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RESEARCH PAPER

Development of rice analogues by utilising broken rice and broken pigeonpea dhal

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Abstract: Development process of rice analogues by utilising the broken rice (BRF) and broken pigeonpea dhal (BPDF) flours together with water and sodium alginate as binding agent through extrusion was carried out. Two variable *viz*., BPDF (20, 30 and 40%) and moisture content (25, 30 and 35%) were controlled in the study to produce rice analogue resembling the raw rice. The optimum combination of flour mixture established for 30% BPDF and 30% water content with highest desirability of 0.855. The optimum combination had highest crude protein, carbohydrate andash contentof 12.73, 71.72 and 0.990 %, respectively. The colour values L^*, a^* and b^* were found to be 69.30, 4.62 and 26.31, respectively. The pasting temperature and peak viscosity were 77.65 °C and 23.17Pa.s. The physico-chemical and pasting properties can be modified by altering the different constituents for specific quality requirements.

Keywords: Broken rice, Dhal, Extruded rice, Rice analogue

Introduction

Rice is one of the leading food crops and sustains two third of the world's population, providing 20% of the world's dietary energy supply (Choi *et al*., 2010) and is the staple food for 2.5 billion people (Khan *et al*., 2009). Rice is a rich source of macro and micronutrients in its unmilled form (Steiger *et al*., 2014) but milling is an important criterionfor obtaining whole rice kernel. An issue of concern is breakage of kernels during milling (30-50 % Patel *et al*., 2001) and removal of micronutrient-rich bran layers. The broken grains are mainly used as feed or brewing raw materials, which has a low economic value (Mishra *et al*., 2012). However, there is considerable potential for value addition of this relatively cheaper by-product of rice milling industry. This would not only supplement nutrition for a large part of population but could also help in conservation of food and additional monetary benefit to the rice milling industry (Steiger *et al*., 2014).

Pulses are another important global food cropsprovidingmuch needed protein to the carbohydrate rich vegetarian diet (Yadav *et al*., 2019). It is contributing significantly to the nutritional security of the country (Singh *et al*., 2015) hence, commonly known as Poor man's meat Pigeonpea (*Cajanascajan*) is an important pulse crop in India followed by gram contributing 15 to 20 % to the total production. Pigeonpea is consumed in the form of dehusked split pulse known as dhal. Processing of pulses into dhal is being coupled with losses and wastage estimated to be about 10-25 % (Singh, 1995). Utilising these milling by-products would supplement nutrition to a large part of population and economic benefit to the pulse milling industry.

Despite being a primary food, rice is low in protein and high in starch. The low protein levels in rice cause deficiencies of protein and some essential amino acids in people who take it as their primary diet. One approach to overcome the problems is to produce "faux" rice kernels using milling by-products of rice and dhal mills by extrusion technology (Dexter, 2012). Based on the above facts the investigation was undertaken to standardize the composite flour for production of rice analogues using by-products of rice and dhal mills by extrusion processing and analyze the quality parameters.

Material and methods

The experiment was conducted in the Department of Processing and Food Engineering, College of Agricultural Engineering, UAS Raichur during the year 2018-19.

Raw materials

The raw material used for the study namelywhole rice grains and broken rice (BPT 5204) were procured from M/s. Radhe Agro Industries, Raichur and broken pigeonpea dhal (TS-3R) were procured from M/s. Raghavendra Pulses, Kalaburagi. The brokens were ground using hammer mill and then sieved manually by using 150 μ sieve to obtain flour of uniform particle size (Patel *et al*., 2001). The broken rice flour is represented as BRF and broken pigeonpea dhal flour as BPDF in the paper.

Physical properties of whole rice kernels

The engineering properties namely size, true density, bulk density and thousand grain weight of whole rice kernels were measured using standard procedures and instruments explained by Mohsenin, 1986.

Extrusion of rice analogues

Cold extruder (La Monferrina, Dolly mini, Italy) was used for development of rice analogues. The unit is basically a single screw extruder consistingof a stainless steel screw having 3:1 barrel length to diameter ratio with uniform pitch. It was powered by a 2.25 kW electrical motor through a speed reduction system. For preparation of the rice analogues with desirable internal

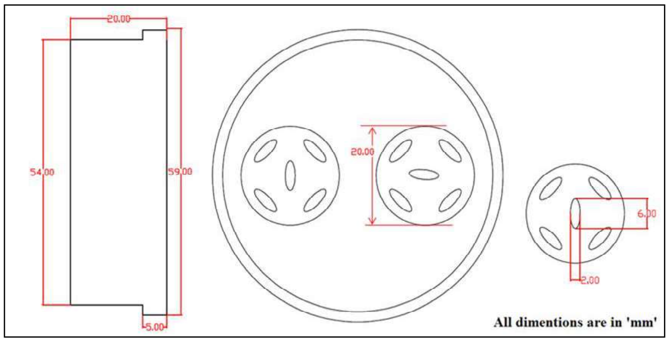

Fig. 1. Schematic diagram of cold extruder die and die hole

and apparent good texture, the blended broken rice flour, dhal flour and binding agent were tempered by adding a predetermined amount of water (25-35 %) by spraying and mixing for 30 min to reach the equilibrium (Yogeshwari *et al.,* 2019). The operating conditions were fixed screw speed of 55 rpm and feed rate of 1.5 kg/h. The temperature profile in the barrel zone towards rice shaped die was 60 °C. After obtaining the dough of required consistency, extruder was operated to produce the rice analogues with desired size using cutter blade attached at the outlet of the die. The extrudates were collected, cooled at room temperature and dried overnight in tray drier at 40 °C before packing.

Fabrication of die for extrusion of rice analogues

The cold extruder die having the external dimensions of 59.00 mm diameter and 20 mm thick was fabricated to fit in the existing cold extruder machine. Based on the physical properties of the rice grains, the size of elliptical shaped die holes resembling the rice like kernel was finalized. The average kernel dimensions obtained from the section 3.1 (5.330 mm length, 1.799 mm width and 1.455 mm thickness) were used and the die hole dimensions selected for fabrication were 6.0 mm length and 2.0 mm width (at the centre) as shown in Fig. 1. The die hole dimensions selected were larger (0.5 mm) than the average size of the rice grain considering the reduction in the size due to shrinkage after drying.

Composite flour formulation for development of rice analogue

The process flow chart for the production of extruded rice analogues is presented in Fig. 2. The process mainly involved

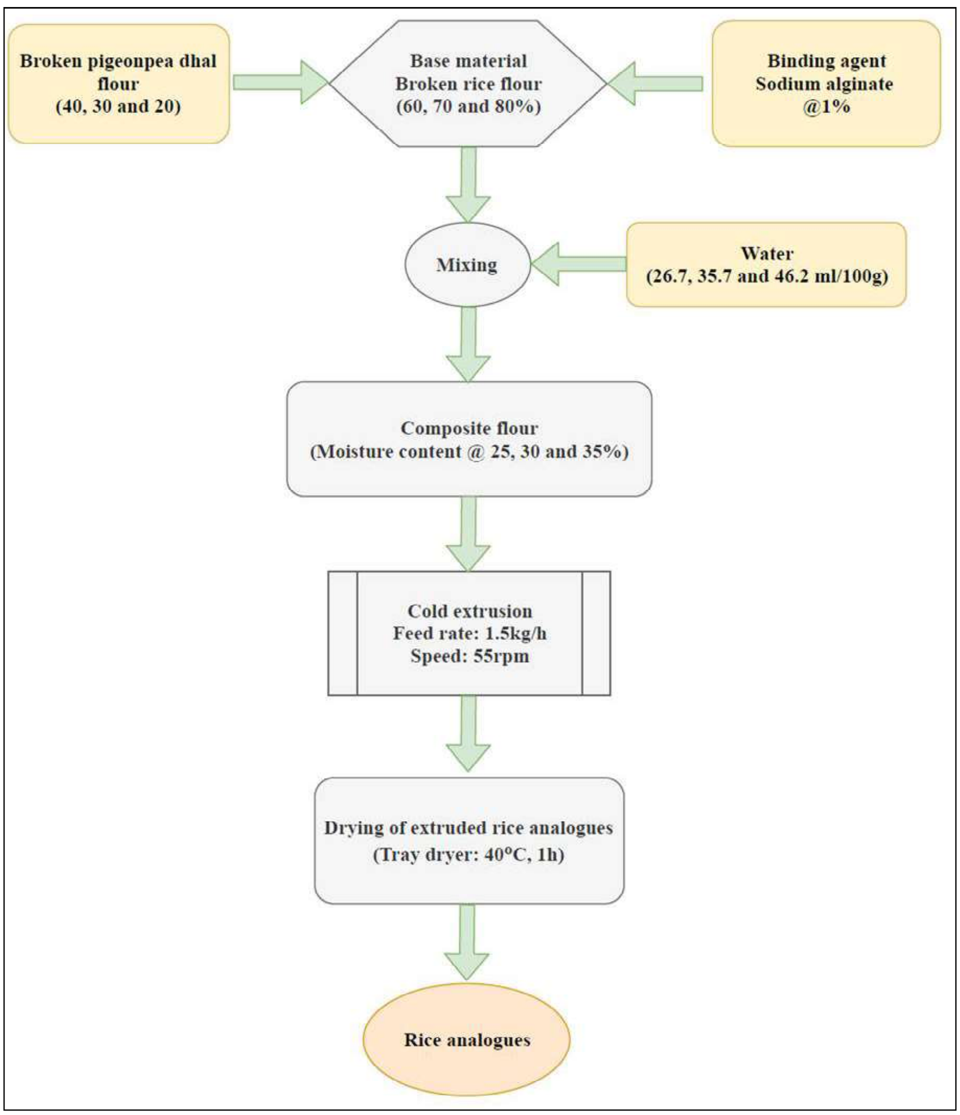

Fig. 2. Process flow chart for development of rice analogues

the optimization of composite flour containing appropriate proportion of BPDF, BRF and water. The BPDF at different levels *viz*., 20, 30 and 40 % were blended with remaining proportion of base material BRF to bring the mixture to 100 %. The moisture content of composite flour was achieved by adding the water at 26.7, 35.7 and 46.2 ml/100 g to obtain moisture content of 25, 30 and 35 per cent considering the initial moisture of the flour as 5 %. Sodium alginate at 1 % (Cox and Cox, 1993) was added as binding agent to provide cohesive powder mixture forming rice analogues due to the poor binding ability of rice flour (Pagani, 1986: Patel *et al*., 2001). Mixing of the flour was continued until the mixture was homogeneous (approx. 10 min) and the dough was rested for 2 hours before putting it into the extruder (Budi *et al*., 2015). The rice analogues were extruded in a cold extruder with cutter blade. After reaching a steady operating state and producing good extrudate (uniform), the product was dried to moisture content not more than 15 per cent on wet basis (Steiger, 2010) using a tray drier at 40°C for 1 h (Patel *et al*., 2001).

Experimental design

The experiments were designed according to the general factorial design. The numerical optimization was carried out using Design Expert software 7.7.0 (Statease Inc., Minneapolis, USA) for two independent variables of extrusion flour mix namely BPDF and moisture content at three levels each as shown in Table 1. The dependent variables/responses selected for optimization process were the quality characteristics namely crude protein, carbohydrate, ash and colour values.

Quality characteristics of extruded rice analogues

The selected proximate characteristics were determined for the developed rice analogues with different treatment combinations. The crude protein, carbohydrate and total ash content were analysed by the AOAC (2005) and the colour values (L^*, a^* and b^*) were determined by Hunter's Lab Colorimeter (Hunterlab, CLFX-45, Reston, USA). The pasting properties of rice analogues were determined by a modular

Table 1. Treatment combinations for standardization of composite flour

Treatments	Broken rice flour (%)	Pigeonpea dhal flour (%)	Moisture content (%)
T_0	100	0	(Avg. values of 25, 30 and 35%)
T_1	80	20	25
T_2	80	20	30
T_3	80	20	35
T_4	70	30	25
T_5	70	30	30
T_6	70	30	35
T_7	60	40	25
T_8	60	40	30
T_9	60	40	35

T_0 - Dhal-0%, M.C-Avg. of 25, 30 and 35%, T_1- Dhal-20%, M.C-25%; T_2- Dhal-20%, M.C-30%;T_3- Dhal-20%, M.C-35%;T_4- Dhal-30%, M.C-25%; T_5- Dhal-30%, M.C-30% ;T_6- Dhal-30%, M.C-35%; T_7- Dhal-40%, M.C-25%;T_8- Dhal-40%, M.C-30%;T_9- Dhal-40%, M.C-35%

compact rheometer (Anton-Paar GmbH, MCR 102, Graz, Austria) as per the procedure explained by Kim *et al.* (2009).

Economics of production of rice analogues

The significant part of rice analogues development depends not only on their legal status, expected bioavailability, stability and sensory acceptability but also on the cost effectiveness. The cost of production for rice analogues was calculated using two important cost concepts namely fixed costs and variable costs.

Results and discussion

Physical properties of rice kernels

The physical properties namely size, bulk density, true density and 1000 grain weight are presented in Table 2. The average values of length, width and thickness of the rice grains were 5.33 ± 0.04 mm, 1.79 ± 0.0 mm and 1.45 ± 0.01 mm, respectively and were similar to that reported earlier (L-6.61mm, W-1.75mm and T-1.40 mm) by Ghadge and Prasad (2012). The average 1000 grain weight was 9.64 ± 0.048 g. The weight of the rice grain was comparatively lesserdue to smaller and finer kernel size after polishing. The bulk density and the true density values were recorded to be 869.60 ± 38.35 kg/m^3 and 1397±46.12 kg/m^3 respectively. The results are in close agreement with bulk density valuerange 770 - 880 kg/m^{3}reported by Singh *et al.* (2005) for different varieties of rice and also with the true density of 1269.1 kg/m^3 reported by Varnamkhasti *et al.* (2008) for rough rice.

Development of fortified rice analogues using broken rice and pigeonpea dhal

Rice analogues were produced by the process of extrusion using laboratory scale cold extruder. The extruded rice analogues developed using different treatment combinations of moisture content and pigeon pea dhal flours is shown in Plate 9. The process mainly involved the formulation of appropriate flour mix of broken rice, broken pigeon pea dhal, binding agent and moisture content as per the treatment combinations. The flour mixture was then extruded in a cold extruder through rice shaped die and dried to a moisture content of not more than 15 % on wet basis.

Effect of BPDF and moisture content on chemical properties of rice analogues

The important components of proximate composition which have the major effect on the optimisation of composite flour *viz*., crude protein, carbohydrate, ash and colour values for different treatment combinations of extruded rice analogues were estimated and are shown in Table 3.

Table 2. Engineering properties of raw rice (BPT 5204)

Sl. No.	Properties		Value (s)
1	Size (mm)	L	5.33 ± 0.04
		W	1.79± 0.01
		T	1.45 ± 0.01
2	Bulk density (kg/m^3)		869.6 ± 38.35
3	True density (kg/m^3)		1397 ± 46.12
4	Thousand grain weight (g)		9.64 ± 0.048

Crude protein

The addition of pigeonpea flour was focused on utilizing the brokens and enhancing protein content of analogue rice. The result presented in Table 3 showed significantly higher protein in the extruded rice analogues with BPDF (10.84 ± 0.06 to 13.47 ± 0.07 %) as compared to raw rice (8.51 ± 0.05 %) and rice analogue without BPDF (8.37 ± 0.32 %). It was observed that, the crude protein content of the rice analogues increased with increase in pigeonpea level and moisture content. The high protein content of pigeonpea flour (20.893 ± 0.58 %) contributed in increasing the protein content of extruded rice analogues and in-situ development of temperature might have destructed the protein levels resulting in lower levels of protein in low moisture extrusion. The results reported by Patel *et al*. (2001) for protein (11.63 %) content of rice analogues produced by broken rice and blackgramandKhairunnisa *et al.* (2017) for production of high protein (11.34 %) rice analogues by incorporation of soybean flour were in agreement with the results.

Carbohydrate

The results of carbohydrate content of the extruded rice analogues ranged from 69.54 ± 0.53 to 74.65 ± 0.23 per cent as compared to 78.05 ± 0.31 per cent in raw rice and rice analogue without BPDF 78.42 ± 0.62 per cent. The carbohydrate content of rice analogues decreased with the increase in BPDF and moisture content.This might be due to increase in the protein contributed from BPDF. Similar results of carbohydrate contents of 71.94 % were reported by Sumardiono *et al.* (2014) for production of rice analogues using composite flour and Khairunnisa *et al.* (2017) for production of high protein rice analogues by incorporation of 30 % soybean flour (75.65 ± 0.31 %).

Total ash

Ash content represents the total minerals in the extruded rice analogue. The ash content rangedfrom 0.58±0.01 to 1.18±0.02% compared to raw rice (0.52±0.02%) and rice analogue without BPDF (0.50±0.01%). It was observed that with an increase in the amount of pigeonpea flour, the ash content of the blends increased significantly. The increase in the ash content was probably due to the addition of pigeonpea flour which had higher amount of ash content (Kaushal *et al.,* 2012). The ash content alsoincreased with increase in moisture content. Thisis attributed to the addition of minerals through water added during extrusion and also from the extruder barrel (Singh *et al*., 2000). Similar results were reported by Khairunnisa *et al.* (2017) for high protein rice analogues by incorporation of soybean flour (1.40 ± 0.03 %).

Colour (*L, *a** and *b**)**

The colour value *L** (whiteness) ranged from 64.58 ± 0.78 to 72.89 ± 0.60 compared to raw rice (93.69 ± 0.00) and rice analogue without BPDF (86.50 ± 1.88). It was observed that, the whiteness (*L**) value decreased with the increase of BPDF and resulted in dark colored rice analogue. Thiscolour change might be attributed to the composition of the flour and colored pigments in the flour, which in turn depends on the botanical origin of the plant (Aboubakar *et al.*, 2008). Whereas, the *L** decreased with the decrease in the moisture content due to higher temperature generation during the process of extrusion.

The *a** (redness) value ranged from 3.54 ± 0.07 to 5.07 ± 0.33 for rice analogues and the same for raw rice and rice analogue without BPDF were 0.08 ± 0.03 and 1.65 ± 0.26, respectively. The values of *b** (yellowness) for extruded rice analogues ranged from 24.09 ± 0.73 to 28.73 ± 0.58 whereas, the value of raw rice and rice analogue without BPDF were 5.54 ± 0.06 and 10.48 ± 0.67, respectively. The redness (*a**) and yellowness (*b**) increased with increase in BPDF and decreased with increase in moisture. The increased *a** and *b** was due to colored pigments of BPDF based on botanical origin (Aboubakar *et al.*, 2008) and the development of non-enzymatic

Table 3. Proximate composition and colour values of extruded rice analogues

Treatments	Proximate composition and colour values of extruded rice analogues					
	Crude protein (%)	Carbohydrate (%)	Ash(%)	L* value	a* value	b* value
T_R	8.51±0.05	78.05±0.31	0.52±0.02	93.69±0.00	0.08±0.03	5.54±0.06
T_0	8.37±0.32	78.42±0.62	0.50±0.01	86.50±1.88	1.65±0.26	10.48±0.67
T_1	10.84±0.06	74.65±0.24	0.58±0.01	67.51±0.20	4.34±0.09	26.25±0.15
T_2	11.00±0.02	73.97±1.48	0.63±0.01	69.01±0.31	3.74±0.05	25.70±0.57
T_3	11.08±0.04	73.00±0.57	0.65±0.03	72.89±0.60	3.54±0.07	24.09±0.73
T_4	12.38±0.02	72.76±1.27	0.97±0.03	66.17±1.37	4.78±0.32	27.18±0.59
T_5	12.70±0.03	71.72±0.82	0.99±0.02	68.30±0.76	4.62±0.10	25.91±0.22
T_6	12.71±0.02	70.84±0.61	1.01±0.01	70.87±0.79	4.56±0.19	26.30±0.40
T_7	13.02±0.01	70.24±0.31	1.06±0.02	64.58±0.78	5.07±0.33	28.73±0.58
T_8	13.43±0.31	70.04±0.19	1.12±0.00	66.12±1.16	4.95±0.29	27.66±0.54
T_9	13.47±0.07	69.54±0.53	1.18±0.02	69.17±1.28	4.80±0.15	27.22±0.61
C.D.@1%	0.417	2.208	0.066	2.921	0.610	1.527
S.Em.±	0.141	0.748	0.022	0.990	0.207	0.517
CV	2.112	1.775	4.589	2.372	9.349	3.863
Significance	S	S	S	S	S	S

*S- Significant, NS- Non significant

T_R - Raw rice (Control), T_0 - Dhal-0 %, M.C-Avg. of 25, 30 and 35 %, T_1- Dhal-20 %, M.C-25%; T_2- Dhal-20 %, M.C-30 %; T_3- Dhal-20%, M.C-35 %;T_4- Dhal-30 %, M.C-25 %; T_5- Dhal-30 %, M.C-30 % ;T_6- Dhal-30%, M.C-35 %;T_7- Dhal-40 %, M.C-25 %;T_8- Dhal-40 %, M.C-30 %;T_9- Dhal-40 %, M.C-35 %

browning of carbohydrates. The results reported by Khairunnisa *et al.* (2017) for high protein rice analogues by incorporation of soybean flour also showed similar trend.

Pasting properties of extruded rice analogues

The important pasting properties namely peak viscosity and pasting temperature were determined and data on mean values are summarized in Table. 4.

Peak viscosity (PV) is the rapid increase in viscosity when sufficient number of sample granules becomes swollen. All the flours showed a gradual increase in viscosity with increase in the temperature. The peak viscosity ranged from 22350 ± 132.8 (22.35 ± 0.13 Pa-s) to 24678 ±146.2 cP (24.68 ± 0.14 Pa-s) compared to the raw rice (31340 ± 240.9 cP) and rice analogue without BPDF (29752 ± 689.4 cP). The peak viscosity decreased with increase in BPDF and moisture content. Pasting temperature (PT) is another important component of pasting property indicating the minimum temperature required to cook the flour. The PT rangedfrom 79.46 ± 0.18 ºC to 77.29±0.08 ºC as compared to raw rice (76.43 ± 0.17ºC) and rice analogue without BPDF (77.09 ± 0.50 ºC). The PT increased with increase in pigeonpea dhal flour. The changes in the pasting properties could be attributed to the swelling power of pigeonpea containing protein as high protein and starch content in the flours might cause the starch granules to be embedded within a stiff protein matrix which limits the access of the starch to moisture and restricts the swelling (Kaushal *et al.,* 2012).

Table 4. Pasting properties of extruded rice analogues

Treatments	Peak viscosity (cP)	Pasting temperature (°C)
T_R	31340±240.9	76.43±0.17
T_0	29752±689.4	77.09±0.50
T_1	24678±146.2	77.29±0.08
T_2	24444±197.5	77.65±0.26
T_3	24310±292.6	77.79±0.26
T_4	23373±191.6	78.34±0.25
T_5	23173±153.7	78.68±0.34
T_6	23120±100.6	78.94±0.49
T_7	22673±172.4	79.09±0.18
T_8	22623±213.2	79.30±0.19
T_9	22350±132.8	79.46±0.18
C.D.@1%	816.8	0.927
S.Em.±	276.7	0.314
C.V.	1.940	0.696
Significance	S	S

*S- Significant

T_R – Raw rice (Control), T_0 – Dhal-0%, M.C-Avg. of 25, 30 and 35%, T_1- Dhal-20%, M.C-25%; T_2- Dhal-20%, M.C-30%;T_3- Dhal-20%, M.C-35%;T_4- Dhal-30%, M.C-25%; T_5- Dhal-30%, M.C-30% ;T_6- Dhal-30%, M.C-35%;T_7- Dhal-40%, M.C-25%;T_8- Dhal-40%, M.C-30%;T_9- Dhal-40%, M.C-35%.

Optimisation of BPDF and moisture content for production of extruded rice analogues

Numerical optimization was applied to determine the optimal flour composition containing BPDF and moisture content for production of rice analogues. Optimum points established 9 solutions based on the condition that it satisfied the criteria mentioned. The optimum desirability of 0.855 was obtained for flour composition having 30 % BPDF and 30 % moisture content for production of rice analogues as depicted in Fig. 3.

Economics of rice analogues production

The rice analogues can be produced at a cost of Rs. 41.0 per kg by utilising the brokens rice and dhal. The production seems to be costly whereas, increase in the cost can be reducedby adding the nutrients in the rice analogues and mixing with raw rice @ 1:50 ratio. The fortification process involves simple operations and minimum additional investment is needed in particularly rice consuming states as a whole to accomplish fortification to combat the malnutrition. Given the present technology, a set of equipment for blending fortified rice analogues with raw rice could be accomplished easily in any rice mill.

Conclusion

The rice analogues were developed utilising the broken rice and broken pigeonpea dhal flours along with water and binding agent in an extruder. The laboratory model cold extruder could be used to produce rice analogues resembling the rice kernels. The process optimisation was carried out for composite flour containing broken pigeonpea dhal flour (BPDF) and moisture with the broken rice flour as base material.The numerical optimisation resultedcomposite flour containing 30 % BPDF and 30 % moisture contentcould yield higherprotein (12.70 ± 0.03 %) andash (0.99 ± 0.02 %).The colour of the extruded rice analogues was resembling the raw rice without much variations. The peak viscosity and pasting temperatures were 23173 ± 153.7cP(23.17 ± 0.15 Pa-s) and 78.68 ± 0.34 ºC.The rice analogue production technology can be utilized for fortification process involving simple operations and minimum additional investment needed in particularly rice consuming states as a whole to accomplish fortification to combat the malnutrition.

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