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Study on Physical, Functional and Sensory Qualities Of Soy Fortified Maize-Millet Based Extrudate

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Abstract
The current research experiment was aimed to investigate the physico-functional and sensory behaviors of extruded product affected by extrusion process parameters. Three factors five level statistical software of central composite rotatable design was used to design the experiment. The process variables barrel temperature (100-150°C), screw speed (110-350 rpm) and feed moisture content (12-20% wb) was used in this research. The outcomes of process parameters on responses like expansion ratio (ER), bulk density (BD), water absorption index (WAI), water solubility index (WSI) and overall acceptability of extruded product were investigated using response surface methodology. The responses were found to be significant with process parameters. The feed moisture had encouraging influence on BD and WAI whereas negative on ER, and WSI of the extruded products. Overall acceptability score had significantly affected by screw speed and other factors had affected non-significant. ER, BD, WAI and WSI values of extruded product had been ranged from 2.017-3.391, 0.13-0.28 g/cm^3, 5.76-7.25 g/g and 12.76-20.97%, respectively. The score of overall acceptability (8.20) was assigned maximum to the sample prepared with the combination of independent factors of feed moisture 14% (wb), barrel temperature 110°C and screw speed 301 rpm.

Keywords - Barrel temperature, Bulk density, Expansion ratio, Overall acceptability, Water absorption index.

I. INTRODUCTION

Due to health consciousness of consumers, balanced and nutritious foods are demanded in recent years. Ready-to-eat or extruded products are generally prepared from starch rich cereals and/or protein sources raw materials. This may be due to development of good texture, structure, expansion, crispy, binding and many more qualities necessary for finished products [1]. To improve the protein value of breakfast snacks or extruded foods in India, research and development activities by incorporation or fortification of legumes like soybeans, grams, lathyrus, green gram, *etc.* in extruded foods is being focused. Maize starch is crucial for development of extruded product which produces highly puffed or expanded products as well as provides proper binding and good texture of products.

Millets are considered to be food for poor people but it is highly nutritious, tasty, pleasant and nut-like flavour. Finger millet is rich in protein, iron, magnesium, calcium, phosphorus, fiber, polyphenols and vitamins. Its poly phenol has wellbeing effects like anti-inflammatory, anti viral, anti-cancer, reduces risk of diabetes [2]. Soy proteins help in water binding capacity of mix during extrusion. Defatted soy is high in lysine and low in methionine, cysteine and tryptophan which are contrast of cereals [3]. It also helps in lowering the cholesterol level, reducing obesity, avoiding occurrence of cancer, *etc*. [4-5]. Its protein quality is considered to be at par with the protein obtained through animal sources and also easily digested. Elephant foot yam (*Amorphophallus paeoniifolius)* also known as *jimikand* is a potential tropical tuber crop and mostly consumed as vegetable in various Indian cuisines. It is rich in zinc, phosphorus, potassium, calcium along with vitamins, steroids, phenols, alkaloids, flavonoids, *etc*. The presence of Omega-3 fatty acid has reduces bad cholesterol, prevents unnecessary blood clotting, increasing good cholesterol level, blood purifying and antioxidant activity. Despite medicinal and health benefits, it is yet to find industrial use, and hence, the literature on the development of value added extruded products using elephant foot yam is scanty [6].

Extrusion minimizes the risk of thermal influences on nutritional value of the products due to low residence time. The final product quality depends on many factors like screw configuration, screw speed, cutting knife speed, extrusion temperature, die diameter, feed rate, *etc.* This suggests proper adjustment of process variables to produce desired quality products [7, 8]. Previous researchers have found that feed moisture, screw speed and extrusion temperature had significantly affected on physical, functional and sensory qualities of extruded product [9]. The goals of current study was to study the influence of process parameters on physic-functional and sensory qualities of extruded product made from optimal composite blend of maize-millet based soy fortified flour.

II. MATERIALS AND METHODS

2.1 Raw ingredients and preparation of sample-

Maize, finger millet and elephant foot yam were acquired from local market of Raipur, Chhattisgarh (India) and the powder of defatted soy was procured from Bhatnagar Industry, Bhopal (MP). The flours developed from all the raw ingredients were packed in zip-lock polyethylene pouches and stored under cool and dry places before use. The optimum blend ratio of maize, defatted soy, finger millet and elephant foot yam was used for production of extruded products [6]. Hot air oven method was applied to found out the moisture content of the blend [10]. The blends were hydrated to achieve required moisture content (12-20% wb) by adding calculated amount of water to the blend and it was calculated by from the equations (Eqs. (1-2)) as below [11].

$$C_i = \frac{[r_i \times M \times (100 - w)]}{[100 \times (100 - w_i)]} \quad (1)$$

$$W_x = M - \sum_{i=1}^{4} C_i \quad (2)$$

Where, C_i Mass of ingredient i (g), r_i Percentage of ingredient i, M Total mass of the blend (g), w_i Moisture content of ingredient i (% wb), w Moisture content of the blend (% wb), W_x Amount of water to be added (g).

The blend samples were then filled in LDPE pouches and placed at refrigerated condition (4°C) for 2 h for conditioning.

2.2 Extrusion cooking-

The sample was extruded with a twin screw extruder of co-rotating type (BTPL, Kolkata). The feed rate (5kg/h) and cutting knife speed (22 rpm) were maintained constant throughout the experiments. The extruder die of circular type (3 mm diameter) was employed in the experiment as recommended by manufacturer for similar product development. Once the steady state condition of barrel temperature attained, the composite blend (500 g) was fed into the extruder through feeder hopper. The developed products were packed in zip-lock polyethylene pouches (LDPE) and stored in room temperature until used for further analysis.

2.3 Experimental design-

Experiment was framed out by using three factors with five levels of central composite rotatable design (CCRD) to study the mutual effect of process parameters *viz.,* extrusion barrel temperature, screw speed and feed moisture (Design Expert software version 10.0.5.0) as presented in Table 1 [12]. Statistical tools of Response surface methodology (RSM) was adopted to find out the effect of process parameters (independent) on dependent variables *viz.,* ER, BD, WAI, WSI and overall acceptability score of product. The RSM method is to co-relate the properties of the prepared product by regression equations which describe relationship between independent and dependent variables. Response surface plots were created through this technique which is a function of two variables and third one was kept fixed value. This tool also develops a mathematical model that explains the relationship between processes and response. A multiple regression equation (Eq. 3) was employed to describe the relationship.

$$y_i = \beta_0 + \sum_{i=1}^{3} \beta_i\, x_i + \sum_{i=1}^{3} \beta_{ii}\, x_i^2 + \sum_{i=1}^{2} \sum_{j=i+1}^{3} \beta_{ij}\, x_i\, x_j \qquad (3)$$

Where x_i, x_i^2, x_ix_j are linear, quadratic and interaction terms of the variables, respectively which manipulate the responses y_i. β_0, β_i, β_{ii} and β_{ij} are the multiple regression coefficients. The adequacy of the developed model and significance of the model terms at different levels (0.1%, 1% and 5%) were evaluated by ANOVA.

Table 1 Coded and actual values of process parameters used in CCRD

Parameters	Coded and actual values					
	Coded	-α (-1.68)	-1	0	+1	+ α (+1.68)
Barrel temperature, °C (x_1)		100	110	125	140	150
Screw speed, rpm (x_2)		110	159	230	301	350
Feed moisture content, % (wb) (x_3)		12	14	16	18	20

2.4 Product characteristics-

The qualities of extruded products such as ER, BD, WAI and WSI, were evaluated as described below.

2.4.1 Expansion ratio-

Expansion ratio (ER) is expressed as the ratio of extruded diameter to the die diameter [6, 13].

2.4.2 Bulk density-

Mass of each sample was determined by using laboratory weighing balance. The actual dimension of extruded product was found out by using digital vernier caliper. Bulk density (BD) was determined as the mass of the product divided by the product volume and presented in g cm^{-3} [6]. The expression for BD is given in equation (Eq. 4) below:

$$BD = \frac{(4 \times m)}{(\pi \times d^2 \times L)} \quad (4)$$

Where L is length of the extrudate (cm), d is diameter of the extrudate (cm) and m is mass of the extrudate (g).

2.4.3 Water absorption index (WAI) and water solubility index (WSI)-

WAI and WSI were found out according to the method described by Stojceska et al. [14] and Sahu and Patel [6]. The WAI and WSI values were measured as per formulas given below.

$$WAI\ (g/g) = \frac{\text{Weight of sediment}}{\text{Weight of dry solids}} \quad (5)$$

$$WSI\ (\%) = \frac{\text{Weight of dissolved solids in supernatant}}{\text{Weight of dry solids}} \times 100 \quad (6)$$

2.4.4 Sensory quality-

Sensory or organoleptic properties of extruded products were assessed by using 9-point Hedonic scale [15]. The attributes considered for evaluation were colour, body and texture, appearance, taste and overall acceptability. The sensory characteristics of samples was accomplished by a semi-trained judges consisted of 15 members. Samples placed before the judges for evaluation were coded to avoid disclosure of the sample information and biasness. A glass of warm water was also given to the judges for cleansing the palate before and within the testing. Acceptability scores were recorded as the mean of the score assigned by the panelists.

III. RESULTS AND DISCUSSION

The results of responses obtained with different combinations of process parameters during extrusion are depicted in Table 2. The values of these responses were statistically evaluated through regression techniques through Design Expert software to decide adequacy of the predicted value of the model. Effect of feed moisture content, screw speed and barrel temperature on ER, BD, WAI, WSI and overall acceptability are presented in 3D surface graphs.

3.1 Expansion ratio-

Table 2 indicated that ER of extruded product was varied from 2.02 to 3.39 with the variation in process parameters. ER had significantly affected by process parameters at 0.1% level (Table 3). The interaction effect was also significant ($p < 0.05$). Among the quadratic terms of X_1 and X_2 significantly affected the process whereas as the feed moisture (X_3) had insignificant. The developed quadratic model with high F-value (54.99) was found to be significant ($p < 0.001$). The higher value coefficient of determination ($R^2 = 0.98$) suggests that the model could be adequately preferred to depict the experimental data. The predicted value of R^2 (0.92) was found to be in good concurrence with the adjusted R^2 (0.96) which further shows its competence to describe the relationship. The developed regression model (Eq. 7) is given below.

$$ER = 2.64 + 0.29X_1 + 0.26X_2 - 0.051X_3 - 0.068X_1X_2 + 0.057X_1X_3 + 0.062X_2X_3 + 0.075X_1^2 + 0.097X_2^2 \quad R^2 = 0.98 \quad (7)$$

The highest positive coefficient of X_1 had the highest positive influence on expansion ratio followed by X_2 (Eq. 7). This means that ER of extruded product elevated with the raise in barrel temperature and screw speed which is also shown in Fig. 1a. This may be due to increased superheating of water causes more bubble formation and produces porous structure at higher temperature with the increase in screw speed. A similar result has also been supported by Ainsworth [16] for corn snack with brewers spent grain inclusion. On the other hand, the minus sign of X_3 had negative effect on ER which showed that increased feed moisture produces the product with lesser puffing. It is also evident from the Fig. 1b that ER of extruded products diminished with the raise in feed moisture. This might be due to decrease in elasticity of dough at higher moisture through melt plasticization which adversely affects the formation and stability of bubbles. The finding has also in agreement with the development of wheat base expanded snacks [17].

Table 2 Effect of process parameters on quality characteristics of extrudates

Run	X_1 (°C)	X_2 (rpm)	X_3 (% wb)	Expansion ratio	Bulk density (g cm^{-3})	WAI (g g^{-1})	WSI (%)	OAA
1	125	230	12	2.789	0.17	5.94	19.72	6.90
2	150	230	16	3.391	0.13	6.37	20.97	7.20
3	125	230	16	2.619	0.14	6.23	18.91	7.00
4	125	230	16	2.517	0.15	6.25	17.33	6.90
5	125	110	16	2.537	0.21	6.21	13.38	6.40
6	140	159	18	2.825	0.16	6.35	14.98	7.30
7	140	159	14	2.915	0.16	6.32	13.62	7.30
8	100	230	16	2.384	0.26	7.11	18.67	7.40
9	125	350	16	3.361	0.14	6.45	18.99	7.60
10	125	230	16	2.638	0.15	6.14	18.98	6.90
11	140	301	18	3.358	0.17	6.54	18.85	6.90
12	125	230	20	2.516	0.20	7.25	12.76	6.80
13	110	159	18	2.017	0.28	7.16	13.79	6.90
14	125	230	16	2.679	0.15	6.26	17.07	6.90
15	140	301	14	3.162	0.13	6.39	19.76	7.70
16	125	230	16	2.724	0.16	5.76	19.21	7.10
17	125	230	16	2.645	0.16	6.29	17.74	7.70
18	110	301	14	2.852	0.17	6.53	18.91	8.20
19	110	159	14	2.296	0.24	6.42	14.87	7.00
20	110	301	18	2.783	0.19	7.21	18.29	7.10

X_1: barrel temperature, X_2 : screw speed, X_3: feed moisture content, WAI: water absorption index, WSI: water solubility index, OAA: overall acceptability

3.2 Bulk density-

The BD value of extruded product was recorded from 0.13 to 0.28 g cm^{-3} as depicted in Table 2. The regression (Table 3) indicated that all the linear expressions of process variables and the interaction term X_1X_2 had significantly affected the BD ($p < 0.01$). Quadratic terms had also significant on bulk density. The developed quadratic model with high F-value (40.20) was established to be significant ($p < 0.001$) with insignificant lack-of-fit. High value of R^2 (0.97) suggests its close adequacy. The predicted R^2 (0.83) was in closely co-related with the adjusted R^2 (0.95) which further strengthen its capability. Regression model predicting the BD with coded value of independent variables is given below (Eq. 8).

$$BD = 0.15 - 0.035X_1 - 0.022X_2 + 0.011X_3 + 0.018X_1X_2 + 0.015X_1^2 + 0.00835\,X_2^2 + 0.012\,X_3^2 \qquad R^2 = 0.97 \qquad (8)$$

The positive coefficient of X_3 had constructive influence on bulk density. The negative coefficients of X_1 and X_2 indicated that reduction in BD with the increase in the levels of these parameters. Feed moisture has been recognized as a major influencing thing on bulk density (Fig. 1c). This may be due to increased availability of moisture provokes transform in amylopectin molecular arrangement of starch causing the reduction in elasticity of the melt, which in turn reduces the expansion capacity [17]. Increase in screw speed tends to reduce melt viscosity of the blend which in turn increases the dough elasticity thereby reduces the extrudate density (Fig. 1d). Bulk density of extruded products reduced with the raise in barrel temperature, which might be more vapour pressure variation between the vapour pressure of water inside the extruder and atmospheric pressure at the die end. Similar effects in the case of soybean protein and starch based extrudates has been demonstrated [18].

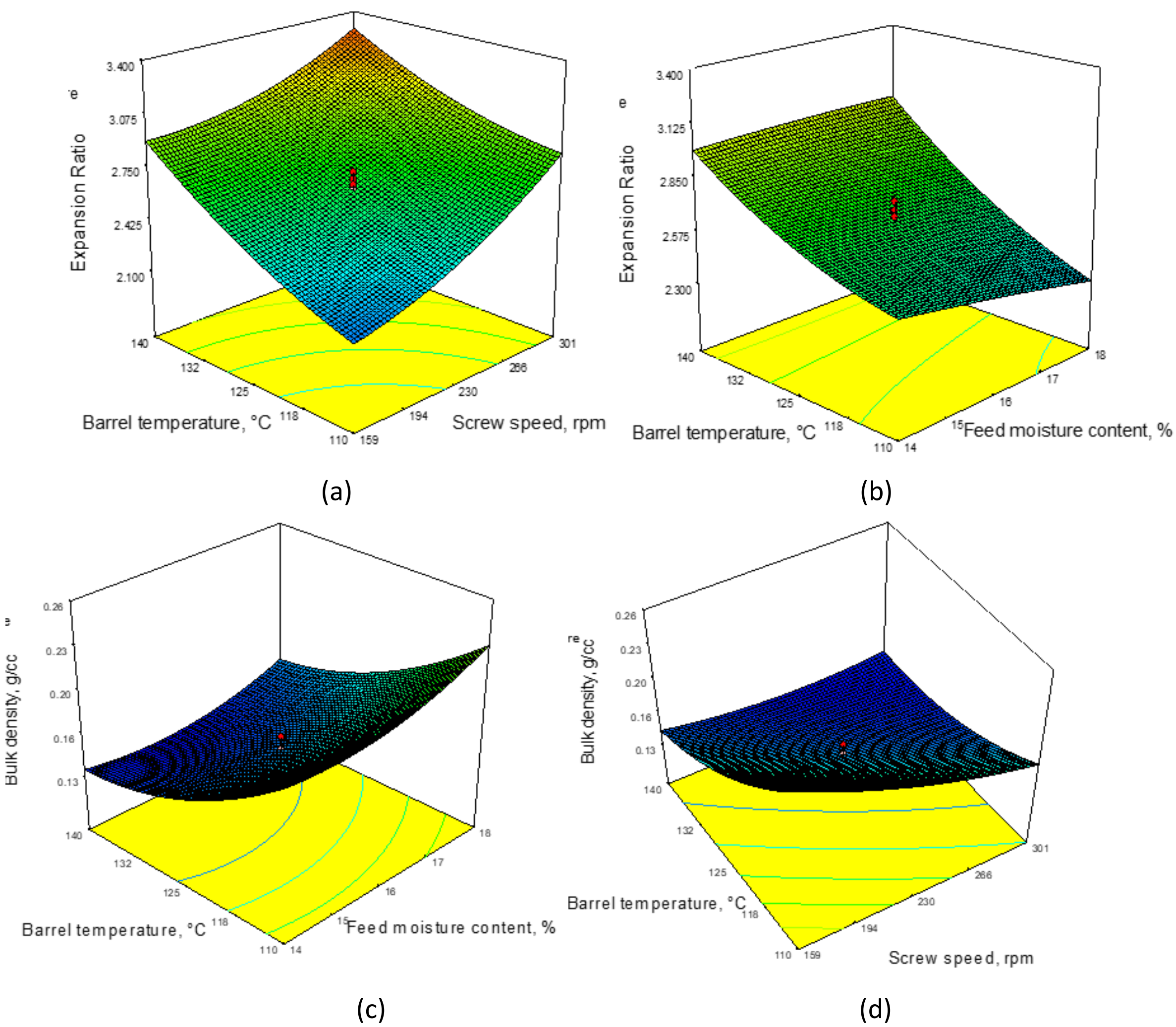
Table 3 Regression coefficients for process variables on product responses

Process variables	Expansion ratio	Bulk density	WAI	WSI	OAA
Model (Intercept)	2.64***	0.15***	6.15 ***	18.23**	7.08
X_1- Temperature	0.29***	-0.0.35***	-0.22**	0.38	-0.025
X_2- Screw speed	0.26***	-0.022***	0.06	2.05***	0.25*
X_3- Feed moisture	-0.051*	0.011**	0.28***	-0.95*	-0.16
$X_1 X_2$	-0.068*	0.018***	0.013	0.18	-0.17
$X_1 X_3$	0.057*	-0.0025	-0.15*	0.27	0.05
$X_2 X_3$	0.062*	0.0025	0.007	-0.23	-0.22
X_1^2	-0.075**	0.015***	0.21**	0.42	0.13
X_2^2	0.097***	0.0083**	0.069	-0.87*	0.024
X_3^2	-0.0083	0.012***	0.16**	-0.85	-0.029
Model F-value	54.99	40.20	9.88	5.03	2.44
Lack of Fit F-value	1.01	2.22	0.64	3.90	1.00
R^2	0.98	0.97	0.90	0.82	0.69
Adjusted R^2	0.96	0.95	0.81	0.66	0.41
Predicted R^2	0.91	0.83	0.61	-	-
APR	27.11	20.20	9.05	7.85	6.16
CV (%)	2.53	5.42	2.81	8.44	4.37

3.3 Water absorption index-

The water absorption index (WAI) of products calculated for all the experiments are presented in Table 2 and value was varied in the range of 5.76-7.25 g g^{-1}. ANOVA Table 3 describes that among the linear terms, X_1 and X_3 affected significantly ($p < 0.01$). The interaction term X_1X_3 and quadratic terms, X_1^2 and X_3^2 also significantly affected the WAI. The developed model was found to be significant at 0.1% level of significance. A high value of coefficient of determination ($R^2 = 0.90$) further indicates its close adequacy. A high adequate precision ratio (9.05) and low CV (2.81) are well within the acceptable level for the limit of variables. Regression equation indicating the connection between process variables and WAI is given below (Eq. 9).

$$WAI = 6.15 - 0.22X_1 + 0.060X_2 + 0.28X_3 - 0.15X_1X_3 + 0.21X_1^2 + 0.16 X_3^2, \quad R^2 = 0.90 \qquad (9)$$



F 1. Effect of barrel temperature, screw speed and feed moisture on ER and BD of extruded products

Highest positive coefficient (0.28) of X_3 had highest positive influence on WAI followed by X_2 (Fig. 2a). This was because of decrease in melt viscosity of starch at higher moisture content, which allows free movement of molecules in the melt coupled with uniform heat causing increased gelatinization of starch. Similar type of result has also been found [19]. The negative coefficient of X_1 had affected negatively on WAI. The response surface graph (Fig. 2b) indicated that WAI reduced with the raise in barrel temperature. This may probably the degradation or decomposition of starch [12]. Fig. 2b also showed that WAI enlarged with the boost in screw speed, which could be due to enhanced shearing leading to increased gelatinization. But this increase was non-significant. Similar types of outputs have also been accounted for rice-soy extruded snack [20] and for soybean and moringa leaf powder enriched extruded snacks [21].

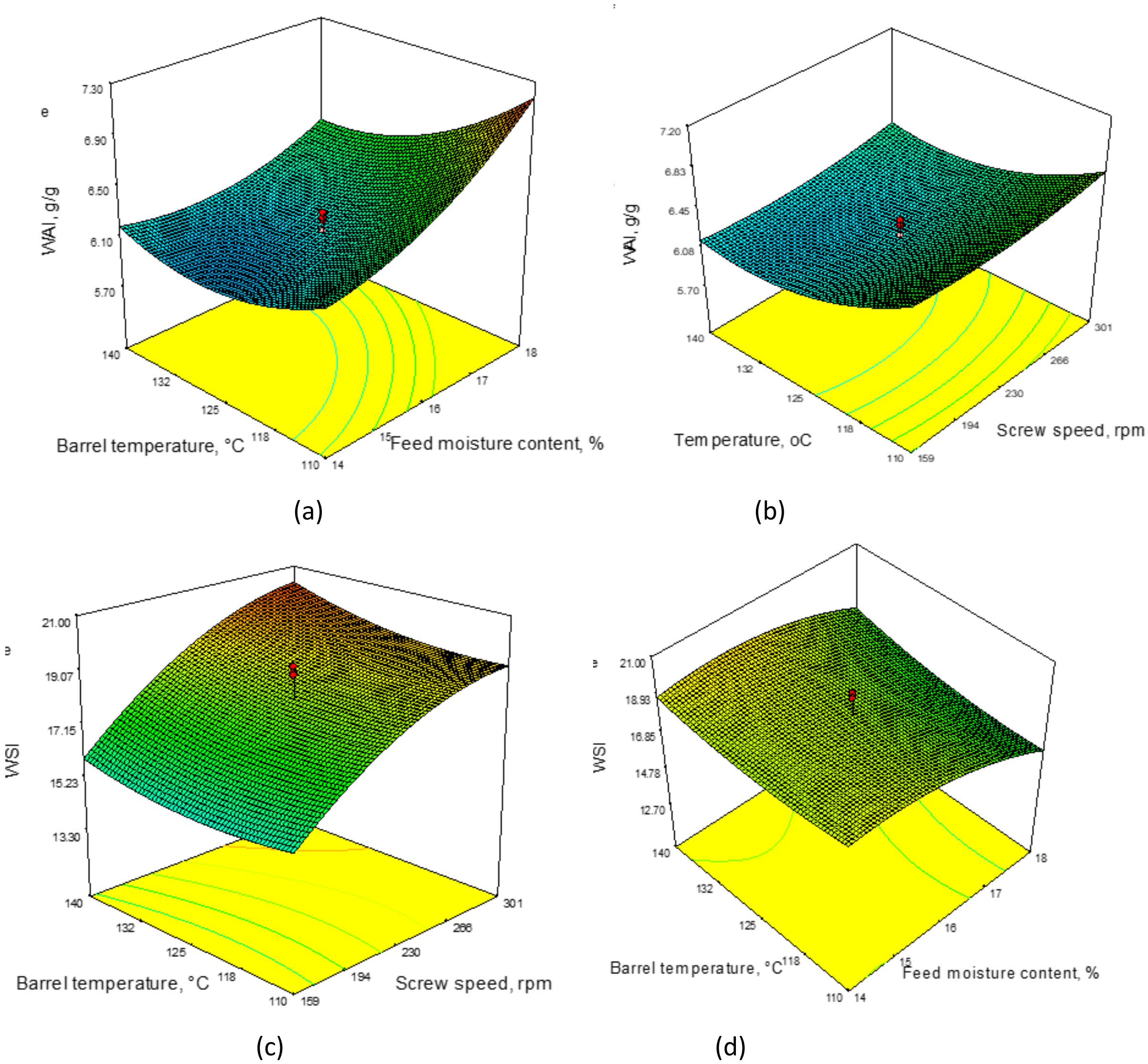


Figure 2. Effect of barrel temperature, screw speed and feed moisture on WAI and WSI of extruded products

3.4 Water solubility index-

Decomposition or degradation of starch molecules is concerned with the water solubility index (WSI) and measures the soluble polysaccharide solids dissolved in excess water from starch. WSI of extruded products varied from 12.76-20.97% (Table 2). It can be seen from ANOVA Table 3 that linear terms X2 and X3 affected significantly the WSI. All the interaction terms had non-significant on WSI whereas only the quadratic term X2 significant. The model with high F-value (5.03) was found to be significant at 1% level. The regression equation (Eq. 10) in terms of coded values of independent variables after ignoring the non-significant expressions for WSI is given below.

$$WSI = 18.23 + 0.38X1 + 2.05X2 - 0.95X3 - 0.85\ X3^2 \qquad R^2 = 0.82 \qquad (10)$$

The positive contribution of X_2 with high coefficient (2.05) is the major influencing factor on WSI followed by X_1 whereas X_3 had adverse effect on it. The WSI value enlarged with the increase in screw speed (X_2) and barrel temperature (X_1) whereas declined with the enhance in feed moisture. Fig. 2c depicted that WSI enlarged with the raise in screw speed. At high screw speed the moisture present in the melt remains in the form of vapour, which induces higher expansion and rough surface of product. Macromolecule of starch degrades during extrusion cooking at higher temperature which induces increased WSI. The interaction of X_1 and X_2 (Fig 2c) clearly proved that there is no appreciable change in the WSI indicating their non-significance if clubbed together. Fig. 2d shows that WSI boosted initially with the raise in feed moisture, which might be because of appropriate gelatinization and tangential expansion of starch. A further raise in moisture content of the feed decreases the WSI which may be recognized in reduced tangential expansion owing to melt plasticization [22-23].

3.5 Sensory quality-

The average sensory scores assigned by the judges for overall acceptability is presented in Table 2. Overall acceptability score for all the experiments was found to be ranged from 6.40-8.20. The maximum overall acceptability score (8.20) was assigned to the sample prepared with the combination of barrel temperature 110°C, screw speed 301 rpm and feed moisture 14% (wb) indicating best sample of product among them. The regression coefficients and goodness of fit terms are shown in Table 3. Upon examination of ANOVA, it was found that except screw speed (X_2) no other variable and interaction terms had significant on overall acceptability of products.

Second order regression equation (Eq. 11) for overall acceptability (OAA) is given below.

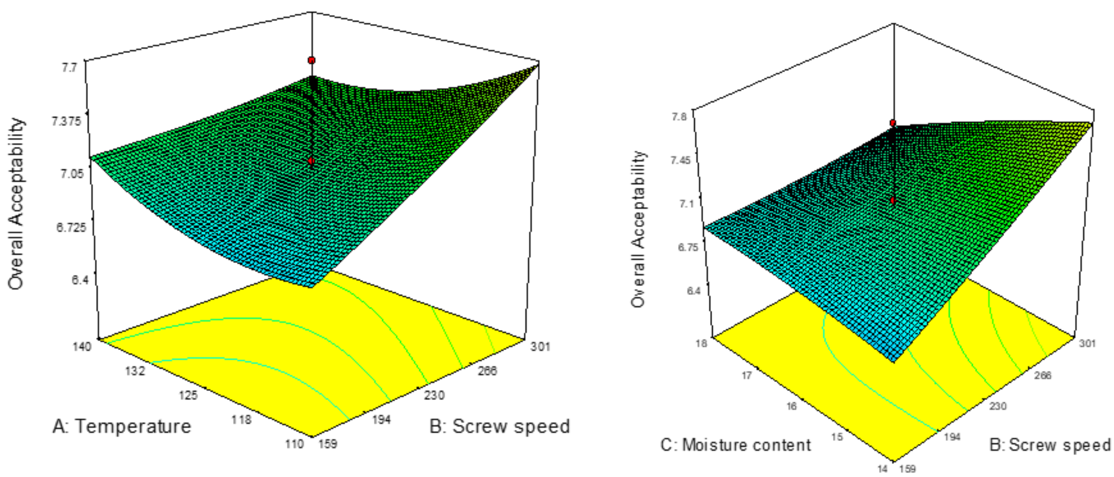
$$OAA = 7.08 - 0.0.025X_1 + 0.25\ X_2 - 0.16\ X_3 - 0.17\ X_1X_2 + 0.050\ X_1X_3 - 0.22\ X_2X_3 + 0.13\ X_1^2 + 0.024\ X_2^2 - 0.029\ X_3^2 \qquad R^2 = 0.69 \qquad (11)$$

The equation (Eq. 11) suggests that positive coefficient (0.25) of screw speed (X_2) had positive influence on overall acceptability, which means that overall acceptability score increased with the enhance in screw speed. On the other hand, the negative coefficient of X_1 and X_3 had decreasing effect on overall acceptability but non-significant.

It was perceived from Fig. 3a and b that overall acceptability score enhanced with the raise in screw speed. This is probably to development of high specific mechanical energy in the barrel during extrusion influencing extrudate attributes. The overall acceptability increased slowly with the raise in barrel temperature but this increase was non-significant. The OAA score of extruded product decreased slowly with the boost in feed moisture content (Fig. 3b). Similar type of observations have also been found in the case of extruded food development from barnyard millet and legume flour [24] and blend of rice, carrot pomace and pulse powder [25].

IV. CONCLUSION

Process parameters were found to be prominent effect on physical, functional and sensory characteristics of extruded products. Speed of screw in the extruder had significant effect on overall acceptability of the extruded products. The feed moisture had affected positively on bulk density and WAI whereas negatively influenced on ER and WSI of the product. The extruder barrel temperature and speed of screw had constructive influence on ER, WSI but negatively affected on bulk density and WAI. The highest overall acceptability score (8.20) was assigned to the product developed in the combination of barrel temperature 110°C, screw speed 301 rpm and feed moisture content 14% (wb). This study was performed to standardize the process parameters for the preparation of extruded product from composite blend of maize, finger millet, defatted soy and elephant foot yam.



(a) (b)

Figure 3. Effect of (a) barrel temperature and screw speed (b) screw speed and feed moisture on overall acceptability of extruded products

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