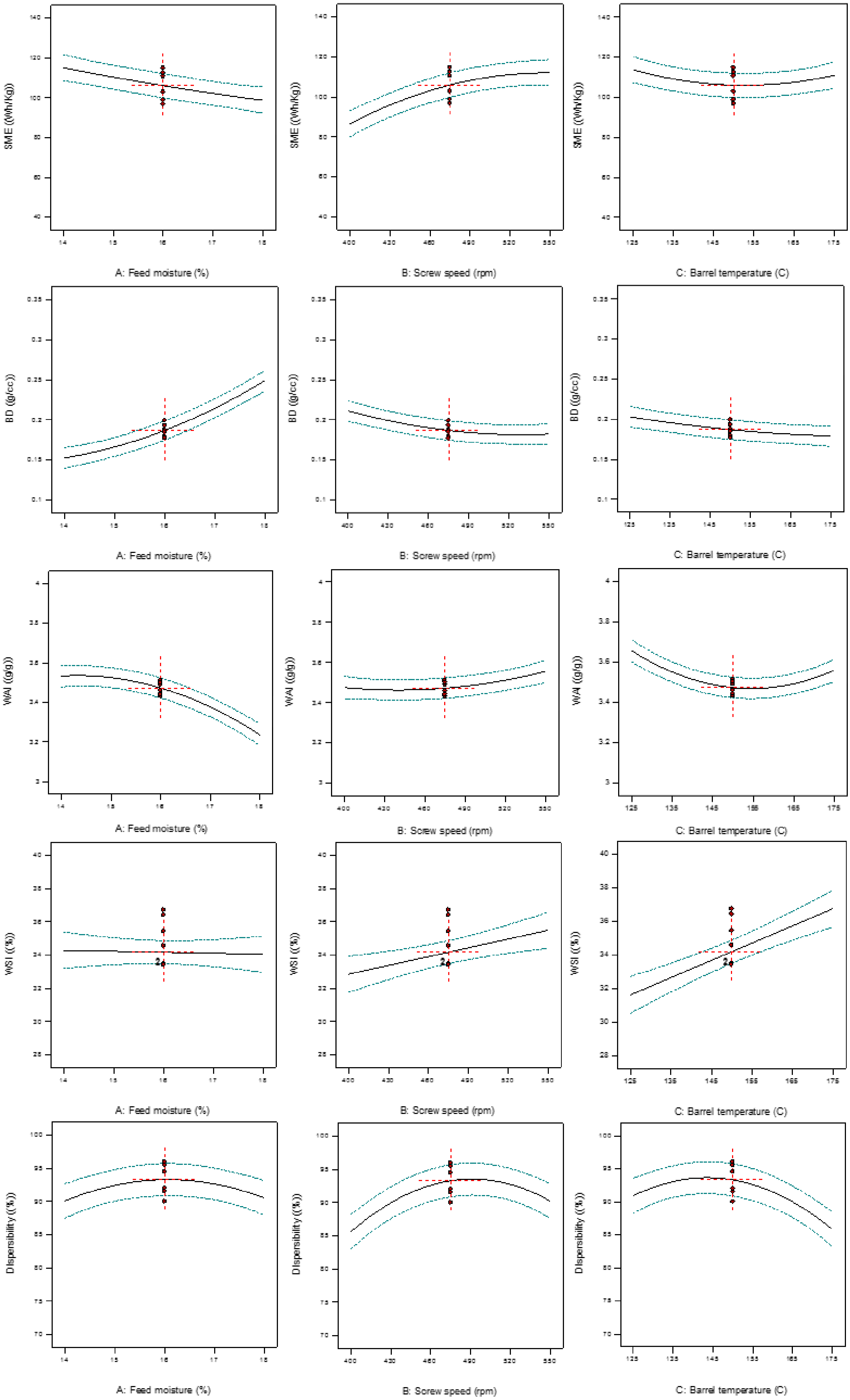

Fig 4: Model graphs depicting the behaviour of SME, BD, WAI, WSI and D at different feed moisture content, screw speed and barrel temperature of QPM based instant porridge

Water absorption index (WAI)

WAI determines the degree of instantaneous of the powder or cereals which depends upon the processing parameters and raw material used (Chetan *et al*. 2017). It is mainly due to the presence of hydrophilic groups (Ali *et al*. 2016b, Gomez and Aguiera 1983) [3, 15]. WAI increases with the degree of starch damage as extrusion induces fragmentation of starch amylose and amylopectin chains (Mason and Hoseney 1986; Yagci and Gogus 2008) [22, 39]. Results given in Table 2 illustrates that values of WAI for instant porridge varied from 3.27 to 4.26 g/g (NM) and 3.04 to 3.98 g/g (QPM). In both cases NM as well as QPM, Feed moisture had highly significant effect on WAI ($P < 0.01$). Feed moisture and screw speed showed negative and positive linear coefficient, respectively. It indicates that WAI increases with decrease in feed moisture content and increase in screw speed, significantly (Fig 3, 4). The interactions between feed moisture and screw speed ($P < 0.01$) were found to have significant positive correlation with WAI values (Fig 5). Similar research finding were found by Filli *et al*. (2013) [13], which concluded that increase in moisture content decreases the cooking extent and starch solubility and resulted in the decrease in WAI. Increase in temperature causes starch degradation and dextrinization which can results in the reduction of WAI value (Ali *et al*. 2016b) [3].

Water Solubility Index (WSI)

The WSI reflects the amount of soluble polysaccharides released from the starch after extrusion. WSI can measure the amount of degraded starch formed due to the breakdown of molecular compounds (Ding *et al*. 2005) [10]. Table 2 presented that WSI values for NM and QPM which ranged from 22.32 to 33.79 % and 28.02-38.61%, respectively. WSI was affected significantly by feed moisture ($p < 0.05$) and barrel temperature ($p < 0.01$) but non significantly by screw speed in NM porridge. However, In case of QPM porridge, the feed moisture showed non significant and screw speed as well as barrel temperature exhibited the negative regression coefficient. Negative regression coefficient of feed moisture indicated that WSI significantly decreased with increasing feed moisture which indicates that extrusion at low feed moisture increases the water solubility of starch molecules due to the increase in amount of degraded starch granules (Pathania *et al*. 2013; Silva *et al*. 2009) [28, 35]. However high moisture content diminishes the protein denaturation and lowers the WSI values (Badrie and Mellowes 1991) [5]. On the other hand, positive regression coefficients of screw speed and barrel temperature showed that WSI increases by increasing these two variables. Moisture and temperature interaction also showed positive but non significant correlation in NM porridge (Fig 6). The results revealed the quadratic and interaction effect of Independent variables only in NM porridge. Our results are in agreement with a research study which states that an increase in screw speed results in high mechanical shear which leads to fragmentation of macromolecules to smaller units possessing higher solubility and subsequently increases WSI (Dogan and Karwe 2003; Singh *et al*. 2015) [36]. As the temperature increases, starch gelatinization occurs which increases the amount of soluble starch in water and also increases in WSI (Ding *et al*. 2005) [10].

Dispersibility (D)

Dispersibility is an important functional property of the food products which significantly affects the consumer acceptability. It was evaluated to exhibit its reconstitution in water without the formation of lumps. It relates to the instantisation as a food with high dispersibility can be considered as instant food (Nahemiah *et al*. 2016) [25]. Data displayed in the Table 2 displayed the range of NM and QPM porridge, which was varied from 47.50 to 98.82 % and 71.06-95.50 %, respectively. From regression coefficients table significant effect of feed moisture, barrel temperature and screw speed on dispersibility at $P < 0.01$ was observed. The negative coefficients of barrel temperature revealed that dispersibility decreases with increase in temperature while positive coefficients of feed moisture and screw speed indicated that dispersibility increased with increase in these two variables. It increase in dispersibility with respect to screw speed can be due to fragmentation of starch molecule at high shear force (Hagenimana *et al*. 2006). The interactions between feed moisture and temperature ($P < 0.01$) were showed to have significant negative correlation with dispersibility. The model for dispersibility showed high degree of coefficient of determination (R^2) of 0.86 and adjusted R^2 of 0.734 with a coefficient of variation (CV= 8.79 %) for NM porridge (Table 2). Regression analysis also revealed that the quadratic negative correlation coefficient of feed moisture (A^2), and screw speed (B^2) and barrel temperature (C^2) significantly affected dispersibility of QPM porridge. Otegbayo *et al*. (2013) reported that soy enriched tapioca showed dispersibility range from 63.0 to 87.0%.

Optimization

Figures 5 (A, B) and 6 (A, B) depicted the overlay contour plots of the optimum extrusion processing conditions (OEC) to develop instant porridge from NM and QPM, respectively. Optimum extrusion conditions of feed moisture and barrel temperature were found in the range for 14-14.87%, 14.86-16.66 % and 137.472-175ºC, 125-144.496ºC at 475 rpm screw speed to produce instant porridge from normal maize (NM) and quality protein maize (QPM), respectively. At constant barrel temperature (150ºC), observed optimized extrusion condition were varied from 14-14.72%, 15.53-16.55% for feed moisture and 400-497.798 rpm, 483.9-550 rpm for screw speed to produce NM and QPM based instant porridge.

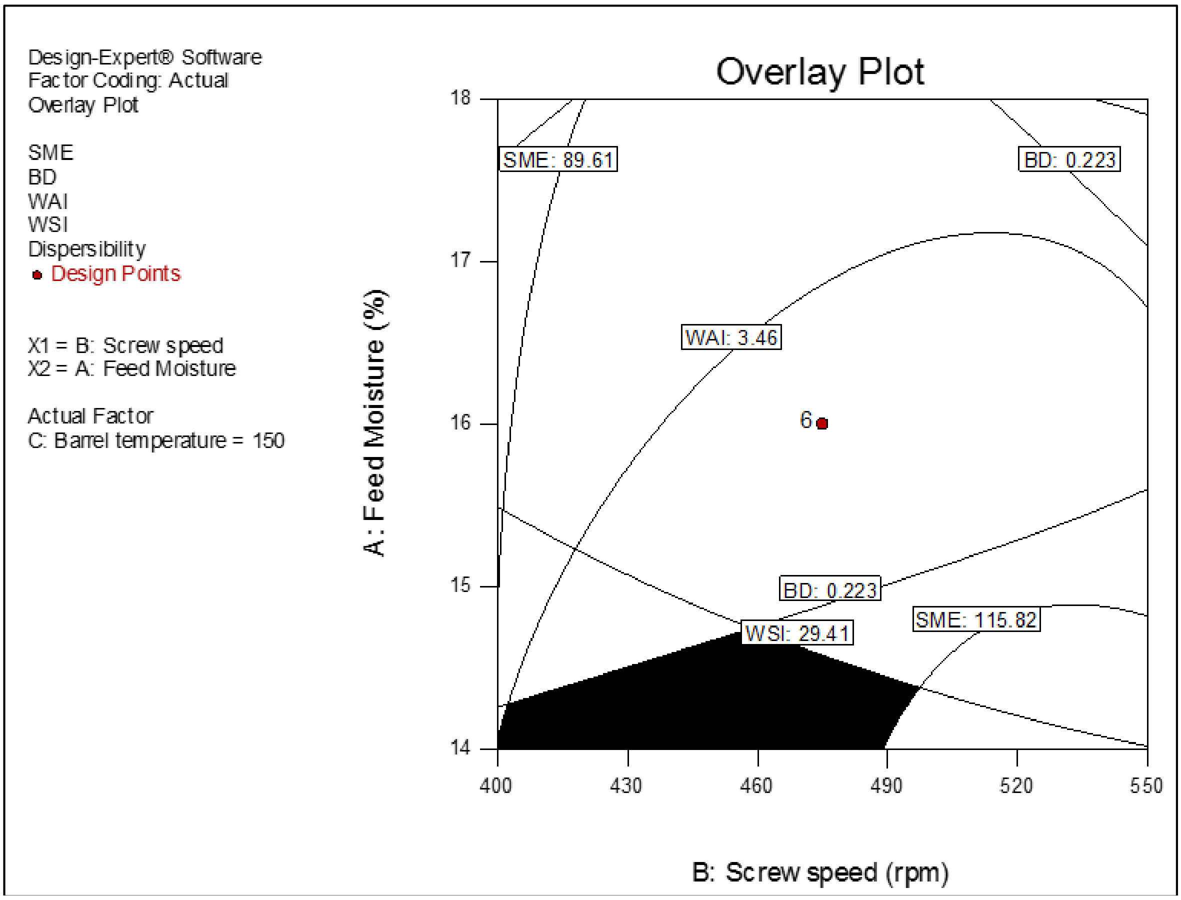

Fig 5(A): Overlay plots for product responses affected by feed moisture content and screw speed of Normal maize (NM) based instant porridge

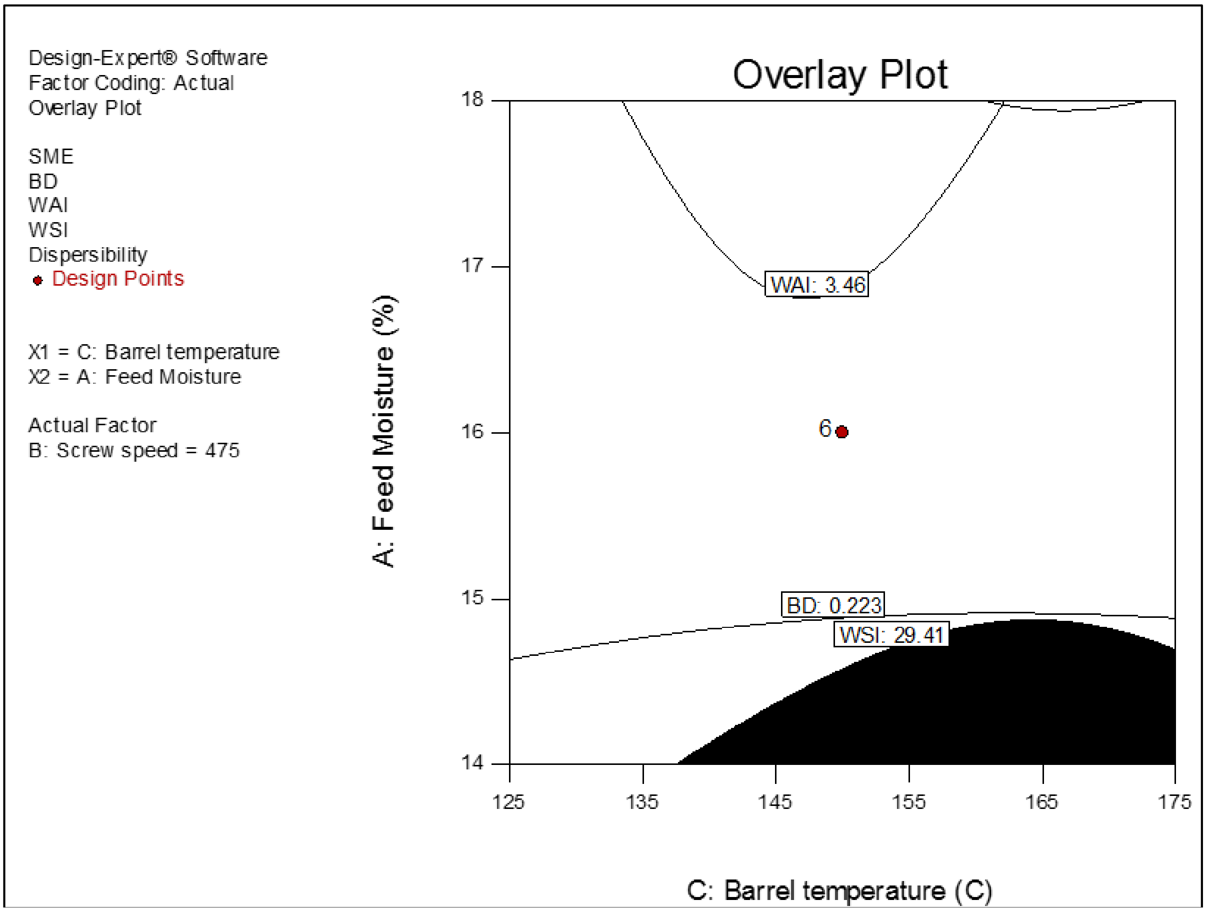

Fig 5(B): Overlay plots for product responses affected by feed moisture content and barrel temperature of Normal maize (NM) based instant porridge

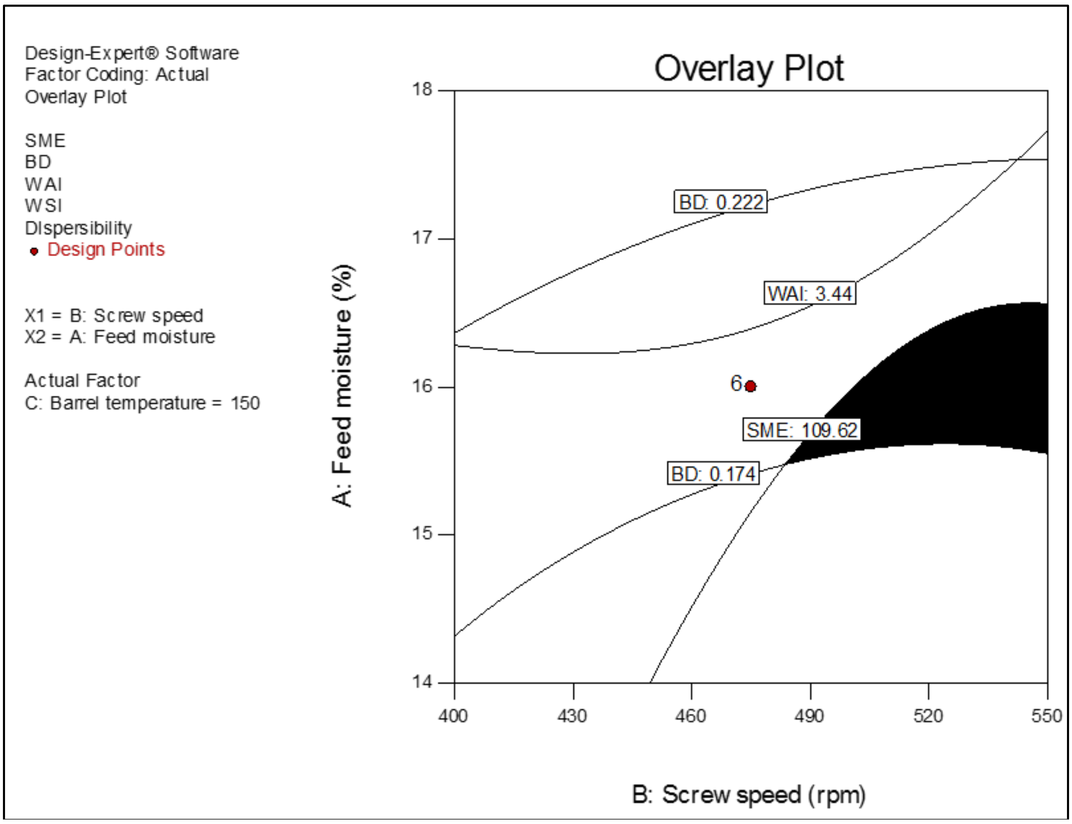

Fig 6(A): Overlay plots for product responses affected by feed moisture content and screw speed of Quality protein maize (QPM) based instant porridge

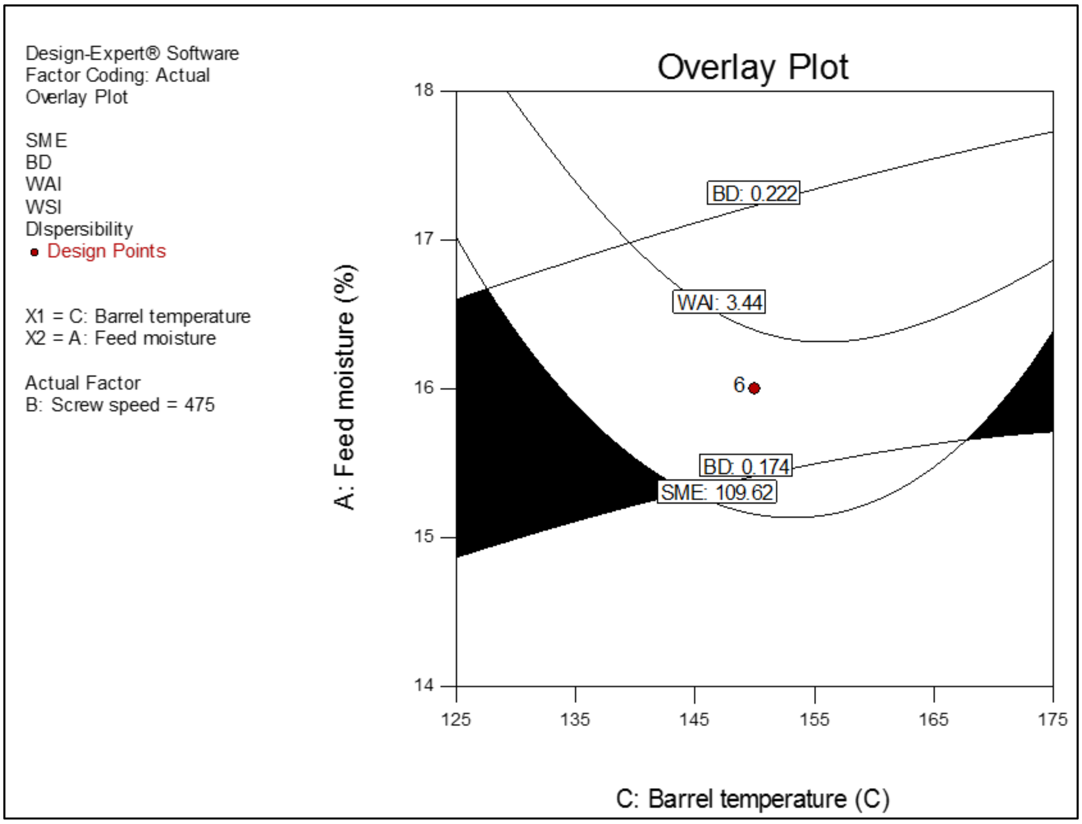

Fig 6(B): Overlay plots for product responses affected by feed moisture content and barrel temperature of Quality protein maize (QPM) based instant porridg

Conclusion

RSM was performed to examine the effect of extrusion conditions (FM, SS and BT) on the functional properties of NM and QPM based porridge produced with twin screw extruder. All the independent variables showed linear, quadratic as well as interaction effect on the product responses except on water solubility Index of QPM porridge. Specific mechanical energy was negatively affected by barrel temperature and feed moisture and positively influenced by screw speed. This study explored an innovative approach for utilization of quality protein maize having nutritional importance as it contains essential amino acids. It could be used to prepare nutritious and acceptable instant breakfast cereal using extrusion technology. As its high quality protein would help in decreasing the malnutrition among children.

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