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Extrusion Conditions Effects Functional and Pasting Properties of Finger Millet

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Abstract

Extrusion is an effective tool for modifying functionality of coarse cereals for various food applications. Response surface methodology (RSM) was used to evaluate the effect of different extrusion variables on functional and pasting properties of finger millet. The experiment was conducted using a five level Central Composite Design (CCD).The expansion ratio (EX) of extrudates was found to significantly increase with decreasing feed moisture and increasing barrel temperature. Increasing feed moisture significantly ($p<0.05$) increased water absorption index (WAI) and decreased water solubility index (WSI). However, screw speed exerted no significant ($p>0.05$) effects on responses. WAI and WSI of extruded flour increased specifically by 2.0 to 14.0 fold over raw flour. WAI had a significant negative linear association ($r=-0.96$, $p<0.01$) with WSI and a positive linear correlation with peak and final viscosity. Results suggest that tailoring extrusion conditions offer opportunity for obtaining finger millet extrudates and pre-gelatinized flour with varied functionality.

Keywords

Finger millet; Extrusion; RSM; Functional properties; Pasting properties

Introduction

Rising levels of life style diseases such as type 2 diabetes and obesity, and increased health care costs have resulted in a paradigm shift in patterns of our diet and nutrition. There is increased awareness on alternative cereals and millets to reduce glycemic index and increase health promoting phenolic compounds in foods. Among millets, finger millet is one of the commonest millet consumed by rural population and by large in southern India. Finger millet (*Eleusine coracana*) popularly known as 'Ragi' is one of the nutritious millet high in dietary fiber (18%), mineral (2.5-3.5%) and calcium content (0.38%) than wheat [1]. It contains more balanced protein and has high lysine, threonine and valine than other millets. The seed coat of the millet is an edible component of the kernel and is a rich source of polyphenols (200.45-900.56 mg GAE/100 g) and flavonoids [2]. High phenolic content is known to have cholesterol lowering properties and helps regulates glucose homeostasis by inhibiting pancreatic amylase and intestinal α-glucosidase activity, thus useful in managing type-2 diabetes [3].

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Fortification of finger millet to corn, rice or wheat flour can be exploited for developing more nutritious composites blends rich in calcium and phytochemicals for health market and baby foods. However native or raw flours, have poor functional properties, water absorption, solubility and high pasting profile than processed flours [4] which seriously affects their rheological behavior in composite dough and batters. Hydrothermal treatments such as extrusion can effectively improve functional properties in composite cereal matrices by means of starch gelatinization, increase solubility, protein denaturation, and reduction of phytates [5]. Roman et al., [6] in their recent review critically highlight the potential use of extruded flours in gluten free elaborations and as fat replacer for low fat mayonnaises in frozen foods. Flours obtained by extrusion and the posterior milling of the extruded products can be used in batter recipes with similar effects to those achieved by hydrocolloids or modified starches, but with a cleaner label and lower costs [7]. Thus can be useful alternatives to synthetic hydrocolloids.

Nevertheless extrusion is a complicated process and process variables of feed moisture, composition, screw speed, barrel temp can significantly affect product characteristics. Ding et al., [8,9] and Chang and Ng [10] have reported significant effects of extrusion variables on rice and wheat and wheat-ginseng based extrudates. Feed moisture and temperature significantly affected the functional quality of extrudates. The gelatinized starch hydrates faster than unmodified raw starch thus displaying improved functionality [11,10].

Previous work with respect to optimization of extrusion variables has largely been focused on wheat, corn, rice since they have high starch content and good functional properties after extrusion. However, to best of our knowledge, there is no information on effect of extrusion variables on the physical (bulk density, expansion) and functional (WAI, WSI) properties of finger-millet. With this background in mind, the present study was undertaken to study the effect of moisture content, barrel temperature and screw speed on the functional and pasting properties of finger millet extrudates using response surface methodology to model the process parameters. The information generated can be useful for designing finger millet based extrudates as well as use of flours in composite bread, flat bread, fermented food, and infant foods as a useful functional ingredient.

Materials and Methods

Materials

Finger millet grains (var. unknown) were purchased from local commercial suppliers. Grains were grounded in hammer mill and sieved through a 35 mesh screen. The proximate composition of finger millet flour was: moisture-8.99% (wb); ash-3.51%; protein-6.88%; crude fat-1.57%; crude fibre-3.43% and carbohydrate-75.62%. Extrusion was performed using a co-rotating and intermeshing twin-screw extruder (BTPL, Kolkata, India) having length to diameter ratio (L/D) as 20:1 with 3 mm circular die. Raw material was metered in to the extruder with a twin-screw volumetric feeder. The feed rate was kept constant at 8 kg/h during the experiment. A variable speed die face cutter with two blades was used to cut the extrudates. Prior to extrusion flour was conditioned to different moisture content levels (14.95, 17, 20, 23 and 25.05% wb), to achieve moisture content as per

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CCD (Table 1) and subjected to different temperature (103.18, 110, 120, 130 and 136.82°C) and screw speed (357.96, 375, 400, 425 and 442.04 rpm). Extrudates obtained were cooled to room temperature and sealed in polyethylene bags until measurements were taken. After measurement (expansion ratio and bulk density), the final dried samples were grounded in a hammer mill to sieved through 35 mesh screen. Raw or un-extruded finger millet flour served as control. The extruded finger millet flour was analyzed for its proximate composition (moisture-5.4%; ash-3.78%; protein-7.2%; crude fat-1.55%; crude fibre-3.49% and carbohydrate-78.58%).

Experiment design

A central composite RSM design (3-factors, 5-levels) was used to optimize and study the effect of independent variables (feed moisture, temperature and screw speed) on the response (Table 1). The experimental design and statistical analysis were performed using Design Expert 9.0 (State-Ease Inc., Minneapolis, USA). The design comprised 17 runs, including three replicates of the center point used to determine the lack of fit of the model (Table 2). Three experiments of each condition were carried out and the mean values were stated as observed responses. Only, those input parameters found significant, were used for the further optimization process.

The model used for fitting response surface is in the form:

$$Y = B_0 + B_1X_1 + B_2X_2 + B_3X_3 + B_4X_1X_2 + B_5X_1X_3 + B_6X_2X_3 + B_7X_2^1 + B_8X_2^2 + B_9X_3^2$$

Where, Y is the response variable. X_1, X_2 and X_3represents the three independent factors under study [viz., X_1,Moisture content (wb, %), X_2Temperature (°C) and X_3Screw speed (rpm)]. B_i (i=0,1,2,…,9) are the parameters of the model to be estimated. The model was fitted using stepwise regression, to identify the significant parameter estimates and the model fitness was assessed using adjusted R^2. The graph of response surface curve was used to visualize the change in response, at different levels of the input variables. Correlation analysis was also done to know the linear association among the response variables and its significance was also noted, using SAS (9.4) software.

Analysis

Bulk density: The bulk density (ρ) of extrudates was calculated using the methods described by Ding et al., [5] as follows:

$$Density = \frac{4*M}{\Pi * D^2 * L}$$

Where, M is the mass in gram of extrudate with length L of cooled extrudate with diameter D. The samples were randomly selected and replicated 10 times and the average value taken.

Expansion ratio: Expansion ratio is the ratio of diameter of extrudate to the diameter of die; was used to express the expansion of extrudate [12,13]. Six samples were used for each extrudate to calculate the mean.

Water absorption index (WAI) and Water solubility index (WSI): The WAI and WSI were measured using a method developed by Anderson et al. [14] for cereals. The ground extrudate was suspended in water at room temperature for 30 min, gently stirred during this period, and then centrifuged at 3000 g for 10 min. The supernatant was decanted into an evaporating dish of known weight. The WSI is the weight of dry solids in the supernatant expressed as a percentage of the original weight of sample. The WAI is the weight of gel obtained after removal of the supernatant per unit weight of original dry solids. Determinations were made in triplicate.

Pasting properties: A Rapid Visco Analyzer (RVA) was used to determine the pasting properties of the finger millet extruded flours. Analysis was performed on the flours in triplicate according to the standard Newport Scientific method for whole meal flour (4 g flour,

Table 1: Independent Variables and Levels used for Central Composite Design (CCRD).

Variables	Coded variable Levels				
	-1.68	-1	0	1	1.68
Feed moisture (% wb), X_1	14.95	17	20	23	25.05
Temperature (°C), X_2	357.96	375	400	425	442.04
Screw Speed (rpm), X_3	103.18	110	120	130	136.82

Note: X_1 = Feed moisture (% wb), X_2 = Screw Speed (rpm), X_3 = Temperature (°C), wb: wet basis

Table 2: Response surface design for the extrusion.

Execution Order	Runs	Coded values			Actual values		
		X_1	X_2	X_3	**Feed moisture (% wb)**	**Barrel Temperature (°C)**	**Screw Speed (rpm)**
1	17	-1	-1	-1	17	110.00	375
2	14	0	0	-1.68	20	120.00	357.96
3	4	0	1.68	0	20	136.82	400
4	1	-1	1	-1	17	130.00	375
5	12	1	1	1	23	130.00	425
6	7	-1	1	1	17	130.00	425
7	11	0	0	0	20	120.00	400
8	8	1	-1	1	23	110.00	425
9	3	0	0	0	20	120.00	400
10	5	1	1	-1	23	130.00	375
11	13	1.68	0	0	25.05	120.00	400
12	2	-1	-1	1	17	110.00	425
13	15	1	-1	-1	23	110.00	375
14	6	0	0	0	20	120.00	400
15	16	0	0	1.68	20	120.00	442.04
16	10	-1.68	0	0	14.95	120.00	400
17	9	0	-1.68	0	20	103.18	400

Note: Coded values = X_1 = Feed moisture (% wb), X_2 = Temperature (°C), X_3 = Screw Speed (rpm), wb: wet basis

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14 g moisture basis) with slight modification: flour samples (2 g dry weight) was transferred to an RVA canister, and double distilled water was added to the flour to give a final weight of starch suspension of exactly 25 g. The starch suspension was held in the RVA at 50°C for 1 min, heated from 50 to 95°C at a rate of 12°C/min, held at 95°C for 2.5 min, cooled to 50°C at a rate of 12°C/min, and held at 50°C for 2 min [15]. The heating process was accompanied with a constant shear at 960 rpm for the first 10 s followed by a constant shear at 160 rpm until the end of the analysis. The peak viscosity, breakdown, setback, final viscosity, and pasting temperature of the flour were identified from the pasting curve using Thermocline Version 2.2 software (Newport Scientific, Warri wood, NSW and Australia).

Results and Discussion

Expansion ratio and bulk density

Expansion ratio (ER) is a manifestation of puffing and high values of ER is a desirable characteristic of snack extrudates. ER is inversely proportional to bulk density (BD) and is indicative of compact and nonporous structure of extruded snacks. The barrel temperature and feed moisture were found to have the greatest significant ($p<0.05$) effect on ER and BD; however screw speed (SS) exerted no significant ($p>0.05$) effects on both responses (Table 3). Increased feed moisture (17%-23%) led to a sharp increase in extrudate density and decrease in ER (Figures 1 and 2). Generally, BD of extruded products is a function of moisture content; excess of moisture has a lubricating effect, causes inadequate cooking, impedes gelatinization and decreases the radial and volumetric expansion, leading to a dense product and low ER. Also, high moisture content may hinder the sudden vapour pressure release due to lack of pressure barrier. Our results are in agreement with previous work on barley rice, wheat-ginseng extrudates [8,10,16,17]. In addition, increased feed moisture may also alter the structure of amylopectin, reducing melt elasticity, decreasing expansion and increasing BD.

Water absorption index and water solubility index

The extrusion conditions significantly affected the WAI and WSI of extrudates and results are presented in Figures 3 and 4 respectively. WAI indicates the amount of water absorbed or bonded by starch [18], whereas WSI is a parameter that indicates the severity of degradation undergone by processed starch and molecular components and determines the amount of leached molecular components out of the starch granule. Increasing moisture significantly ($p<0.05$) increased the WAI and decreased WSI. The quadratic effect of barrel temperature was also found significant on both responses (Table 3). Our results are consistent with previous work on extrusion of rice, corn and wheat [8,9,19]. Significant effects of increasing barrel temperature (110°C-130°C) were observed in WAI. Differences in results are mainly attributed to severity of extrusion conditions, of feed moisture, temperature and screw speed. High WAI and low WSI with increasing moisture is associated with gelatinization of starch with concomitant swelling, protein denaturation, and solution properties of dietary fiber such as hemicelluloses and pectin polysaccharides [20] and low degradation of starch. However, increasing WSI with temperature at constant feed moisture reveals extensive polymer damage, dextrinization thereby decreasing the ability of starch molecules to bind water. Our results are in agreement with previous work [10,19,21,22].

Effect of extrusion cooking on pasting properties

The pasting properties of extruded flour were lower compared to native flour, demonstrating that extrusion cooking at all variables studied partly/fully gelatinized the starch of the flours (Figure 5). The feed moisture had significant ($p<0.05$) influences on peak, final, setback trough viscosity and holding strength. High moisture conditions has a plasticization effect, thus acting as a lubricant, leading to residual un-gelatinized starch granules and resulting increased viscosity profiles. On the other hand, results for increased

Table 3: Coefficient of the model equation for the responses.

	Expansion Ratio	Bulk Density	WAI	WSI (%)	Peak Time	Peak Viscosity	Pasting Temp.	Holding Strength	Breakdown Viscosity	Final Viscosity	Setback Peak Viscosity	Setback Trough Viscosity
B_0	2.333*	268.882*	3.871*	40.798*	1.532^{ns}	404.191^{ns}	52.401^{ns}	172.875^{ns}	231.315^{ns}	240.001^{ns}	164.190^{ns}	67.126^{ns}
	-0.073	-22.598	-0.284	-3.094	-0.206	-36.062	-1.21	-21.765	-23.125	-36.733	-24.885	-15.309
B_1	-0.173*	48.379*	0.599*	-7.811*	0.145^{ns}	55.542*	0.861^{ns}	32.313*	23.229^{ns}	52.591*	2.952^{ns}	20.278*
	-0.034	-10.612	-0.134	-1.453	-0.097	-16.935	-0.568	-10.221	-10.86	-17.25	-11.686	-7.189
B_2	0.114*	-37.663*	0.343*	-3.347^{ns}	-0.041^{ns}	14.778^{ns}	-0.233^{ns}	12.645^{ns}	2.132^{ns}	19.400^{ns}	-4.623^{ns}	6.755^{ns}
	-0.034	-10.612	-0.134	-1.453	-0.097	-16.935	-0.568	-10.221	-10.86	-17.25	-11.686	-7.189
B_3	0.003^{ns}	8.175^{ns}	0.194^{ns}	-2.968^{ns}	0.029^{ns}	-10.046^{ns}	0.189^{ns}	-5.161^{ns}	-4.884^{ns}	-7.382^{ns}	-2.664^{ns}	-2.220^{ns}
	-0.034	-10.612	-0.134	-1.453	-0.097	-16.935	-0.568	-10.221	-10.86	-17.25	-11.686	-7.189
B_4	-0.02^{ns}	-6.874^{ns}	0.292^{ns}	-1.750^{ns}	-0.029^{ns}	24.560^{ns}	-0.133^{ns}	8.333^{ns}	16.228^{ns}	12.063^{ns}	12.498^{ns}	3.730^{ns}
	-0.045	-13.865	-0.175	-1.898	-0.127	-22.127	-0.742	-13.355	-14.189	-22.538	-15.269	-9.393
B_5	0.051^{ns}	-14.783^{ns}	-0.307^{ns}	2.130^{ns}	-0.086^{ns}	3.363^{ns}	-0.501^{ns}	-2.213^{ns}	5.575^{ns}	-1.270^{ns}	4.633^{ns}	0.942^{ns}
	-0.045	-13.865	-0.175	-1.898	-0.127	-22.127	-0.742	-13.355	-14.189	-22.538	-15.269	-9.393
B_6	-0.046^{ns}	6.247^{ns}	-0.100^{ns}	1.300^{ns}	-0.139^{ns}	-5.063^{ns}	-0.764^{ns}	-5.486^{ns}	0.422^{ns}	-8.620^{ns}	3.558^{ns}	-3.135^{ns}
	-0.045	-13.865	-0.175	-1.898	-0.127	-22.127	-0.742	-13.355	-14.189	-22.538	-15.269	-9.393
B_7	0.023^{ns}	-11.430^{ns}	-0.247^{ns}	1.248^{ns}	0.001^{ns}	-14.884^{ns}	0.016^{ns}	10.690^{ns}	-25.574^{ns}	16.964^{ns}	-31.848*	6.274^{ns}
	-0.038	-11.68	-0.147	-1.599	-0.107	-18.639	-0.625	-11.25	-11.953	-18.986	-12.862	-7.913
B_8	0.010^{ns}	8.132^{ns}	-0.403*	4.162*	0.007^{ns}	-35.821*	0.029^{ns}	-7.339^{ns}	-28.482*	-9.496^{ns}	-26.325^{ns}	-2.157^{ns}
	-0.038	-11.68	-0.147	-1.599	-0.107	-18.639	-0.625	-11.25	-11.953	-18.986	-12.862	-7.913
B_9	0.015^{ns}	-19.920^{ns}	-0.026^{ns}	-0.774^{ns}	0.055^{ns}	2.555^{ns}	0.336^{ns}	20.189^{ns}	-17.633^{ns}	36.191^{ns}	-33.635*	16.002^{ns}
	-0.038	-11.68	-0.147	-1.599	-0.107	-18.639	-0.625	-11.25	-11.953	-18.986	-12.862	-7.913
R^2	0.658	0.664	0.687	0.717	"-"	0.349	"-"	0.351	0.254	0.317	0.158	0.249

Note: * At 5% Significant of level, R^2 = Adjusted R-Square, Figures in parenthesis denotes standard error

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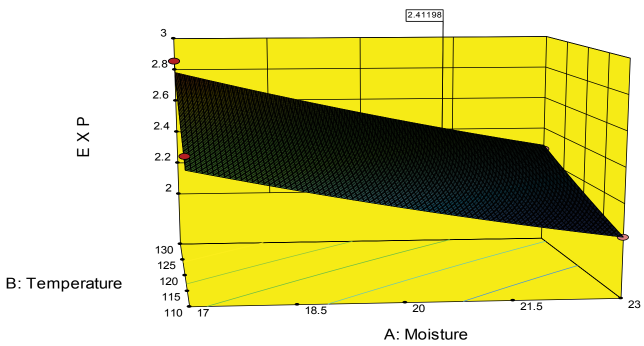

Figure 1: The expansion ratio of extrudate as a function of temperature and moisture at optimized screw speed (375 rpm).

Note: EXP: Expansion ratio.

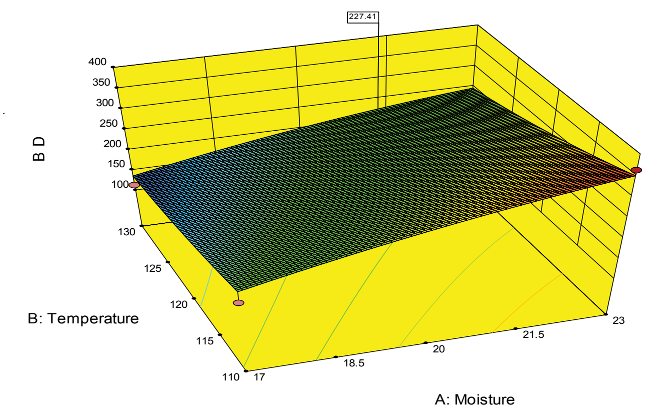

Figure 2: The bulk density of extrudate as a function of temperature and moisture at optimized screw speed (375 rpm).

Note: BD: Bulk density.

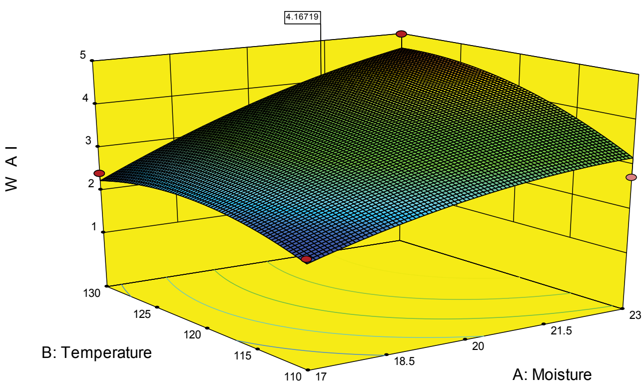

Figure 3: The WAI of extrudate as a function of temperature and moisture at optimized screw speed (375 rpm).

Note: WAI: Water absorption.

temperature and screw speed had reciprocal effects on Peak and Final Viscosity. There was also found a significant quadratic effect of barrel temperature on peak and breakdown viscosity. Setback peak viscosity had significantly influenced by quadratic effects of moisture and screw speed (Table 3). This can be attributed to the fact that a higher degree of gelatinization coupled with starch degradation occurred during extrusion cooking under high temperature and screw speed, it is a likely significant factor associated with low viscosity profiles. Significant variation in setback peak viscosity of extruded flour samples is indicative of their retro gradation tendency. Flours with lower pasting profiles, lower WAI and higher WSI exhibit low stickiness of end-products, thus are of special interest for children's foods and beverages. High stress extrusion cooking (lower moisture, high temperature and high screw speed) causes greater friction and energy dissipation, resulting in dextrinization or degradation of starch, and an increased formation of water-soluble molecules [23,24]. Results were in agreement with other studies [25,26].

Response surface modeling

In order to verify the predictive capability of the model, optimum conditions were established by RSM and comparisons between predicted results and the practical values were done by experimental rechecking using those presumed optimal conditions. The coefficients of fitted model for responses along with the standard error are presented in Table 3. Further, we optimized the responses (expansion ratio, bulk density, water absorption index and water solubility index) using multi-response optimization technique. The optimum values

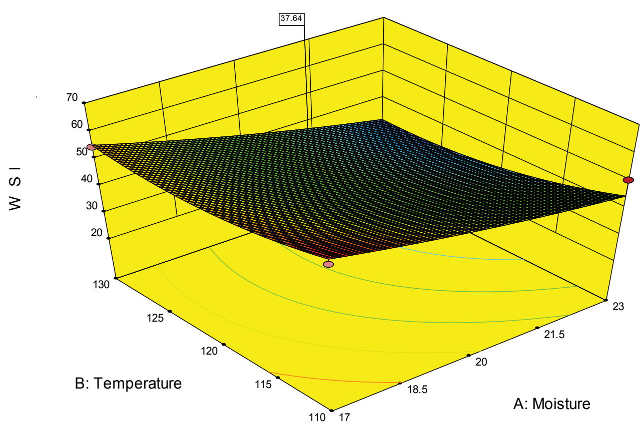

Figure 4: The WSI of extrudate as a function of temperature and moisture at optimized screw speed (375 rpm).

Note: WSI: Water solubility index.

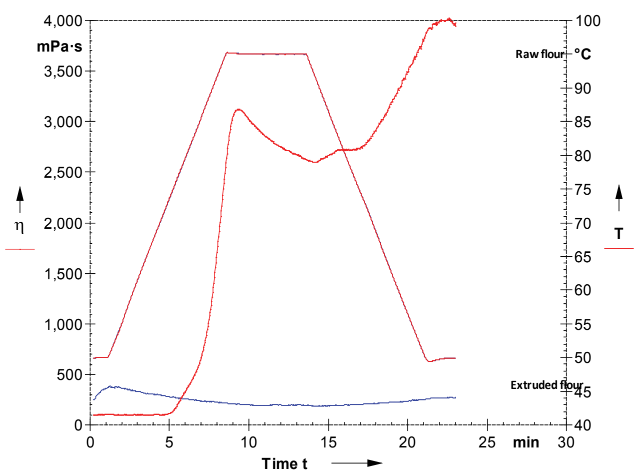

Figure 5: Pasting profile of raw and extruded finger millet flour.

Note: η: viscosity (Cp).

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Table 4: Pearson's correlation coefficients between functional and pasting properties of finger millet extrudates.

	Expansion ratio	Bulk Density	WAI	WSI (%)	Peak Time	Peak viscosity	Pasting Temp.	holding strength	Breakdown viscosity	final viscosity	Setback Peak Viscosity	Setback Trough Viscosity
Expansion Ratio	1											
Bulk Density	-0.87**	1										
WAI	-0.31^{ns}	0.17^{ns}	1									
WSI (%)	0.37^{ns}	-0.23 ^{ns}	-0.97**	1								
Peak Time	-0.52*	0.58*	0.36^{ns}	-0.44^{ns}	1							
Peak Viscosity	-0.40^{ns}	0.14^{ns}	0.84**	-0.85**	0.25	1						
Pasting Temp.	-0.52*	0.57*	0.37^{ns}	-0.45^{ns}	0.99**	0.25^{ns}	1					
Holding Strength	-0.28^{ns}	0.08^{ns}	0.75**	-0.79**	0.33^{ns}	0.83**	0.33^{ns}	1				
Breakdown viscosity	-0.39^{ns}	0.15^{ns}	0.65**	-0.61**	0.08**	0.83**	0.08^{ns}	0.38^{ns}	1			
Final viscosity	-0.26^{ns}	0.08^{ns}	0.74**	-0.79**	0.35^{ns}	0.81**	0.35^{ns}	0.99**	0.35^{ns}	1		
Setback Peak viscosity	-0.23^{ns}	0.09^{ns}	0.18^{ns}	-0.11^{ns}	-0.16^{ns}	0.31^{ns}	-0.16^{ns}	-0.26^{ns}	0.79**	-0.30^{ns}	1	
Setback Trough viscosity	-0.24^{ns}	0.08^{ns}	0.71**	-0.76**	0.36^{ns}	0.78**	0.37^{ns}	0.98**	0.31^{ns}	0.99**	-0.35^{ns}	1

Note: *Significant at $p <0.05$; ** Significant at $p <0.01$; ^{ns} Non-significant.

for X_1, X_2 and X_3 for finger millet extrudates are obtained as X_1=21.3% wb, $X_2$130°C, $X_3$375 rpm.

Responses at optimal extrusion conditions

The best combination of process variables for the best set of response properties included a feed moisture content of 21.3% (wb), Barrel temperature 130°C and Screw speed 375 rpm. The response calculated at optimal extrusion conditions, were expansion ratio, bulk density, water absorption index, water solubility index, peak time, peak viscosity, pasting temperature, holding strength, breakdown viscosity, final viscosity, setback peak viscosity and setback trough viscosity of 2.41 ± 0.08, 227.37 ± 25.45 kg/m^3, 4.17 ± 0.32, 37.65 ± 3.48 %, 1.75 ± 0.23 min, 431.43 ± 40.62 cP, 53.65 ± 1.36°C, 229.73 ± 24.52 cP, 201.70 ± 26.05 cP, 334.06 ± 41.38 cP, 97.38 ± 28.03 cP and 104.33 ± 17.24 cP respectively. The same response was confirmed through experimentation.

Correlation between responses

Pearson correlation coefficients (r) were determined between the response variables of the extruded finger millet. It was found that expansion ratio, water absorption index, and water solubility index negatively correlated with (bulk density, pasting temperature and pasting time), (water solubility index) and (holding strength, peak, breakdown, final and setback trough viscosity), respectively. The bulk density, water absorption index, pasting time, holding strength, peak, breakdown, and final viscosity had a positive correlation with (pasting temperature and time), (peak, breakdown, final, setback trough viscosity and holding strength), (pasting temperature, breakdown viscosity), (peak and setback trough viscosity), (holding strength, final, breakdown, setback trough viscosity) (setback peak viscosity) and (setback trough viscosity), respectively. However, pasting time had no association with any responses. The coefficients of correlation and level of significance are presented in Table 4. Chang and Ng [10] also observed correlation between water absorption index and peak viscosity in wheat-ginseng extrudates.

Thus the present study shows the functional and pasting properties of finger millet extrudates are strongly governed by extrusion process variables. Feed moisture and barrel temperature exerted most significant effect on various extrudate properties.

References

1. Chethan S, Malleshi NG (2007) Finger millet polyphenols: Characterization and their nutraceutical potential. American Journal of Food Technology 2: 582-592.

2. Devi PB, Vijayabharathi R, Sathyabama S, Malleshi NG, Priyadarisini VB (2014) Health benefits of finger millet (Eleusine coracana L.) polyphenols and dietary fiber: a review. J Food Sci Technol 51: 1021-1040.

3. Shobana S, Sreerama YN, Malleshi NG (2009) Composition and enzyme inhibitory properties of finger millet (Eleusine coracana L.) seed coat phenolics: Mode of inhibition of α-glucosidase and pancreatic amylase. Food Chem 115: 1268-1273.

4. Angioloni A, Collar C (2012) Effects of pressure treatment of hydrated oat, finger millet and sorghum flours on the quality and nutritional properties of composite wheat breads. J Cereal Sci 56: 713-719.

5. Martinez M, Rosell C, Gomez M (2014) Modification of wheat flour functionality and digestibility through different extrusion conditions. J Food Eng 143: 74-79.

6. Roman L, Martinez MM, Gomez M (2015) Assessing of the potential of extruded flour paste as fat replacer in O/W emulsion: A rheological and microstructural study. Food Res Int 74: 72-79.

7. Martinez M, Sanz T, Gomez M (2015) Influence of wheat flour subjected to different extrusion conditions on the rheological behaviour and thermal properties of batter systems for coating. J Food Sci Technol 64: 1309-1314.

8. Ding Q, Ainsworth P, Tucker G, Marson H (2005) The effect of extrusion conditions on the physicochemical properties and sensory characteristics of rice-based expanded snacks. J Food Eng 66: 283-289.

9. Ding QB, Ainsworth P, Plunkett P, Tucker G, Marson H (2006) Effect of extrusion conditions on the functional and physical properties of wheat-based expanded snacks. J Food Eng 73: 142-148.

10. Chang YH, Ng PKW (2011) Effect of extrusion process variables on quality properties of wheat-ginseng extrudates. International Journal of Food Properties 14: 914-925.

11. Zeng J, Gao H, Li G, Liang X (2011) Extruded corn flour changed the functionality behaviour of blends. Czech J Food Sci 29: 520-527.

12. Alvarez–Martinez L, Koundry KP, Harper JM (1988) A general model for expansion of extruded products. J Food Sci 53: 609-615.

13. Fan J, Mitchell JR, Blanshard JMV (1996) The effect of sugars on the extrusion of maize grits: II. Starch conversion. Int J Food Sci Technol 31: 67-76.

14. Anderson RA, Conway HF, Pfeifer VF, Griffin EL (1969) Gelatinization of corn grits by roll and extrusion cook. Cereal Science Today 14: 4-11.

doi:http://dx.doi.org/10.4172/2229-4473.1000126

15. Li E, Hasjim J, Dhital S, Godwin ID, Gilbert RG (2011) Effect of a gibberellin-biosynthesis inhibitor treatment on the physicochemical properties of sorghum starch. J Cereal Sci 53: 328-334.

16. Chakraborty SK, Singh DS, Kumbhar BK, Singh D (2009) Process parameter optimization for textural properties of ready-to-eat extruded snack food form millet and legume pieces. J Texture Stud 40: 710-726.

17. Stojceska V, Ainsworth P, Plunkett A, Ibanoglu S (2009) The effect of extrusion cooking using different water feed rate on the quality of ready-to-eat snacks made from food by-products. Food Chem 114: 226-232.

18. Gutkoski LC, El-Dash AA (1999) Effect of extrusion process variables on physical and chemical properties of extruded oat products. Plant Foods Hum Nutr 54: 315-325.

19. Martinez M, Rosell C, Gomez M (2014) Modification of wheat flour functionality and digestibility through different extrusion conditions. J Food Eng 143: 74-79.

20. Zhang S, Rodrigue D, Riedl B (2005) Preparation and morphology of polypropylene/wood flour composite foams via extrusion. Polym Compos 26: 731-738.

21. Vargas-Solorzano JW, Carvalho CWP, Takeiti CY, Ascheri JLR, Queiroz VAV (2014) Physicochemical properties of expanded extrudates from colored sorghum genotypes. Food Res Int 55: 37-44.

22. Moisio T, Forssell P, Partanen R, Damerau A, Hill SE (2015) Reorganisation of starch, proteins and lipids in extrusion of oats. J Cereal Sci 64: 48-55.

23. Hagenimana A, Ding X, Fang T (2006) Evaluation of rice flour modified by extrusion cooking. J Cereal Sci 43: 38-46.

24. Repo-Carrasco-Valencia R, Pena J, Kallio H, Salminen S (2009) Dietary fiber and other functional components in two varieties of crude and extruded kiwicha (Amaranthus caudatus). J Cereal Sci 49: 219-224.

25. Sompong R, Siebenhandl-Ehn S, Berghofer E, Schoenlechner R (2011) Extrusion cooking properties of white and coloured rice varieties with different amylose content. Starch 63: 55-63.

26. Sarawong C, Schoenlechner C, Sekiguchi K, Berghofe E, Ng PKW (2014) Effect of extrusion cooking on the physicochemical properties, resistant starch, phenolic content and antioxidant capacities of green banana flour. Food Chem 143: 33-39.

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