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Effect of Extrusion Process Parameters on Physical, Functional and Textural Properties of Broken Rice-Foxtail Millet-Maize based Extrudates

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The effect of extrusion on the physical, functional and textural properties of broken rice extrudates blended with foxtail millet and maize flours of various formulations (10:80:10, 20:60:20, 30:40:30, 10:60:30 and 30:60:10) on density, true density, porosity, expansion ratio, water absorption index (WAI), water solubility index (WSI), solubility index, swelling power, colour values, hardness and fracturability by varying the parameters of feed moisture content, screw speed and barrel temperature were investigated. The density of blends ranged from 0.09 to 0.57 g/cm^3, expansion ratio (1.47-2.58), true density (40.08-559.48 kg/m^3), porosity (22.83-38.18 per cent), WAI (3.52-7.81 g/g), WSI (0.0-6.6 per cent), swelling power (5.03-8.18 g/g) and hardness (1.91-10.44 N). It was observed that the increase in feed moisture content resulted in extrudates with a lower expansion ratio and WAI, higher density, WSI and hardness. Among the various combinations investigated the blend with broken rice (30), foxtail millet (60) and maize (10) yielded good sensory results. The results obtained from the experiments were significantly different at ($P \leq 0.01$) all combinations.

Key words: Extrusion, broken rice, functional, physical properties

The extrusion cooking process is high temperature short time process in which moist, soft grain is fed into the extruder, where the desired temperature and pressure are obtained over the required period of residence time. For cooking the product generally external heat is not supplied, and it is achieved through shear and friction in the extruder. Extrusion cooking is used worldwide for the production of expanded snack foods, modified starches, ready-to-eat cereals, baby foods, pasta and pet foods (Deshpande and Poshadri, 2011). Extrusion cooking because of its low cost and continuous processing capability has been accepted as one of the most useful technologies during the recent years in the field of food processing.

Rice (*Oryza sativa*) is the staple food crop for a large part of the world's population, making it the second most consumed cereal grain. Cereals have been popular raw materials for extrusion because of their functional properties, low cost and ready availability. Owing to high protein content, millets can be effectively utilized for enhancing the nutritional quality of cereal based extruded food.

Foxtail millet (*Setaria italica*) ranks second in the total world production of millets and contains 9–14 per cent protein, 70–80 per cent carbohydrates, and is a rich source of dietary fiber. It contains maximum amount of chromium among all other millets with an account of 0.030 mg per 100 g. Millet is a starchy food with a 25:75 amylose to amylopectin ratio and is a fairly good source of lipids (3–6%), having about 50 per cent of the lipids in the form of polyunsaturated fatty acids. Although millet is known to contain amylase inhibitors, the carbohydrate digestibility of millet foods is not affected because of heat-labile nature of the inhibitors. Even though the nutritional qualities of millet have been well recorded, its utilization for food is confined to the traditional consumers in tribal populations, mainly due to non-availability of consumer friendly, ready-to-use or ready-to-eat products as are found for rice and wheat. In recent years, millets have received attention, mainly because of their high fiber content and efforts are under way to provide it to consumers in convenient forms (Vanithasri *et al.,* 2012).

Extrusion cooking technology plays a central role in the modern cereal-based food industry especially, for the production of snack and breakfast cereal products from maize, wheat, rice and oats. Since maize flour is widely used to elaborate extruded products, there is a need to improve the nutritional value of this kind of food. The appropriate degree of maize replacement is needed to increase the nutritional contribution of extruded broken rice-foxtail millet-maize pastes, which in turn can help to keep consumer acceptance high. As the extrusion process involves both thermal treatment and mechanical shearing, it has been shown that it is possible to manufacture new food products. Among all flour components, starch plays a key role. The extrusion of starchy foods result in gelatinization, partial or complete destruction of the crystalline structure and

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molecular fragmentation of starch polymers. During extrusion, protein structures are disrupted and altered under high shear, pressure and temperature. Protein solubility decreases and cross-linking reactions occur possibly due to some covalent bonds formed at high temperature (Areas, 1992), as well as protein denaturation and formation of complexes between starch and lipids and between protein and lipids. Recent studies concentrated on extrusion cooking processing effects for creating new products and evaluation of physical and chemical properties.

The objective of this research was to develop a basic formula for producing a standard broken rice: foxtail millet: maize based snack (10:80:10, 20:60:20, 30:40:30, 10:60:30 and 30:60:10). Subsequently, an optimum percentage of broken rice substitution in the standard broken rice: foxtail millet: maize based snack was studied. The aim was to promote the utilization of broken rice as a substituting raw material in broken rice: foxtail millet: maize based snack that would be beneficial for consumers, snack processors and the most important, is to add value to broken rice.

Materials and Methods

Preparation of feed

Broken rice, foxtail millet and maize were purchased from rice mill, Kangeyam, Tirupur District, Tamil Nadu, Millets Department and Maize Department TNAU, Coimbatore respectively, ground separately in commercial flourmill to a particle size that passed through BIS 40 sieve and dried and stored in airtight containers for further experiments.

Blends were prepared by mixing broken rice, foxtail millet and maize flours in the different ratios on a weight basis shown in the Table 1. These blends were chosen according to preliminary tests and for acceptable product physical characteristics as well as better nutritive value in the final product. The blends were tempered by spraying a calculated amount of distilled water to adjust to 16-20 per cent (w.b.), sealed in high-density polyethylene bags and stored in food grade plastic containers at 4°C for 48 h. Blends were allowed to reach 29 to 30°C (room temperature), prior to extrusion processing. This preconditioning procedure was employed to ensure uniform mixing, hydration and to minimize variability in the state of feed material. Moisture content of samples was determined by hot air oven method AOAC (1990).

Table 1. Levels of processing variables and different flours quantities (g/100g total mix)

Sl. No.	Addition of flour (per cent)	Proportions of composite flour samples					
		A	B	C	D	E	F
1	Broken rice	100	10	20	30	10	30
2	Foxtail millet	0	80	60	40	60	60
3	Maize	0	10	20	30	30	10

Extrusion process

Several reports had attempted to relate extrusion parameters to chemical and physical properties of extrudates such as raw material composition, feed moisture content, screw speed and barrel temperature (Hagenimana *et al.,* 2006). In this study, extrusion was carried out in four factor experiment and the interaction impact of different extrusion conditions was considered. In this way, the effects of extrusion temperature (90–110°C), screw speed (230–290 rpm),feed moisture content (16–20%, wet basis) and blends of broken rice flour: foxtail millet flour: maize flour(10:80:10, 20:60:20, 30:40:30, 10:60:30 and 30:60:10%) on the physical, functional and textural properties of extrudates were studied.

Extrusion was performed in a co-rotating twin screw extruder (M/S. BTPL, Kolkata, India). The effective cooking zone was set to 90, 100 and 110°C in the barrel. The length to diameter (L/D) ratio for extruder was 20:1. The diameter of the hole in the die was 8 mm. The temperature near the die was measured by a thermocouple. The broken rice: foxtail millet: maize blend was prepared for extrusion process. The moisture of different blends was adjusted by addition of a pre-determined amount of water (16-20%, wet basis).The extruded products were cut into small pieces and the extruded products were collected and dried in hot air oven at 100°C for 5 min, the products were cooled and tempered at 4°C before being stored into plastic bags for future analysis. All experiments were conducted in duplicate.

Physical properties of extrudates

Density

Density of the extrudates was determined from the weight and measurement of the actual dimensions of the extrudates. The diameter and length of 25 pieces of randomly selected extrudate samples were measured using vernier caliper of 0.01mm least count. The weight of these extrudate pieces were taken in an electronic weighing balance having an accuracy of 0.001 g. The density was calculated using the following formula, assuming a cylindrical shape of extrudate (Rodriguez-Miranda *et al.,* 2011).
Where,

$$\text{Density (g/cm}^3\text{)} = \frac{4W}{\pi d^2 l}$$

W = weight, g

d = diameter, cm

l = length of the extrudate, cm

Porosity and true density

True volume of extrudates was determined using multivolume pycnometer (Micromeritics model USA: model 1305). Extrudates were placed inside the sample cup (35 cc capacity) and the pore volume was filled with helium gas. From the initial and final pressure of the gas in the chamber $p_1$and $p_2$values recorded. Porosity is calculated using the following relationship. The true density was calculated as the ratio of mass of the sample to the true volume.

$$P = \frac{p_1 \quad p_2}{p_2}$$

$$\rho_t = \frac{w}{V_t}$$

Where,

ρ_t = true density (kg/m^3)

w = weight of the samples (kg)

V_t = true volume (m^3)

Expansion ratio

The ratio of diameter of extrudate and the diameter of die was used to express the expansion of extrudate (Rodriguez-Miranda *et al.,* 2011). The diameter of extrudate was determined as the mean of 10 random measurements made with a vernier caliper. The extrudate expansion ratio was calculated as

$$Expansion\ ratio = \frac{Extrudate\ diameter\ (mm)}{Die\ diameter\ (mm)}$$

Functional properties of extrudates

The samples were evaluated for Water Absorption Index (WAI), Water Solubility Index (WSI), Solubility index (So) and Swelling Power (Sp).

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

WAI and WSI were determined by the method of (Anderson *et al.,* 1969).The extruded puffs were milled to a mean particle size of 200–250 µm. A 2.5 g sample was dispersed in 25 g distilled water, using a glass rod to break up any lumps and then stirred for 30 min. The dispersions were rinsed into tarred centrifuge tubes, made up to 32.5 g and then centrifuged at 4000 rpm for 15 min. The supernatant was decanted for determination of its solid content and sediment was weighed. WAI and WSI were calculated as

$$WAI = \frac{Weight\ of\ sediment}{Weight\ of\ dry\ solids}$$

$$WSI = \frac{Weight\ of\ dissolved\ solids\ in\ supernatant}{Weight\ of\ dry\ solids} \cdot 100$$

Solubility index and swelling power

Solubility index (SO) and swelling power (SP) of the samples were determined in triplicate. One gram of each sample was suspended in 20 ml of deionized water and heated at 90°C for 1 hour in water bath with constant stirring. The suspension was cooled at 30°C and then centrifuged at 4000 rpm for 15 minutes. The supernatant was poured into aluminum dishes, decanted and weighed the swollen granules. After weighing, the supernatant was dried at 110°C for 12 h and the weight of dry solids was determined. The solubility index and swelling power were determined using the formulae:

$$So = \frac{Weight\ of\ supernatant\ dried}{Sample\ weight} x100$$

$$Sp = \frac{Weight\ of\ sediment}{Sample\ weight} x\ (100\text{-}so)$$

Texture measurement

Texture analyzer was used to conduct objective sensory test for the extrudate samples. The peak force as an indication of hardness was measured with Stable Micro System TA-XT2 texture using three point bend rig. The test speed was 0.15 mm/s, pre-test speed was 2.0 mm/s and the distance between two supports was 70 mm. Ten measurements were performed on each sample. Fracturability is the force with which a sample crumbles cracks or shatters. Foods that exhibit fracturability are products that possess a high degree of hardness and low degree of adhesiveness. The degree of fracturability of a food is measured as the horizontal force with which a food moves away from the point where the vertical force is applied. The setup provided a variable support length up to 70 mm and sample width up to 80 mm through a rig located on heavy-duty platform. The results obtained gave peak force value to break the samples into 2 halves. This peak value is observed as the maximum force and can be referred to as the 'hardness' of the sample. The distance at the point of break is the resistance of the sample to bend and so relates to the 'fracturability' of the sample *i.e.* a sample that breaks at a very short distance has a high fracturability.

Experimental design and statistical analysis

A four factors experiment design was employed to investigate the influence of feed moisture (16-20%, wet basis), barrel temperature (90–110°C), screw speed (230–290 rpm) and formulations (10:80:10, 20:60:20, 30:40:30, 10:60:30, 30:60:10%) on the physical, functional and textural properties of extruded dispersions of broken rice-foxtail millet-maize blend. The feed moisture, barrel temperature and screw speed were optimized and kept constant at 18 per cent, 100°C, 230 rpm and formulations10:80:10, 20:60:20, 30:40:30, 10:60:30, 30:60:10 per cent, respectively for further experiments. Duncan's multiple range test was used to estimate significant differences among means at a probability level of 1 and 5 per cent using the IRRISTAT software Version 3/93, Biometrics Unit, International Rice Research Institute, Philippines, Completely Randomized Design with ANOVA was carried out on each of the variables and the Least Significant Difference (LSD).

Sensory evaluation

The sensory assessment was conducted with a panel of 25 members with the age between 19 to 50 years consisted of staff, under graduate and post graduate students of the Agricultural Engineering College and Research Institute, TNAU, Coimbatore. The panelists were not known to project objectives. Commercial control, samples (A, B, C, D, E and F) was fried to develop taste and texture added with flavor plus other spices was used in the evaluation. Samples were coded using random three-digit numbers and served with the order of presentation counter-balanced. Panelists were provided with a glass of water and instructed to rinse and swallow water between samples. They were given written instructions and asked to evaluate the products for acceptability based on its flavour, texture, taste, colour and overall acceptability using nine-point hedonic scale (1 = dislike extremely to 9 = like extremely, Meilgaard *et al.,* 1999).

Results and Discussion

Physical characteristics of extrudates

Density

The density is an index of the extent of puffing and values for the dry extrudates were between 0.09 and0.57 g/cm ^{3}. The lowest density value was obtained when broken rice-foxtail millet-maize flour was extruded at lower moisture contents and higher temperatures, whereas the highest value was obtained at higher moisture contents and lower temperatures. Density values decreased when the extrusion temperature and the screw speed increased probably due to starch gelatinization (Table 2). According to Hagenimana *et al.* (2006) as gelatinization increases, the volume of extruded product increases and density decreases. This proposal is in agreement with our observations. Further, the density increased with an increase in moisture content at low extrusion temperatures, whereas the opposite effect occurred at high temperature. A similar observation was reported by Sacchetti *et al.* (2004). Moreover, low shear screw configurations resulted in a higher extrudate density than high shear screw configurations. Analysis of variance attributed (*P*≤0.01) of total density to the dependent variables.

Table 2. Effect of extrusion process parameters on physical properties and colour values of extrudates

		Physical properties				Colour values			
Variables	Levels	Expansion ratio	Density (g/ cm^3)	TD (kg/ m^3)	Porosity (%)	L*	a*	b*	ΔE
Feed moisture (per cent w.b.)	16	2.23	0.17	363.11	34.27	41.2	4.93	10.42	42.79
	18	2.04	0.24	206.29	33.41	40.97	4.93	11.14	42.77
	20	1.80	0.34	126.62	32.08	39.78	5.41	10.28	41.48
Barrel tempe rature (°C)	90	1.87	0.31	253.45	31.76	42.85	5.79	11.93	44.87
	100	2.12	0.25	222.97	33.03	39.17	4.84	9.99	40.74
	110	2.18	0.20	219.61	34.97	39.93	4.63	9.92	41.42
Screw Speed (rpm)	230	1.97	0.26	265.21	32.73	41.15	5.19	10.74	42.87
	260	2.03	0.23	217.17	33.35	40.44	5.15	10.87	42.21
	290	2.08	0.21	213.66	33.68	40.36	4.93	10.22	41.95
Addition of broken rice: maize: foxtail millet (per cent)	10:80:10	1.99	0.24	217.40	33.71	39.34	4.91	9.75	40.85
	20:60:20	2.05	0.24	235.96	33.61	40.58	5.15	10.44	42.25
	30:40:30	2.07	0.27	238.06	32.03	40.87	5.01	11.18	42.69
	10:60:30	2.00	0.25	212.72	33.18	41.84	5.21	11.35	43.68
	30:60:10	2.02	0.27	255.89	33.72	40.63	5.16	10.34	42.25
LSD		0.05	0.05	0.04	0.04	0.03	0.04	0.04	0.05

TD: True density

True density

The true density of the extrudate product is approximately constant for every feed moisture, barrel temperature and screw speed levels increased from 16-20 per cent, 90-110°C and 230-290 rpm for formulations. This should be expected since particle density ranges between the density of water and the dry solid density. Thus, for the extruded product of very low moisture content, the particle density reaches the value of the dry solid density (Table 2). A similar observation was reported by Thymi *et al.* (2005) for corn grits extrudates. Increasing the moisture content changes the amylopectin molecular structure in the starch-based material reducing the melt elasticity that decreased the radial expansion ratio and increased the density.

Expansion ratio

A temperature increase leads to higher expansion ratio values, resulting in lower densities. The expansion ratio of extrudate product is presented in Table 2 as a function of extrusion characteristics. The expansion ratio was found to depend mostly on feed moisture content, product temperature and screw speed (residence time). The expansion ratio of broken rice-foxtail millet-maize extruded product ranged from 1.47 to 2.58. Feed moisture content had a highly significant effect on the expansion ratio. The expansion ratio decreased with increased feed moisture content. Thymi *et al.* (2005) suggested that expansion was most dependent on the melt elasticity. The stored energy was released in the expansion process, increasing the expansion ratio. Increased feed moisture content during extrusion would change the amylopectin molecular structure of the starch-based material, reducing the melt elasticity that decreases the expansion ratio. The increase of residence time results in a degradation of amylopectin networks in the material that changes the expansion. The increase of melt temperature significantly increased the expansion ratio for all the examined feed moisture contents.

Porosity

The porosity is presented as a function of screw speed for various moisture contents and product temperatures (Table 2). The porosity increased slightly as the screw speed and temperatures increased and there was a negative effect on feed moisture contents. Increased feed moisture content during extrusion decreased the porosity.

Colour

Colour is an important quality factor directly related to the acceptability of food products, and is an important physical property to report for extrudate products. Colour changes can give information about the extent of browning reactions such as caramelization, maillard reaction, degree of cooking and pigment degradation during the extrusion process (Ilo and Berghofer, 1999).Total color change (ΔE) values in the experiments varied widely between 39.2 and 65.4. Total colour change was mostly dependent on temperature, but also on moisture content. The lower the feed moisture content, the brighter was the colour of the extrudates, which were characterized by a high *L** value and low *a** value (Table 2). The lightness (*L**) is an indication of the brightness. The lightness value of the products ranges from 39.34 to 41.84. Table 2 shows that the lightness of the extruded samples increases with increasing level of foxtail millet and maize flours in respective composite mixes. Increasing moisture reduced the lightness due to different competing effects during the process. Minimum total colour change was found at 16–20 per cent moisture and also when process temperature was increased from 90 to 110°C. In fact, high temperatures in combination with low water content are known to favour the maillard reaction between reducing sugars and free amino groups.

Table 3. Effect of extrusion process parameters on functional and textural properties of extrudates

Variables	Levels	Functional properties				Textural properties	
		WAI (g/g)	WSI (per cent)	Swelling power	Solubility index	Hardness (N)	Fracturability (mm)
Feed moisture (per cent w.b.)	16	6.81	1.57	6.98	33.02	6.08	2.77
	18	6.66	1.74	6.93	20.57	6.09	2.78
	20	6.63	2.92	6.85	28.26	6.11	2.79
Barrel temper ature (°C)	90	7.11	1.45	7.30	24.50	6.19	2.79
	100	6.75	2.28	6.85	20.93	6.06	2.78
	110	6.24	2.49	6.62	36.41	6.03	2.77
Screw Speed (rpm)	230	6.86	1.66	6.98	25.18	6.13	2.86
	260	6.79	2.16	6.97	26.63	6.08	2.76
	290	6.45	2.40	6.82	30.04	6.06	2.72
Addition of broken rice: maize: foxtail millet (per cent)	10:80:10	6.85	2.20	7.07	30.86	6.11	2.74
	20:60:20	7.30	1.60	7.51	22.72	5.78	2.89
	30:40:30	7.10	2.22	7.37	18.47	6.13	2.76
	10:60:30	5.24	2.39	5.46	34.01	6.22	2.88
	30:60:10	7.00	1.95	7.20	30.35	6.22	2.62
LSD		0.04	-	0.04	0.01	0.01	1.18

Functional properties of extrudates

It measures the volume occupied by the extrudate starch after swelling in excess water, which maintains the integrity of starch in aqueous dispersion. It describes the rate and extent to which the component of powder material or particles dissolves in water. The water absorption index was found to be more for extruded sample 20:60:20 (7.3 g/g). Table 3 showed that the water absorption index of the extrudates decreased with increase in feed moisture from 16 to 20 per cent (w.b), the overall WAI decreased from 6.81 to 6.33 g/g and WSI increased from 1.57 to 2.92 per cent (Table 3) in the composite mixes. The water solubility index was more for the extrudates made from composite mix sample 10:60:30 (2.39%) and it was less for the sample 20:60:20 (1.60%). The water solubility index of the extrudates increased as feed moisture content, barrel temperature and screw speed increased from 16 to 20 per cent, 90 to 110°C and 230 to 290 rpm in the composite mix samples. These results are in conformity with the observations made by (Shirani and Ganeshranee, 2009).

The swelling power is determined by the ability of starch granules to swell in the presence of excess water when heated. Swelling power ranges from 3.56 to 8.18 g/g and solubility index ranges from 0 to 83.16 per cent of broken rice-foxtail millet-maize extrudates. Generally speaking, swelling power of starches reflects the interactions between water molecules and starch chains in amorphous and crystalline domains, respectively.

Textural measurement

The textural characteristics of extrudates were measured using a Stable Micro System TA-XT2 texture. The hardness of broken rice-foxtail millet-maize based extrudates was determined by measuring the force required to break the extrudates. The higher the value of maximum peak force required in gram, which means the more force required to breakdown the sample, the higher the hardness of the sample to fracture. Hardness of broken rice-foxtail millet-maize based extrudates varied between 1.52 and 10.44 N and fracturability 1.39 to 10 mm. As is shown in table 3 increasing feed moisture content, barrel temperature and decreasing screw speed resulted in increase in peak force and distance of extrudates. This is in agreement with the experiments by Sawant *et al.* (2013) on composite flours mixes.

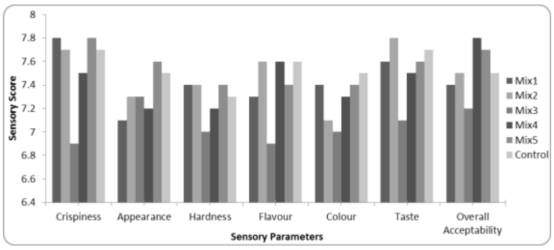

Fig. 1. Sensory scores of formulations flours of broken rice:foxtail millet:maize (Mix1-10:80:10, Mix2-20:60:20, Mix3-30:40:30, Mix4-10:60:30, Mix5-30:60:10, Control-100:0:0)

Sensory characteristics

The panels of semi- trained judges consisting of 25 members were given the extruded snack food samples for evaluation of organoleptic characteristics *viz*. appearance, colour, taste, flavour, texture and overall acceptability. It was served to judges on the day of preparation. The average score recorded by judges was considered, presented and discussed (Fig.1.). The mean scores of sensory evaluation showed that all the extruded products prepared from composite flours were within the acceptable range, while the extruded product prepared from composite flour sample 30:60:10 had significantly better appearance (7.6), colour (7.4), flavour (7.4), hardness (7.4), crispness (7.8), taste (7.6) and overall acceptability (7.7), when all the prepared extruded samples were compared with the commercial control. It was revealed from the scores of the overall acceptability that the broken rice, foxtail millet and maize can be successfully mixed to the level of 30:60:10 to produce a better acceptable product.

Conclusion

The present study revealed that composite flour(broken rice: foxtail millet: maize) in the ratio of 30:60:10 best suits to the sensory point of view. The physico-chemical properties and sensory characteristics of broken rice-foxtail millet-maize based extrudate were dependent on process variables, *viz*., moisture content, feed rate, screw speed and barrel temperature. The utilization of broken rice as a substituting raw material in foxtail millet and maize based snack that would be beneficial for consumers, snack processors and the most important is to add value to broken rice.

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