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Developement of extruded flakes from pearl millet

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Abstract
Pearl millet being a good source protein, fiber and mineral can prove to be a great source of product addition to healthy and balanced diet, but it is not being used for consumption on wider scale. The present study was conducted to explore the utilization of pearl millet for the preparation of extruded flakes as an innovative new product. The extruded flakes were prepared at different moisture content (14-18 %), screw speed (425-550 rpm), and barrel-temperature (125-175ºC). The effect of these three processing parameters on expansion Ratio (ER), water absorption index (WAI), water solubility index (WSI) were studied. The results showed that feed moisture had highly significant effect on all product responses; as increase in feed moisture reduces water solubility; whereas increase in screw speed increases water solubility. The results of the study revealed that with optimization of extrusion processing conditions pearl millet could be converted into highly acceptable extruded flakes.

Keywords: Pearl millets, extrusion, bulk density, milk absorption capacity

1. Introduction

Millets are small-grained, annual, warm-weather cereals belonging to grass family, widely grown around the world as cereal crops or grains for fodder and human food. Pearl millet is major warm season course grain cereal grown crop with its annual production of more twenty nine million ha in the arid as well as semi-arid tropical areas of Latin America, Asia and Africa (ICRISAT 2002) [11]. In terms of area (which is 7.12 million ha) and production (accounts to 8.06 million ton) India is considered to the largest producer of this crop with the average productivity of 1132 kilogram per hectare. The pearl millet is also said to the sixth principal and drought tolerant crop of the world as whole (Jain and Bal, 1997; Girgi and Keneddy, 2007) [12]. It constitutes more calories than the wheat mostly because of comparatively higher oil content of 5% is present. This oil is said to have 50% polyunsaturated fatty acids. Several studies have shown that compared to a crop like maize, pearl millet is said to have 40% higher amino acid such as lysine and methionine. It is also higher in 8-60% crude protein and it addition of crude protein it is also considered to be high in riboflavin, niacin, thiamine, lysine, tryptophan, manganese, potassium and calcium. Pearl millet being gluten free retains its alkaline properties while and after being cooked this proves to be edible and for the people suffering from gluten allergies. It has more complete amino acid profile than several other grains and it is also found that it is rich some essential micronutrients like Iron (Fe) and Zinc (Zn).

Extruded traditional products like Flakes and Breakfast cereals are usually eaten with milk (Dischsen *et al.*, 2013) [3]. Change in eating habits and living standard transformation has created a vast market for snack foods and the value addition of this category has achieved significant relevance due to some industrial and socio economic factors in the last decade. The increase in awareness towards healthy food had opened a wide scope for underutilized but nutritional crops as millets. The consumption of Breakfast cereals and other related products is said to be increased due to lack of time for the preparation of meal during these modern times (Oliveira *et al.*, 2013) [16] which provides us with a great opportunity to increase the Flakes and Breakfast cereals varieties in the market. On the basis of an IBGE survey there has been a noticeable decline the household consumption of conventional items such as Beans (from 6.6% it declined to 5.4%) and Rice (from 17.4% it declined to 16.2%), while the consumption of industrialized food is said to have been increased in case of Biscuits (from 3.1% it increase to 3.4%), Breads (from 5.7% it increase to 6.4%), ready to eat meals (from 3.3% it increase to 4.6%) and many others.

The consumption of this kind of product creates a great appeal to the consumers, especially for those who are looking for daily consumption of nutritive product along with the essential amount of nutrients. Ready to Eat (RTE) Breakfast cereals are highly favored by customers of all the ages as they offer variety, convenience and most of all high nutrient value (Faller el al., 2000) [6]. Mainly Iron (Fe) deficiency is considered to be the most common case of nutritional deficiency. Findings by Crawley (1993) [5] and Nicklas *et al*. (1992) [15] showed that children who ate RTE breakfast cereals ha higher daily intakes of Iron and Vitamins such as A,B than those who ate traditional breakfast meals. Even consuming fiber constituting RTE breakfast cereal in the morning showed lower plasma cholesterol levels in the teenagers (Faller *et al*., 2000) [6].

Extrusion is a cooking process which involves high temperature and short time combination which further cooks the expansive, moistened, protein rich and/or starchy food materials in a tube by a combination of mechanical shear, temperature, pressure and moisture resulting in chemical reaction and transformation of molecules (Castells *et al*., 2005) [2]. It decreases the various anti-nutritional factors such as trypsin inhibitor, phytate and tannins) and it also increases the bioavailability of various nutrients (Sreerama *et al*., 2008) [21] as well imparts less nutrient loses as compared to cooking. In the processing of food, extrusion cooking process has become a highly used process in pet foods, cereal and snack industries that utilizes protein as well as starch as raw materials to produce a high valued food products (Lin *et al*., 2000) [13] Extrusion cooking gives a big opportunity to create an exciting and new product which is also versatile, efficient method of converting raw materials into finished food products. Extruded products have greatly transformed the cereal industry; the most important this is that at a competitive price a high quality extruded product is being offered to consumers. Various advantages includes versatility with regard to the ingredient selection, shapes and texture of the product, efficiency in energy and the lack of effluents in the process. Product can highly depend on the configuration of the screw, type of the extruder, moisture in the feed and the temperature present in the feed rate, screw speed and barrel session (Filli *et al*., 2012) [8]. Extrusion process cooking can help us make conventional product to be better acceptable in this rapidly changing society. In order to boost the importance of the underutilized but highly nutritional rich pearl millet, the present study was conducted with the aim to explore the utilization of pearl millet for the preparation of extruded flakes as an innovative new product.

2. Material and Methods

2.1 Raw Material: Pearl millet was procured from specialty market and ground using lab mill (Perten instruments, Hagersten, Sweden) to make flour which passes through 200µ sieve.

2.2 Product Properties

Functional properties of the extrudates were analyzed and used as criteria for selection of best levels of feed moisture, barrel temperature and screw speed to prepare product under optimized conditions. Expansion ratio (ER) is determined by dividing the extrudate diameter measured using vernier caliper (Absolute Digimatic Caliper, Series-500, Innox, Japan) to the diameter of die nozzle (Fan *et al.,* 1996) [7]. The extrudate expansion ratio was expressed as

$$\text{Expansion ratio} = \frac{\text{Diameter of the extrudates (mm)}}{\text{Diameter of the die (mm)}}$$

Water absorption index (WAI) and Water solubility index (WSI) of the extrudates was determined by previously described method (Anderson *et al.,* 1969) [1]. To determine WAI, 2.5 g dry sample was taken in centrifuge followed by the addition of water. The sample was subjected to shaking for 30 mins and then centrifuged at 3000rpm for 15 mins. After centrifugation, supernatant was separated for WSI and weight of the residue left in centrifuge tube was noted and used to determine WAI. WAI and WSI were expressed in g/g and percent, respectively by using following formulas:

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

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

2.3 Experimental design and statistical analysis

To determine the optimum processing conditions for the preparation of extruded flakes, response surface methodology was used. The independent variables considered in this study were moisture, screw speed and barrel temperature. From commercial statistical package, design expert (version 9.0.3.1, May 2014, Stat- Ease, Inc., Minncapolis, MN, USA) response surface plots were generated to statistical analyze experimental data by a multiple linear regression method. The effect of different extrusion parameters on the product properties was also investigated. The individual effect of each variable and also the effect of interaction terms were determined. The design required the 20 experimental runs with eight factorial points, six center points and six star corner points. Randomization of the experiments was done to reduce the systematic bias in observed responses due to external factors.

2.4 Optimization

Extrusion processing parameters were optimized by using a conventional graphical method of RSM in order to obtain extrudates with acceptable properties. The main criteria for constraints optimization was based on the sensory evaluation. From the samples considered to be best, the contour plots obtained by superimposing or overlying, range of optimum process variables for development of extruded flakes with specified properties can be determined.

3. Result and Discussion

3.1 WAI

WAI measures the water holding capacity of the starch after swelling in excess water corresponds to the weight of the gel formed, which increases by the degree of starch damage during extrusion. Extrusion induces fragmentation of starch amylose and amylopectin chains (Mason and Hoseney, 1986; Yagci and Gogus, 2008) [22]. Results given in Table 2 show that WAI varied from 0.88 to 4.49 g/g. Feed moisture had high significant effect on WAI ($P < 0.05$). Feed moisture showed the negative coefficient which illustrates that WAI decreases with increase in feed moisture content, significantly (Fig 1). The most important effect of extrusion on the starch is gelatinization which converts raw starch to a cooked and digestible material in the presence of water and heat (Pathania *et al.*, 2013) [17]. So, the WAI can be regarded as an index of gelatinization because starch in its native form does not absorb water at ambient temperature (Yagci and Gogus, 2008) [22]. WAI depends on the availability of hydrophilic groups which bind water molecules and on the gel-forming capacity of macromolecules (Gomez and Aguilera, 1983) [9].

3.5 Water Solubility Index (WSI)

Results given in Table 2 indicate that WSI values ranged between 0.54 % and 15.12 %. WSI was affected significantly by feed moisture and barrel temperature ($p < 0.05$). Feed moisture showed negative regression coefficient with WSI which indicate WSI decreased with increasing feed moisture as at low feed moisture, water solubility of starch molecules increases due to the starch degradation (Pathania *et al.*, 2013; Silva *et al.*, 2009) [17, 18]. Both screw speed and barrel temperature showed positive regression coefficients on WSI (Fig 1). High temperature leads to the gelatinization of starch and increases the amount of soluble starch in water and also increases in WSI (Ding *et al.*, 2006) [4]. High mechanical shear imparted due to high screw speed leads to fragmentation of larger molecules which results in an increase in WSI (Dogan and Karwe, 2003; Singh *et al.*, 2014) [20].

3.2 Expansion Ratio

The expansion ratio of the food mainly depends on the difference between atmospheric pressure and water vapour pressure. It is also relies upon the ability of the extrudates to sustain expansion (Singh *et al.*, 2014) [20]. Data shown in Table 1 illustrate that expansion ratio ranged from 0.60 to 1.42 g/cm^3. Regression coefficients table showed the significant effect of feed moisture on ER at $P < 0.05$. Feed moisture negatively affect ER which showed the decreases in ER with increase in feed moisture while positive coefficients of screw speed and barrel temperature indicated that ER increased with increasing of these two variables. The interactions between feed moisture and barrel temperature ($P < 0.01$) were showed to have highly significant and negative correlation with expansion values (Fig 1). The negative effect of moisture can be resulted from high vapour pressure created during extrusion which causes expansion once the product is released to ambient pressure and temperature (Harper, 1989) [10]. The expansion ratio is also directly affected by screw speed as low screw speed causes less expansion. This behaviour could be due to the presence of less shear force and pressure in the barrel (Singh *et al.*, 2014) [20]. The expansion index was found to be low at low extrusion temperatures, increasing gradually as the temperature was increased. Increase in feed moisture reduces the dough elasticity which results in reduced SME and expansion ratio of extrudates (Pathania *et al.*, 2013) [17]. The model for expansion ratio showed high degree of coefficient of determination (R^2) of 0.85 and adjusted R^2 of 0.71 with a coefficient of variation (CV= 12.79 %) (Table 2). Regression analysis also revealed that the quadratic negative correlation coefficient of feed moisture (A^2) significantly affected ER.

Table 1: Effect of extrusion conditions on dependent variables'

S. No	Feed moisture (%)	Screw speed (rpm)	Barrel Temp (ºC)	WAI (g/g)	WSI (%)	ER
1	14(-1)	400(-1)	125(-1)	4.29	10.08	1.05
2	18(+1)	400(-1)	125(-1)	3.76	5.72	0.60
3	14(-1)	550(+1)	125(-1)	4.41	11.6	1.42
4	18(+1)	550(+1)	125(-1)	1.19	0.04	0.71
5	14(-1)	400(-1)	175(-1)	4.13	8.02	0.78
6	18(+1)	400(-1)	175(+1)	4.39	11.16	0.93
7	14(-1)	550(+1)	175(-1)	4.22	8.28	0.99
8	18(+1)	550(+1)	175(+1)	4.08	15.12	1.10
9	12.64 (-1.682)	475(0)	150(0)	4.49	10.92	0.75
10	19.36 (+1.682)	475(0)	150(0)	3.97	4.76	0.60
11	16(0)	349 (-1.682)	150(0)	5.47	7.84	1.37
12	16(0)	601(+1.682)	150(0)	4.1	11.96	1.26
13	16(0)	475(0)	107.95 (-1.682)	4.37	6.44	0.88
14	16(0)	475(0)	192.04(+1.682)	4.03	7.52	1.07
15	16(0)	475(0)	150(0)	1.6	1.9	1.01
16	16(0)	475(0)	150(0)	0.98	0.56	0.84
17	16(0)	475(0)	150(0)	0.99	0.57	1.00
18	16(0)	475(0)	150(0)	0.95	0.58	0.87
19	16(0)	475(0)	150(0)	0.88	0.57	0.95
20	16(0)	475(0)	150(0)	0.98	0.54	0.79

* Coded values are in the parenthesis

Table 2: Analysis of variance for the fit of experimental data to response surface model for extruded flakes

Regression	WAI	WSI	ER
Adequate precision	8.57	9.57	10.07
CV (%)	20.44	29.40	12.79
R^2	0.91	0.92	0.85
Adjusted R^2	0.83	0.85	0.71
Predicted R^2	0.37	0.38	0.09

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

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

Parameters	WAI	WSI	ER
Intercept of Model	1.09	0.78	0.91
Feed moisture (A)	-0.33	-1.19*	-0.083*
Screw speed (B)	-0.36	0.51	0.026
Barrel temperature (C)	0.19	1.24*	0.049
Feed moisture x screw speed (AB)	-0.39	-0.44	0.18
Feed moisture × barrel temperature (AC)	0.48	3.24**	-0.036**
Screw speed x barrel temperature x (BC)	0.28	1.05	-0.012
Feed moisture × feed moisture (A^2)	0.95**	2.51**	-0.094*
Screw speed × screw speed (B^2)	1.15**	3.23**	0.013**
Barrel temperature × barrel temperature (C^2)	0.94**	2.21**	0.13

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

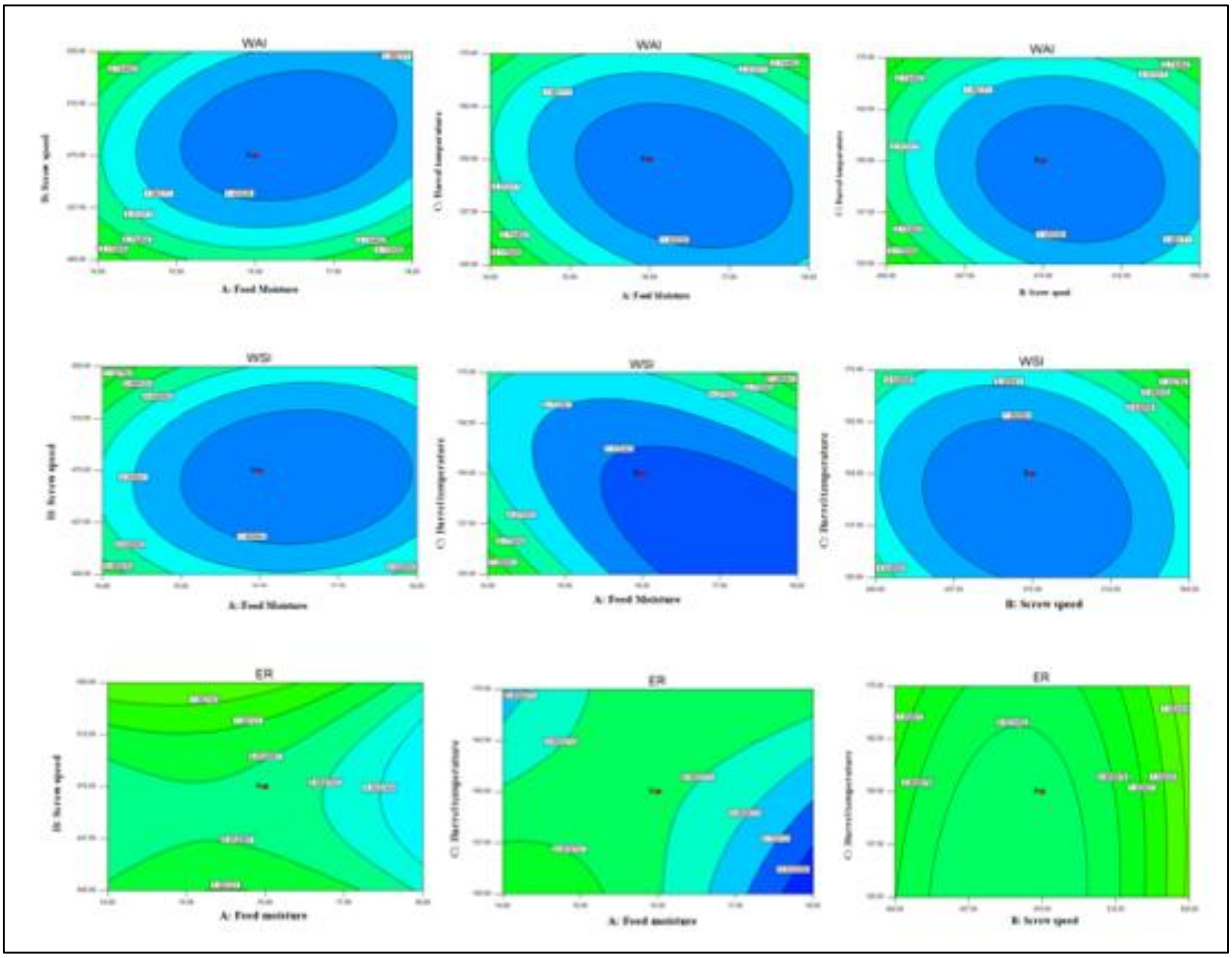

Fig 1: Contour plots depicting the behaviour of WAI, WSI and ER at different feed moisture content, screw speed and barrel temperature of pearl millet flakes

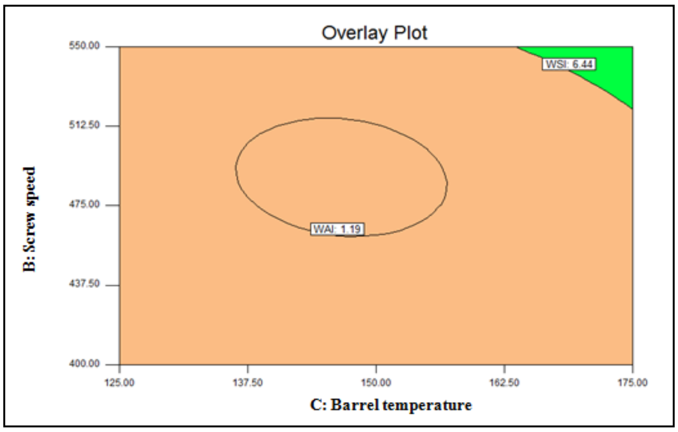

Fig 2: Overlay plots for product responses affected by screw speed and barrel temperature of pearl millet flakes

Conclusion

A significant effect of extrusion conditions (screw speed, feed moisture and barrel temperature) on physical properties of pearl millet based flakes was clearly observed. The effect of independent variables on the product properties was described by using multiple regression coefficients. The extrudates having desirable properties such as maximum expansion ratio and water absorption index can be prepared using optimized extrusion conditions which includes 14.00- 14.80 % feed moisture, 524-550 rpm screw speed at 150°C barrel temperature (Fig 2). It can be concluded that pearl millet based extruded flakes with high quality and nutritional value could be produced by using above optimized extrusion conditions.

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