Chemical Science Review and Letters ISSN 2278-6783

Research Article

Response Surface Optimization of Extrusion Process for Preparation of Instant Maize Porridge

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Abstract

This study was undertaken to study the extrusion behavior of maize (*Zea mays*) for instant porridge. Three independent variables [moisture (12-16 %), screw speed (300-500 rpm) and temperature (120-180^{o}C)] were selected and their effect was studied over five dependent variables [specific mechanical energy (SME), bulk density (BD), water absorption index (WAI), water solubility index (WSI) and colour (L*, a*, b*)]. A surge in moisture increased ($p<0.1$) BD, WAI, L* and b* while declining WSI and a*. Screw speed had linear effect on SME and WSI and inverse on BD and WAI. Temperature had significant inverse effect on SME and linear on WAI. The optimized conditions for preparation of instant maize porridge were 14.5% moisture, 345 rpm screw speed and 171^{o}C temperature. Storage studies were conducted for 4 months and the parameters analyzed were moisture, water activity, free fatty acids and overall acceptability.

Keywords: Maize, Extrusion, Response Surface Methodology, Storage

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Introduction

Cereals prove to be an indispensable source of nutrition in every nook and corner of the world. In fact, cereal grains laid the foundation for the commencement of agriculture in the early days. They usually contain around 60 to 70 per cent of starch and are packed with abounding energy. Amongst the cereal crops, rice and wheat are of principal importance and maize stands third in the row. On an international front, maize is considered as the queen of cereals due to its diversified nature and utmost genetic yield potential, when compared with the rest cereals. The production of maize is highest amid cereal grains grown all over and has a wild cultivation throughout the world. It is nurtured on nearly 150 m ha in roughly 160 countries having extensive diversity of climate, soil, biodiversity and management practices that donates 36 % (782 m t) in the global grain production [1]. It accounts for 9 per cent of total food grain production in India. Global maize production was more than 977 million metric tonnes, while in India it was 21.81 million metric tonnes in 2015-16 [2]. Maize is of cardinal importance in many countries and is also used for animal feed production and many industrial applications. Practically, each part of the plant is put to use. Shelled cobs are dried and used as a fuel. The grains are fed to dairy cattle for higher milk production and the leaves and stems, obtained after maize thinning are used as animal fodder. In comparison to other cereals, corn grain gives greater conversion of dry substance to eggs, milk and meat. Maize has also proven its usage in several processed foodstuffs and can be incorporated in various ways.

Moreover, Indian food habits and tastes have amalgamated in the global melting pot and recently instant foods have gained popularity in the Indian markets. Several factors have contributed to this change which includes rapid urbanization accompanied by increased income levels, higher disposable income, growing retail market and marketing campaigns, hectic lifestyles and increased working women population. Instant foods provide us with the benefits of saving time and providing convenience to the consumers and blend in well with our current lifestyles. They generally consist of a mixture of processed cereals, pulses, vegetables, spices or condiments in varying combination. Instant maize porridge is one of the many instant foods available in the market.

Furthermore, porridge is a processed food of cardinal importance and is prepared chiefly from grains. In several contemporary cultures, it is consumed as morning meal and prepared by boiling oats, wheat, maize or sometimes another cereal in water, milk or both [3]. Instant maize porridges are generally packaged as dried cereal flakes and are easily reconstitutable upon the addition of milk or water. They thus yield a cereal porridge which has a cooked texture and has become increasingly popular among the consumers. Instant porridges are favoured by consumers because the amount of preparation and clean up require less time to prepare as compared to conventional hot grain porridges, which are contemplated to be onerous.

Food extrusion is a unique process in which the fed raw material is forced to move, under the influence of several conditions of mixing, heating and/or shearing, through a tiny opening called die, which is crafted to form or puff dry the ingredients [4]. The machine which performs the above mentioned process is called an extruder, and the mix of ingredients which comes out of the die is known as the extrudate. Extrusion is an extremely versatile assembly that can be applied to several food processes. Extruders can be used to mix, cook, form, texturize and shape food products under circumstances that promote quality retention, low cost and high productivity.

Traditionally, the porridge is prepared by grinding the roasted cereal. The traditional instant porridge is not of consistent quality and there is no possibility of adding other ingredients such as salt or sugar. By the use of extrusion technology, there was a possibility of preparation of highly convenient instant porridge with added sugar, salt, flavour and colour. So, present investigation was undertaken to develop an instant maize porridge with the key objectives of optimization of the process for development of instant maize porridge, to study the effect of extrusion conditions on the properties of instant maize porridge and to assess the storage quality of developed maize porridge.

Material and methods

Raw material and proximate analysis

Variety PMH-1of maize was procured from the Department of Plant Breeding and Genetics, Punjab Agricultural University, Ludhiana, Punjab, India; and used as a raw material for the present investigation. The maize kernels were ground into flour in Lab scale super mill 3303 (Perten instrument AB, Sweden) to fineness that passed through 200 µm sieves. Standard methods devised by AOAC were used to determine the physico-chemical characteristics of maize flour, namely moisture, protein, fat, fibre, ash and carbohydrates [5]. The oven drying method (130^{o}C for 2 hr) was employed for determination of moisture content and micro-Kjeldahl method was used for crude protein estimation (total nitrogen multiplied by a factor of 6.25). Soxhlet extraction method was used for fat assessment, using the instrument SoxtecTM 2045-Foss, Hoganas, Sweden. Weende method using FC 221 FiberCapTM, Foss Instruments, Hilleroed, Denmark, was employed for crude fibre estimation, whereas, measurement of ash was done gravimetrically post ashing at 550^{o}C. The differential amount was used for carbohydrate calculation. The proximate analysis of maize flour was 9.04 per cent crude protein, 4.68 per cent fat, 1.33 per cent ash, 2.08 per cent crude fibre and 68.87 per cent carbohydrates at 14 per cent moisture content. Prior to extrusion, sugar was mixed in the flour at 15 per cent concentration.

Design of experiment and data analysis

For designing of the experiment, statistical package Design-Expert Version 10 (Statease Inc., Minneapolis, MN, USA) was used. Three independent variables were considered under this study, including moisture (A), screw speed (B) and barrel temperature (C) and central composite design was performed for them. The dependent variables under this study were bulk density (BD), specific mechanical energy (SME), water absorption index (WAI), water solubility index (WSI) and colour. The experimental data was analysed statistically and contour plots were generated by utilisation of response surface methodology. A multiple linear regression method was used for result analysis which gave a description of the effects of variables in the derived models. The selected models were fitted with the experimental data and regression coefficients were attained. For each of the response functions, tables for the analysis of variance (ANOVA) were generated. This helped in the determination of the effect of individual variables as well as the combination and interaction effects in terms of coded levels.

Extrusion cooking

Extrusion experiments were performed in a co-rotating intermeshing twin screw extruder (Clextral, Firminy, France) presented in **Figure 1**. The diameter of the barrel was 2.5 mm and its length to diameter ratio (L/D) was 16:1. The barrel of the extruder was divided into four zones. Throughout the experiments, the barrel temperatures in the first three zones was maintained at 40°, 70° and 100°C, respectively, whereas the temperature of the barrel in the fourth zone was changed as per the needs of the experimental model. The die plate had four circular holes, each with a diameter of 1.5 mm. An 8.5 kW motor was used to power the extruder while its speed varied between 0 to 682 rpm. The extruder was equipped with a torque indicator, which showed per cent torque in proportion to the current drawn by the drive motor. For metering the raw materials into the extruder, a single screw volumetric feeder (D S and M, Modena, Italy) was used. In accordance with the screw speed, the feed rate of the extruder was changed for optimum fill. Water was injected in the extruder at approximately 30°C with the help of a pump to adjust the moisture level of the feed. For cutting of the extrudates, a variable speed die face cutter with four bladed knives was used.

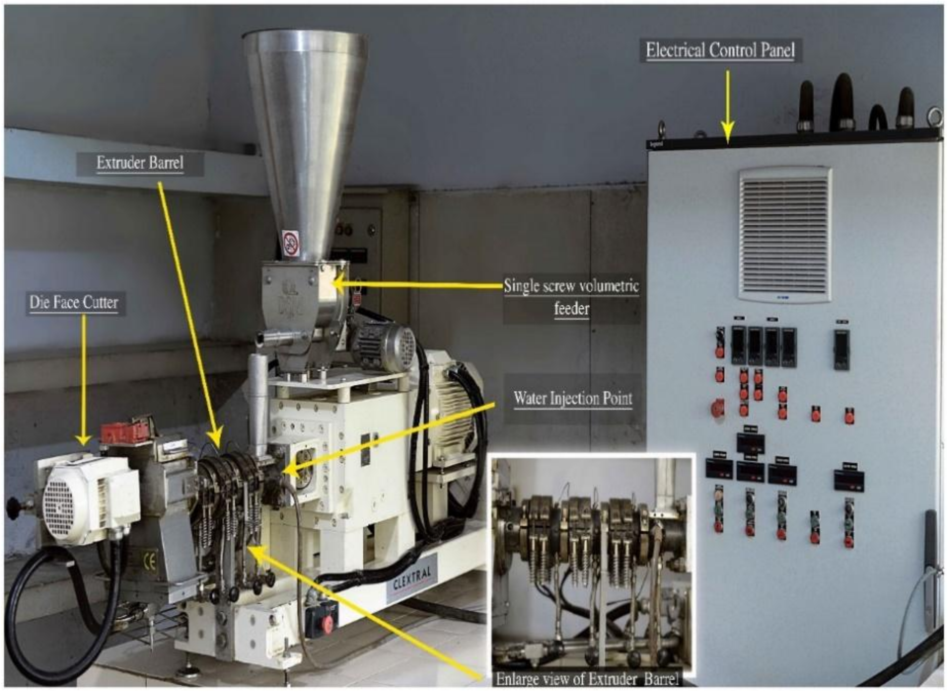

Figure 1 Clextral intermeshing co-rotating twin screw extruder model BC21

Determination of product responses

Specific mechanical energy (SME)

The calculation of specific mechanical energy (Wh/kg) was done using motor power rating (8.5 kW), rated screw speed (682 rpm), per cent motor torque, mass flow rate (kg/h) and actual screw speed using the following formula [6].

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

Bulk density (BD)

Rapeseed displacement method was used for the measurement of bulk density of extruded maize porridge by using a 100 ml graduated cylinder. 20 g of maize porridge sample was measured in a cylinder for its volume. Furthermore, bulk density was calculated as the ratio of weight of sample and the volume replaced in the cylinder [7].

Water absorption index (WAI)

The water absorption index of maize porridge was estimated according to the method framed by Anderson et al. [8]. The starch granule or polymer has a tendency to swell up in excess of water and WAI measures the volume occupied by the swollen starch granule. At room temperature, a suspension of the ground extrudates was made in distilled water by gently stirring for 30 minutes and then centrifuging at 3000 × g for 15 minutes. The empty weight of an evaporating dish was taken and the supernatant liquid obtained after centrifugation was carefully poured into it. The gel portion left behind in the centrifuge tube was weighed and calculation of WAI was done as the grams of gel obtained per gram of dry solids.

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

Water solubility index (WSI)

The amount of free polysaccharide or polysaccharide released from the granule on addition of excess water gives an account of water solubility index. The supernatant obtained from the previous experiment on WAI was dried in a pre-weighed evaporating dish and allowed to dry in an oven. Subsequently, the calculation of WSI was done as the weight of dried solids expressed in terms of a percentage of the original sample weight [8].

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

Colour

A colour meter, CR-300 (Minolta Camera, Japan), was used for the measurement of colour of maize porridge samples. On a levelled platform, three random samples were taken and the readings obtained for several maize porridge samples. Expression of results was done in the CIE L*a*b* space as L* (lightness; 0=black, 100=white), a* (+a*=redness, -a*=greenness) and b* (+b*= yellowness, -b*=blueness) values [9].

Sensory Evaluation

Extruded maize porridge samples were evaluated for sensory attributes (appearance/ colour, consistency, flavour and overall acceptability) through a panel of semi-trained judges using 9-point hedonic scale [10].

Optimization

For optimization Design-Expert Version 10 (Statease Inc., Minneapolis, MN USA) was used. The software allows to set criteria for all dependent variables. By using the optimization parameter, the numerical values could be set for dependent variables as goal. Optimum conditions are defined by the values of the processing variables that yield the desired ideal value and they were determined by keeping SME and WSI in range, minimum BD and maximum WAI, L*, a* and b*. By means of numerical optimization, several solutions were obtained. The range for product responses namely BD, WAI, WSI and colour (L*, a* and b*) acquired through numerical optimization was further used for graphical optimization. The mean values obtained from graphs gave the optimized conditions for the product.

Storage studies

Extruded snacks were packed in LDPE bags. Samples were stored at room temperature conditions for shelf life estimation over a period of 4 months and the product was evaluated for moisture content, free fatty acids, water activity and overall acceptability, at an interval of one month, during the storage period.

Free fatty acids

Procedure for the determination of free fatty acids as mentioned in the standard AOAC guidelines [5] was followed with slight modification. A sample weighing 5 g was put in a flask. Subsequently, for the extraction of free fatty acids, 50 ml of benzene was added and allowed to rest for 30 minutes. The solution was filtered through a filter paper and 5 ml of the extract obtained was put in a flask. Then, 10 ml alcohol and 2 drops of phenolphthalein solution was added to the extract and its titration was done against 0.02N KOH till light pink colour persisted for at least 15 seconds.

$$\text{FFA (per cent)} = \frac{282 \times 0.02\text{N KOH} \times \text{ml. of alkali used} \times \text{dilution factor}}{1000 \times \text{Weight of sample taken}} \text{ x } 100$$

Water activity

Water activity meter was used for the estimation of water activity of the maize porridge samples. A small amount of sample was placed in the meter and the reading was noted. (Pawkit Company).

Moisture Content

2 grams of maize sample were weighed followed by drying in a hot air oven for 1 hour. The temperature used for drying was 130 ±1°C. The loss in weight of the sample was calculated which helped in estimation of per cent moisture content [11].

$$\text{Moisture content (\%)} = \frac{\text{Weight of initial sample} - \text{Weight of dried sample}}{\text{Weight of initial sample}} \times 100$$

Results and Discussion

Proximate analysis of raw materials

The compositional analysis of maize flour (var. PMH-1) showed that it constituted of 9.04 per cent crude protein, 4.68 per cent fat, 1.33 per cent ash, 2.08 per cent crude fibre and 68.87 per cent carbohydrates at 14 per cent moisture content.

Effect of extrusion conditions on dependent variables

Data depicting responses of the product due to the effect of extrusion conditions is presented in **Table 1**. It was observed that, the characteristics of extruded maize porridge were influenced to a great degree by the physico-chemical changes occurring during the extrusion process. These changes were an outcome of the interaction between various extrusion parameters.

Table 1 Design of experiment and product responses obtained for instant maize porridge

Extrusion conditions (actual and coded values)[a]				**Product responses**						
No.	**Moisture (%)**	**Screw speed (rpm)**	**Temperature (°C)**	**SME (Wh/Kg)**	**BD (g/l)**	**WAI (g/g)**	**WSI (%)**	**Colour (L)**	**Colour (a)**	**Colour (b)**
1	12 (-1)	300 (-1)	120 (-1)	171.37	134.37	3.72	36.5	54.95	4.37	15.12
2	12 (-1)	300 (-1)	180 (1)	139.43	147.71	3.96	40.15	65.15	4.61	18.96
3	12 (-1)	500 (1)	120 (-1)	169.81	115.32	3.29	49.78	61.44	5.26	18.25
4	12 (-1)	500 (1)	180 (1)	146.44	127.14	3.48	43.02	60.31	5.56	16.67
5	16 (1)	300 (-1)	120 (-1)	160.47	227.42	4.05	26.78	65.91	1.85	22.74
6	16 (1)	300 (-1)	180 (1)	143.33	192.75	4.11	33.06	68.51	3.44	22.73
7	16 (1)	500 (1)	120 (-1)	162.02	204.82	3.57	31.76	71.56	1.32	25.74
8	16 (1)	500 (1)	180 (1)	144.61	204.25	4.06	38.92	70.94	4.35	25.81
9	10.6 (-1.682)	400 (0)	150 (0)	154.76	127.32	3.27	43.54	62.46	5.75	19.25
10	17.4 (+1.682	400 (0)	150 (0)	151.65	238.77	4.09	29.78	75.27	1.25	26.32
11	14 (0)	232 (-1.682)	150 (0)	167.57	182.46	4.08	30.36	70.23	5.14	24.45
12	14 (0)	568 (+1.682)	150 (0)	176.85	137.13	3.47	42.85	68.84	4.13	20.82
13	14 (0)	400 (0)	100 (-1.682)	171.37	167.46	3.85	27.26	69.16	4.77	22.68
14	14 (0)	400 (0)	200 (+1.682)	131.64	145.82	4.07	35.86	56.87	4.36	18.82
15	14 (0)	400 (0)	150 (0)	159.94	152.64	3.82	37.42	68.96	4.55	22.41
16	14 (0)	400 (0)	150 (0)	160.25	153.21	3.785	36.88	68.81	4.42	22.32
17	14 (0)	400 (0)	150 (0)	159.85	151.25	3.776	37.82	68.59	4.36	22.42
18	14 (0)	400 (0)	150 (0)	160.42	149.45	3.81	37.86	67.74	4.64	21.92
19	14 (0)	400 (0)	150 (0)	159.81	152.72	3.85	37.47	68.93	4.56	22.32
20	14 (0)	400 (0)	150 (0)	160.56	154.54	3.815	36.92	67.47	4.33	21.32

[a] Coded values are in parentheses.

SME, specific mechanical energy; BD, bulk density; WAI, water absorption index; WSI, water solubility index.

Specific Mechanical Energy (SME)

Screw speed and temperature were statistically the most significant parameters with respect to the SME of instant maize porridge (Table 3). Linear, interaction and quadratic regression models were quite significant and contributed substantially to the coefficient of determination (R^2). A regression analysis was conducted for befitting the experimental data with the mathematical design. The anticipated design of specific mechanical energy (SME) could be explained in terms of coded values, by the following equation i.e. x_1= feed moisture, x_2= screw speed and x_3= barrel temperature;

$$SME = +160.27 - 1.60\,x_1 + 1.75\,x_2 - 11.47\,x_3 - 0.33\,x_1x_2 + 2.60\,x_1x_3 + 1.04\,x_2x_3 - 3.34\,x_1^2 + 3.38\,x_2^2 - 3.94\,x_3^2 \qquad (1)$$

The significance of coefficient of fitted quadratic design was appraised by adopting F- test and P- value. For SME, the comparative distribution of the experimental points, from the estimations of the design, i.e. the coefficient of variation (CV), was found to be 1.82 per cent (Table 2). The analysis of variance table (ANOVA) of expansion ratio of the design (Eq. 1) is shown in Table 2. A reasonably good coefficient of determination (R^2) and adjusted R^2

value of 0.9684 and 0.9400 respectively were obtained indicating that the developed model seemed to be appropriate for SME.

Lowest SME of 131.64 Wh/Kg was observed at extrusion conditions of 14 per cent moisture content, 400 rpm screw speed and 200°C barrel temperature. On the other hand, highest value in SME (176.85 Wh/Kg) was recorded at 14 per cent moisture content, 568 rpm screw speed and 150°C barrel temperature (Table 1). It was observed that screw speed had linear effect whereas temperature had highly significant inverse effect on SME (Table 3). The interaction effect of screw speed and temperature was significant and the quadratic response of moisture, temperature and screw speed were highly significant (**Figure 2A**).

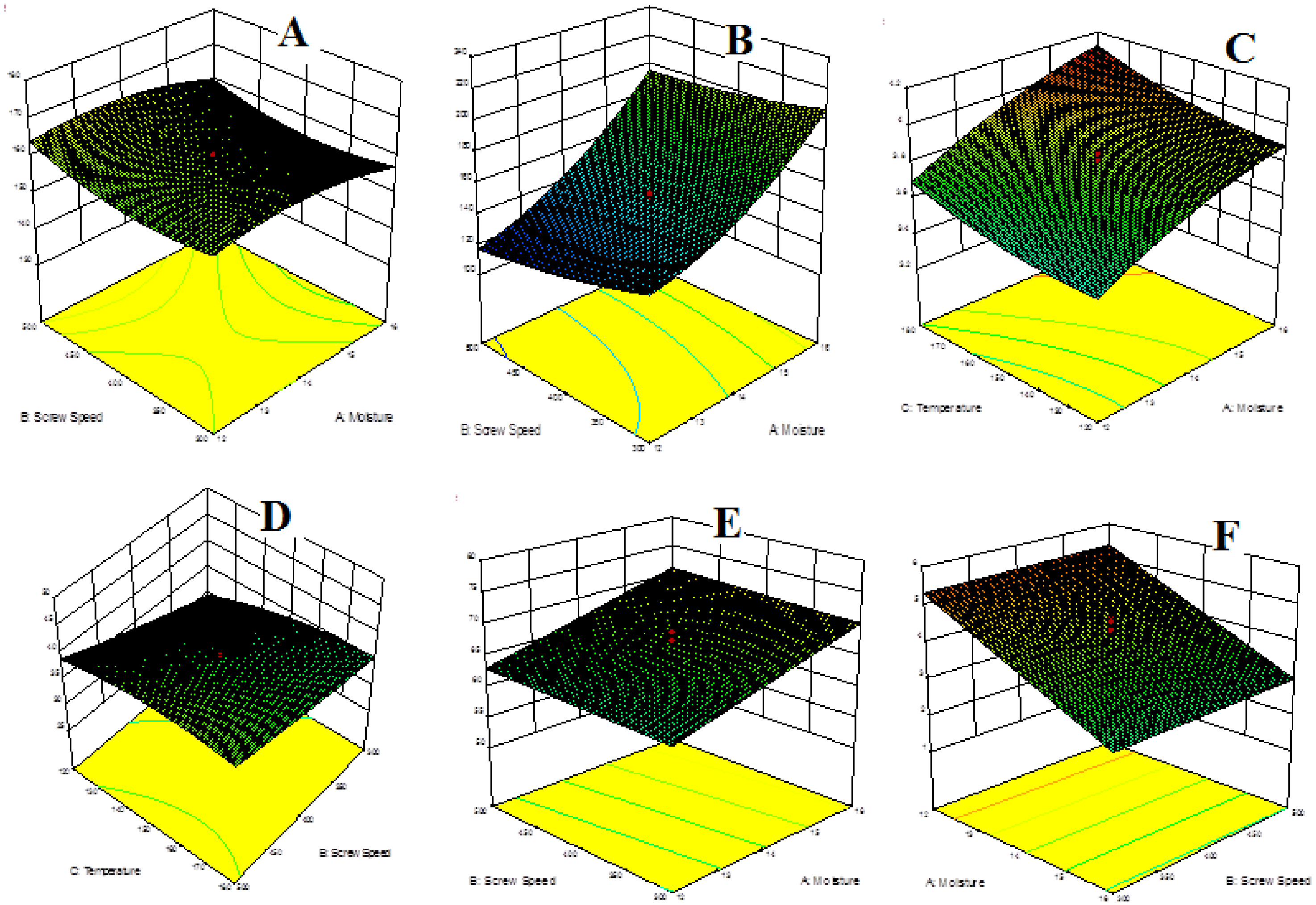

Figure 2 Effect of extrusion processing conditions on (A) specific mechanical energy; (B) bulk density; (C) water absorption index; (D) water solubility index; (E) colour (A); (F) colour (b)

The decrease in SME with elevating moisture content can be elucidated by lubricating effect provided by moisture and eventually reduction in friction. Screw speed was perceived to have a significant positive linear effect on SME. This could be attributed to the fact that with an increase in screw speed, shear rate of the fed raw material increased, thus resulting in its disintegration. It resulted in more energy going into the system with an upsurge in screw speed. This, coupled with reduction in residence time, induced starch gelatinization and probably led to an increase in viscosity and SME [12].

The inverse relationship of temperature with SME can be explained by the conversion of a solid flow to a viscoelastic one at higher extrusion temperatures; which resulted in use of lower energy in the system due to viscosity reduction [13]. A number of authors have reported similar phenomenon in wheat based extrudates [14], quinoa extrudates [15] and wheat, mung-bean and rice blend [16].

Bulk Density (BD)

Moisture content and screw speed were found out to be statistically significant at 1 per cent level of confidence with respect to bulk density (Table 3). An upsurge in temperature, led to a decline in bulk density of the extrudates, but the relationship was statistically non-significant. However, the crossproduct relationship between temperature and moisture was negative and significant at 5 per cent level of significance. The quadratic effect of moisture was highly significant.

The anticipated design for bulk density (BD) can be described by of coded values, in terms of the following equation i.e. x_1= feed moisture, x_2= screw speed and x_3= barrel temperature;

$$\text{Bulk Density} = +151.77 + 35.93x_1 - 9.20x_2 - 3.44x_3 + 3.50x_1x_2 - 7.50x_1x_3 + 4.25x_2x_3 + 11.24x_1^2 + 3.11x_2^2 + 1.87x_3^2 \quad (2)$$

The measured bulk density in the extrusion cooking of maize flour (Table 1) ranged between 115.32 and 238.77 g/l. ANOVA interpreted a remarkably significant model ($P<0.0001$) with coefficient of determination (R^2) of 0.9759 and adjusted R^2 value of 0.9542 (**Table 2**).

Bulk density was reasonably higher at higher moisture contents (Table 3). This is attributed to the fact that extrusion cooking does not contribute to complete evaporation of moisture, and some if it gets retained in the product. This in turn, leads to less puffing of the extrudates. Additionally, the structure of amylopectin gets modified at higher moisture content. This leads to reduction in dough elasticity and hence, reduces the expansion and elevates bulk density. On the other hand, heat developed during extrusion may elevate the temperature beyond the boiling point. During the extrusion process, when the fed raw material passes out through the die, some part of the internal moisture, quickly evaporates as steam and consequently an expanded product is formed which has low bulk density. Furthermore, the bulk density of the extrudates, during extrusion, is influenced greatly by the gelatinization of starch. The extent of gelatinization gets decreased by low processing temperatures which results in low swelling and low volume of the extrudates.

Table 2 Analysis of variance for the fitting response surface model with experimental data

Factor	**Sum of Squares**						
	SME	**BD**	**WAI**	**WSI**	**L***	**a***	**b***
Model F-value	34.06*	44.94*	16.78*	13.50*	5.46*	12.26*	12.12*
CV (%)	1.82	4.48	3.70	5.96	5.81	18.29	8.36
R^2	0.9684	0.9759	0.7588	0.9240	0.5059	0.6968	0.6944
Adjusted R^2	0.9400	0.9542	0.7136	0.8555	0.4133	0.6400	0.6371
Predicted R^2	0.7564	0.8093	0.5570	0.3936	0.1221	0.4569	0.4481

*Significant at p<.01.
SME, specific mechanical energy; BD, bulk density; WAI, water absorption index; WSI, water solubility index.

Water Absorption Index (WAI)

The natural starch molecule does not imbibe water at room temperature, hence, WAI can be used as an indicator of starch gelatinization. It estimates the extent of water imbibed by starch molecule [8]. It is known that temperature during extrusion and moisture content affect starch gelatinization, and consequently the WAI [17].

The anticipated design for water absorption index (WAI) can be described in terms of coded values, by the following equation i.e. x_1= feed moisture, x_2= screw speed and x_3= barrel temperature;

$$\text{WAI} = +3.81 + 0.20\,x_1 - 0.18\,x_2 + 0.099\,x_3 + 0.048\,x_1x_2 + 0.015\,x_1x_3 + 0.048\,x_2x_3 - 0.049\,x_1^2 - 0.018\,x_2^2 + 0.048\,x_3^2 \quad (3)$$

The WAI of the extrudates ranged from 3.27 to 4.11 g/g (Table 1). The fitted regression model coefficient of determination (R^2) was 0.9510 and adjusted R^2 was 0.9068 (Table 2). It was observed that, all the three processing parameters, namely moisture content, screw speed and barrel temperature were statistically significant at 1 per cent level of significance (**Table 3**). Moisture content and barrel temperature had linear relationship, whereas, screw speed had inverse relationship with respect to WAI (Figure 2C). It is widely acknowledged that, water absorption is related to the dissipation of starch in excess of water. This diffusion is enhanced by the extent of starch damage because of gelatinization and fragmentation induced by extrusion, that is, reduction in molecular weight of amylopectin and amylose molecules [18]. Starch viscosity, at higher moisture level, is quite low, thus making way for extensive mixing internally and higher degree of starch gelatinization due to uniform heating [19] which in turn, results in greater water absorption. Similar results have been published for extrudates made from rice [20] and rice extrusion with pea grit [21].

Table 3 Regression coefficients for model fit parameters and response surface equation

Effect	**Product Responses**						
	SME (Wh/Kg)	**BD (g/l)**	**WAI (g/g)**	**WSI (%)**	**Colour (L)**	**Colour (a)**	**Colour (b)**
Intercept of model	160.275	151.772	3.810	37.307	66.605	4.151	21.553
Moisture (A)	-1.599	35.929**	0.199**	-4.545**	4.145**	-1.201**	2.922**
Screw Speed (B)	1.749*	-9.202**	-0.18**	3.514**	0.541	0.038	0.059
Temperature (C)	-11.472**	-3.441	0.099**	1.815*	-0.704	0.327	-0.305
Moisture X screw speed (AB)	-0.327	3.5	0.047	-0.663			
Moisture X temperature (AC)	2.595*	-7.5*	0.015	2.068*			
Screw speed X temperature (BC)	1.037	4.25	0.047	-1.191			
Moisture X moisture (A^2)	-3.341**	11.241**	-0.049*	0.310			
Screw speed X screw speed (B^2)	3.377**	3.109	-0.017	0.291			
Temperature X temperature (C^2)	-3.942**	1.872	0.048*	-1.492*			

**Significant at p<.01.
*Significant at p<.05.
SME, specific mechanical energy; BD, bulk density; WAI, water absorption index; WSI, water solubility index

It was also observed that, a maximum value was attained by WAI at extrusion temperatures of 180–200°C (Table 1). Generally, WAI shows a linear trend with temperature to a certain extent, after which it declines, perhaps due to increase in dextrinization [21]. Results similar to the above mentioned facts have been reported for bean and chickpea extrudates and those based on corn starch [22-24].

WAI had an inverse relationship with screw speed. Mezreb et al. [26] defined this relationship as with higher screw speed, a sharp increment in specific mechanical energy is induced which leads to mechanical disruption of the macromolecules and subsequently, starch's molecular weight declines which lowers the WAI as solubility of starch reduces. Bhattacharya [25] and Chiu et al. [26] also portrayed that a higher screw led to a raise in shear rate but reduced the residence time, therefore, followed by a lesser WAI value due to lesser degree of gelatinization in products.

Water solubility index (WSI)

The WSI of the extrudates ranged from 26.78 to 49.78 per cent (Table 1). Statistically, moisture content and screw speed were the most significantly contributing factors. The interaction effect of moisture and temperature and the quadratic effect of temperature were significant (Table 3). The anticipated design for water solubility index (WSI) can be described in terms of coded values, by the following equation;

$$WSI = +37.31 - 4.55\, x_1 + 3.51\, x_2 + 1.81\, x_3 - 0.66\, x_1 x_2 + 2.08\, x_1 x_3 - 1.18\, x_2 x_3 + 0.31\, x_1^2 + 0.29\, x_2^2 - 1.49\, x_3^2 \quad (4)$$

The analysis of variance table (ANOVA) for the expansion ratio of the given design (Eq. 4) was conducted R^2 value was found out to be 0.9240 while adjusted R^2 for WSI was 0.8555 (Table 2). Moisture had highly significant inverse effect on WSI. WSI declined with an increment in the moisture levels (Figure 2D). Similar results have been cited in literature for snacks based on rice [20] and extrudates made from maize [27]. During the extrusion process, when the moisture levels are low, there is higher shear degradation of starch molecules which in turn raises the WSI. Moreover, it is a widely known fact that the primary mechanism for degradation of starch at low moisture content is dextrinization [23]. At reduced levels of feed moisture, extrudates have greater compressive resistance and lead to changes in the starch solubility. The raise in extrudate solubility implies that the granule of starch has higher fragmentation ratio at lower moisture levels during extrusion process. Hence, tendency of WSI to decrease with moisture level is foreseen and in compliance with earlier publications [24, 28]. Screw speed had positive linear effect on WSI of instant maize porridge samples. With an increase in screw speed, the macromolecules break down to smaller ones due to the high mechanical shear. These resultant smaller molecules have a higher solubility and thus WSI is enhanced [29].

Colour

The colour is a valuable quality factor pertinent to consumer approval. The colour values of L*, a* and b* under various extrusion conditions were estimated. The anticipated design for colour (L*, a*, b*) can be described in terms of coded values, by the following equation i.e. x_1= feed moisture, x_2= screw speed and x_3= barrel temperature;

$$L = +66.61 + 4.15\, x_1 + 0.54\, x_2 - 0.70\, x_3 \qquad (5)$$
$$a = +4.15 - 1.20\, x_1 + 0.038\, x_2 + 0.33\, x_3 \qquad (6)$$
$$b = +21.55 + 2.92\, x_1 + 0.060\, x_2 - 0.31\, x_3 \qquad (7)$$

The measured values of the degree of lightness of extrudates (L*) lied in the range from 54.95 to 75.27 (Table 1). The parameter for colour a*, demonstrative of the redness of the extrudate, ranged between 1.25 and 5.75. The R^2 value, which is the coefficient of determination, for a* was 0.6968 and adjusted R^2 was 0.6400. The b* of the extrudates ranged from 15.12 to 26.32 while their R^2 value was 0.6944 and adjusted R^2 for b* was 0.6371 (Table 2).

Moisture had highly significant direct relationship with the L* value and b* value (Table 3). However, it had highly significant inverse relationship with a* value. The effect of screw speed on the three parameters was positive but non-significant. Temperature on the other hand, had negative non-significant effect on L* and b* value. With an increase in temperature, the lightness parameter (L*) of the maize porridge sample showed a declining trend; however, a direct relationship was seen with feed moisture content. In case of a* value, that is the redness of the sample, it had a linear relationship with temperature but an inverse one with moisture content. Some researchers have illustrated that certain changes occur in the b* value, that is, the yellowness of the sample during the extrusion cooking process (Figure 2E-F). They may be attributed to various biochemical reactions occurring during extrusion. The main ones are non-enzymatic browning and pigment destruction. Certain naturally occurring carotenoids are destroyed by the thermal treatment and a part of the colour loss is made up by the browning that occurs [30, 25, 12]. Another research found the effect of extrusion temperatures on L* value to be insignificant [31]. However, the feed moisture content had a positive linear relationship with the L* value. In yet another study, the interaction relationship between temperature and feed moisture levels was significant [32].

Optimization

For determination of workable optimum conditions for the development of instant maize porridge, multi-response optimization technique was utilized using design expert software (Statease, DE 10.0). The process parameters were optimized for minimum bulk density and maximum WAI, L*, a* and b* whereas SME and WSI were kept in range. Numerical optimization of the product gave several solutions and their range was used for graphical optimization.

The range obtained for dependent variables (BD, WAI, WSI, L*, a* and b*) served as a base for graphical optimization. Furthermore, range for moisture, screw speed and temperature was obtained which gave way for optimization graphs. It was found that the optimized conditions consisted of 14.5 per cent moisture content, 345 rpm screw speed and 171°C temperature (**Figure 3**).

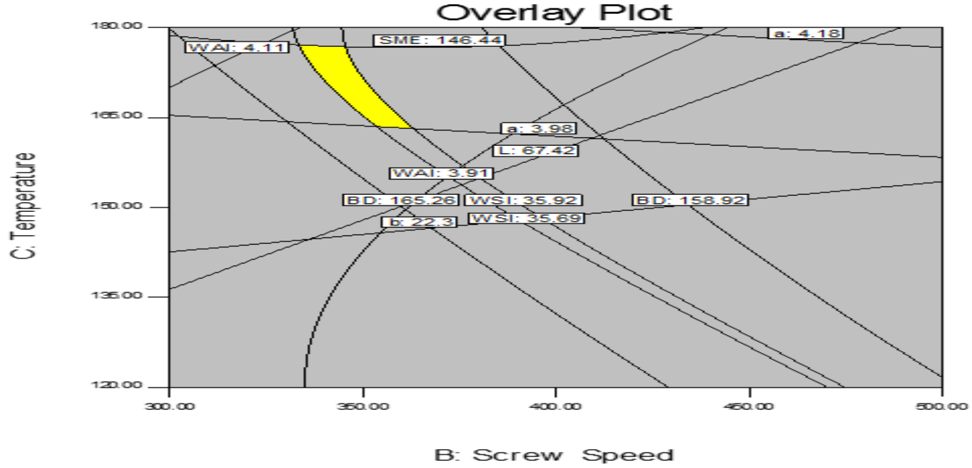

Figure 3 Overlay plot showing the optimum extrusion processing conditions for instant maize porridge at 14% moisture

Storage study of instant maize porridge

Storage study was conducted on maize porridge samples. The product obtained was stored in LDPE (low density polyethylene) pouches. The analysis was carried out at an interval of one month for four consecutive months and the observations were recorded. Overall change in the extruded maize porridge was non-significant and the sample remained organoleptically acceptable throughout the storage period. **Table 4** shows the effect of storage on the moisture content, water activity, free fatty acid content and overall sensory acceptability of instant maize porridge. It was observed that there was a minute change in the moisture content of maize porridge samples. The product remained dry and crunchy till the end of storage and portrayed non hygroscopic nature. The initial moisture content was 3.88 per cent and it raised up to 4.22 per cent at the end of storage concluding that the overall gain of moisture content was less than 1 per cent. The water activity of the porridge samples increased from 0.36 to 0.43. During the storage period, the free fatty acids of the samples increased from 0.247 to 0.461. Though the increase was significant, but the FFA content was still in the acceptable range and hence slightly affected the overall acceptability.

The sensory evaluation of the maize porridge samples was done by semi-trained panelists in accordance with 9-point hedonic scale. The sensory evaluation was done for appearance/colour, consistency, flavour (taste and odour) and overall acceptability over a period of four months. The results showed that the porridge was found to be overall acceptable throughout the storage period. The overall acceptability declined from 8.30 to 7.75 on a 9-point hedonic scale but remained well within the acceptable range.

Table 4 Effect of storage period on moisture content (%), free fatty acids (%), water activity and overall acceptability of instant maize porridge

Storage period (months)	Moisture (%)	Free Fatty Acids (%)	Water Activity	Overall Acceptability
0	3.88	0.247	0.36	8.30
1	4.00	0.270	0.39	8.10
2	4.08	0.356	0.40	8.00
3	4.18	0.394	0.42	7.90
4	4.22	0.461	0.43	7.75

Conclusion

The effects of various extrusion parameters such as barrel temperature, feed moisture content and screw speed on extrusion dependent variables such as bulk density (BD), specific mechanical energy (SME), water absorption index (WAI), water solubility index (WSI) and colour (L*, a*, b*) were assessed. Feed moisture content played a significant role in BD, WAI and L* and b* parameters of colour and inverse effect on WSI and a*. Screw speed had linear positive effect on SME and WSI and inverse on WAI and BD. Temperature, on the other hand, had significant linear relationship with WAI and WSI and inverse with SME. The storage study revealed that instant maize porridge remained of good acceptability with insignificant variations in quality during the 4 months of storage. Therefore, the concept of employing extrusion technology in the production of instant maize porridge is a pristine route towards nutrition and convenience. It will prove to be an ideal product for the existing market where time is always a constraint and nutrition is still placed high among the consumers.

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Publication History
Received 27th Nov 2017
Revised 15th Dec 2017
Accepted 18th Dec 2017
Online 30th Dec 2017