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EFFECT OF EXTRUSION PARAMETERS ON PHYSICAL PROPERTIES OF TUR DAL (*PIGEON PEA*) ANALOGUES DEVELOPED FROM TUR DAL BROKENS

G. RAJENDER[1*], CH.V.V. SATYANARAYANA[2], CH. SOMESWARA RAO[3], B. HARI BABU[4] AND B. ANILA KUMARI[5]

[1]Department of Food Process Engineering, College of Food Science and Technology, Rudrur, Telangana State, India
[2]Department of Food Engineering, Dr. NTR College of Food Science and Technology, Bapatla, Andhra Pradesh, India
[3]Department of Food Processing Technology, Dr. NTR College of Food Science and Technology, Bapatla, Andhra Pradesh, India
[4]Department of Farm Machinery and Power Engineering, Dr. NTR College of Agricultural Engineering, Bapatla, Andhra Pradesh, India
[5]Department of Foods and Nutrition, PJTSAU, Rajendranagar, Hyderabad, Telangana State, India

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Abstract–Dehusking and splitting are typically the steps involved in converting pulses into dal. The milling losses in commercial pulse mills can be attributed to the small brokens and fine powders found during scoring and concurrent dehusking and splitting operations. The fracture of dal kernels during the milling process is a problem in the dal milling industry, and customers don't generally like these broken kernels. The only way to turn these unused milling fractions into profitable products is through extrusion cooking. Extrusion cooking of flour of redgram dal brokens with addition of some additives was done to prepare Tur dal analogues at various extrusion process parameters. The effect of barrel temperature (120 – 175 ^{o}C), feed moisture content (18-25%), feed rate (40-60 kg/h) and screw speed (100-220 rpm) on bulk density, expansion ratio and hardness of Tur dal analogues were investigated. To develop the prediction model, a central composite rotable design (CCRD) using response surface method (RSM) was applied. Each variable's impact on the responses was measured via regression equations. The second-order quadratic regression model fit the variation adequately. The significance was established at $p \leq 0.05$. An increase in bulk density and decrease in expansion ratio with increase in feed moisture content and feed rate was observed. The bulk density and hardness increased as the barrel temperature increased when the feed moisture content was lower; conversely, when the feed moisture content was higher, the bulk density and hardness reduced as the barrel temperature increases.

INTRODUCTION

Pulses are basically grain legumes. They have an important role in human nutrition because of their high protein content than cereals. Majority of Indians are vegetarians, depend largely on pulses for their dietary protein. Pulses contribute a major portion of lysine to the vegetarian diet. They are also fairly good source of vitamins namely thiamine, riboflavin, niacin and iron.

Red gram is an important pulse crop in India. It is also called as pigeon pea, *Arhar* and tur. India is the largest producer and also largest consumer of red gram in the world. Red gram contains about 22% protein, which is almost three times that of cereals. It supplies a major share of protein requirement of vegetarian population of the country. In addition, the high-protein legumes are referred to as "poor man's meat" (Iriti and Varoni, 2017).

Generally, pulses are converted into dal form by

([1]Assistant Prof., [2] Prof. and Univ. Head, [4]Associate Prof., [5]Assistant Prof.)

dehusking and splitting. In dal milling, the average yield of common dals varies from 68% to 80% depends on the type of dal mill and dal milling method (Jennifer, 2017). Milling losses in the commercial mills are in the form of brokens, fines and powders occured during scoring, dehusking and splitting operations. These milling losses may vary from 5% to 15% depending upon the type and quality of grain, the processing method and machinery used for milling. In dal milling industry, the issue of concern is the breakage of dal kernels and these broken kernels are not generally accepted by consumers.

Red gram dal brokens and fines are used to make dal analogues using extrusion technology. Versatility, high productivity, cheap operational costs, energy efficiency, and faster cooking periods are benefits of extrusion cooking (Harper, 1981). Extrusion has been used to treat a number of legumes, and good expansion has been documented (Balandran *et al.*, 1998). In addition, and as a result of high temperatures, high pressures, and numerous shear forces reaching inside the barrel, chemical reactions and molecular modifications can happen, such as gelatinization of starch, denaturation of proteins, inactivation of many food enzymes, and a decrease in the number of microbes (Harper, 1981).

In the present study, the under utilized Tur dal brokens were used to develop Tur dal analogues using twin screw extruder and to examine the effect of extrusion conditions (temperature, feed moisture content, screw speed and feed rate) on physical properties of Tur dal analogues.

MATERIALS AND METHODS

Tur dal brokens and fines were procured from local dal mills of Telangana and Andhra Pradesh. These milling fractions were milled in a Hammer Mill to obtain required quantity of flour. A blend of red gram flour with the addition of Calcium chloride-0.2%, Glycerol monostearate -1% and turmeric powder- 0.2% on weight basis was used for the production of Tur dal analogues. The blended samples were conditioned to 18–25% (w.b) moisture by spraying calculated amount of water and mixing continuously in a blender. The samples were packed in HDPE bags/trays and stored at 4°C temperature over night. The feed material was then allowed to stay for 3hr to equilibrate at room temperature prior to extrusion. This preconditioning procedure was employed to ensure uniform mixing and hydration and to minimize variability in the state of feed material. Moisture content of samples was determined by hot air oven method.

Extrusion was performed using a pilot scale co-rotating twin-screw extruder (Make: M/s Best Engineering Technologies Pvt Ltd, Hyderabad, India. Extrusion cooking was done at different barrel temperatures, feed moisture, feed rate and screw speed conditions as per the experimental design. The barrel temperature, screw speed and feed rate were set as per requirement on control panel. The circular die opening of 6 mm size with 20 holes was used to obtain 6 mm size extrudates.

Experiment design and analysis

Response surface methodology (RSM) was used in designing the experiment. Independent process variables such as barrel temperature, feed moisture content, feed rate and screw speed were coded as A, B, C and D respectively. Five levels of each of the four variables were chosen according to a central composite rotatable design (CCRD). The design required 21 experimental runs with eight factorial points, eight star corner (axial) points and five centre points. The coded and actual parameter values are presented in Table 1. The data obtained from the experiment was processed in Design Expert 13.0 software (2020). The observed data was analyzed, employing multiple regression technique. The best fitting model was chosen, based on lack of fit criteria.

Determination of Physical Properties

Bulk Density

The extruded dal analogues were placed in pre-weighed 100 ml graduated measuring cylinder. The graduated cylinder with extruded dal analogues was tapped gently on a flat surface to a constant volume before determining sample weight. The bulk density was calculated using Eq (1). All the measurements were taken in triplicate and the results of bulk density were reported as g/cc (Harper 1981).

$$\text{Bulk density (g/cm}^3) = \frac{\text{Mass of extrudates sample (g)}}{\text{Volume of extrudates sample (cm}^3)} \quad (1)$$

Expansion Ratio

The ratio of diameter of extrudate and the diameter of die was used to express the expansion of extrudate (Fan *et al.*, 1996 and Jin *et al.*, 1994). The ‘diameter of extrudate was determined as the mean of 10 random measurements made with a Vernier caliper. The extrudate expansion ratio was calculated using Eq (2).

$$\text{Expansion ratio} = \frac{\text{Sample diameter}}{\text{Diameter of the extruder die}} \quad .. (2)$$

Hardness

The texture properties of extruded tur dal analogues and composite dal analogue were evaluated before cooking using a Texture Analyzer (CT3 50K Model: Brookfield Engineering Laboratories, USA). The compression probe (TA 10 type, 12.7 mm dia, clear acrylic cylinder probe with 35 mm length) was applied to measure compression force required for samples breakage which indicates hardness. Hardness (N) is the maximum force required to compress the sample. Testing conditions were 1.0 mm/s pre-test speed, 1.0 mm/s test speed, 10.0 mm/s, post-test speed, 0.8 mm distance and trigger load 0.5 N. The triplicate test was performed for both tur dal and composite dal analogues by using the acrylic cylinder probe, in such a manner that a probe moving at a rate of 1.0 mm/s would break it. This procedure was carried out according to the method described by Mariotti *et al*., (2011).

The data from the experiments were analysed using multiple regression and second order polynomial models, fitted to the experimental data with coded values of independent variables, and are interpreted with the aid of models and graphs. The data were obtained from the experiments for various combinations were shown in Table 2. Three-dimensional graphs were created using the tabular data, using two independent factors as constants and illustrating how the other two variables affected the physical attributes of Tur dal analogues like bulk density, expansion ratio, and hardness.

RESULTS AND DISCUSSION

Effect of process parameters on bulk density of extrudates

The Bulk density varied from range of 0.5203 to 0.6761 g/cc. (Table 2). Regression equation representing the variation of bulk density with different independent parameters in terms of coded factor is shown in Eq (3).

Bulk density (g/cc) = $+0.5650+0.0179A+0.0304B + 0.0087C-0.0015D-0.0261AB-0.0054AC -0.0012AD+ 0.0032BC-0.0231BD+0.0110CD+0.0140A^2+0.0212B^2+ 0.0179C^2 +0.0022D^2$ …. (3)

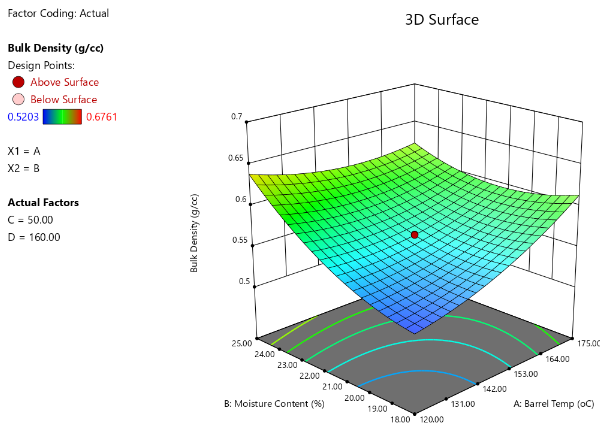
Response surface plots of bulk density of tur dal analogues in relation to the barrel temperature, feed moisture, feed rate and screw speed are presented in Fig. 1. The results showed that the bulk density increased with increase in barrel temperature during extrusion cooking. Due to protein denaturation, high protein containing materials typically tend to get denser as temperature is raised. During extrusion, fiber's non-starch polysaccharides may bind water more firmly than protein or starch. This binding may stop water from evaporating at the die, preventing the formation of pores in the finished product (Camire and King, 1991). However, at higher feed moisture, the barrel temperature has negative impact on bulk density due to evaporation of water from the product when it comes out from the die. Similar results were reported by Sibel *et al.* (2008), in extruded snack foods developed from food-by-products and Mendonca *et al.* (2000), in fiber-added cornmeal extrudates.

The product's bulk density was favourably impacted by the feed moisture. According to Ding *et al.* (2005), increased feed moisture content during extrusion may plasticize the melt and limit expansion, reducing the elasticity of the dough and increasing the density of the extrudate. Similar findings were reported by Chandrahas *et al.* (2022), in their soy protein-enriched extruded snack made from maize, by Shruthi *et al.* (2019), in their report on corn extrudates

The bulk density increased with increase of feed rate and causes plasticity in the product led to denser product output. The similar results were reported by Gamea (2013) in defatted soyabean based high protein snacks. As the screw speed was

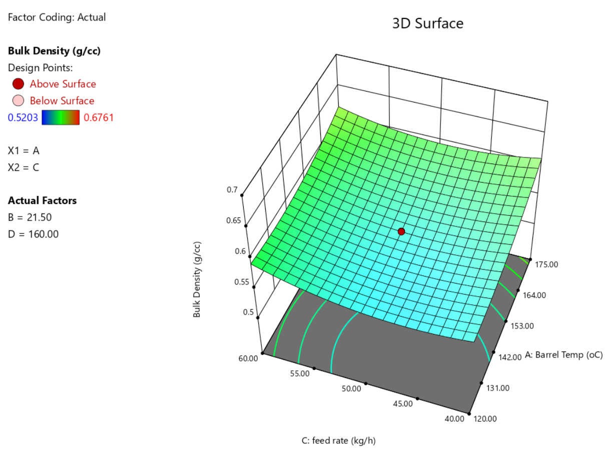
Table 1. Coded and decoded values of extrusion process parameters

Variable	Codes				
	-1.682	-1	0	+1	+1.682
Barrel Temperature(A), °C	101.25	120	147.5	175	193.75
Feed moisture content(B), %	15.6	18	21.5	25	27.4
Feed rate(C), kg/h	33.18	40	50	60	66.82
Screw speed(D), rpm	60	100	160	220	260

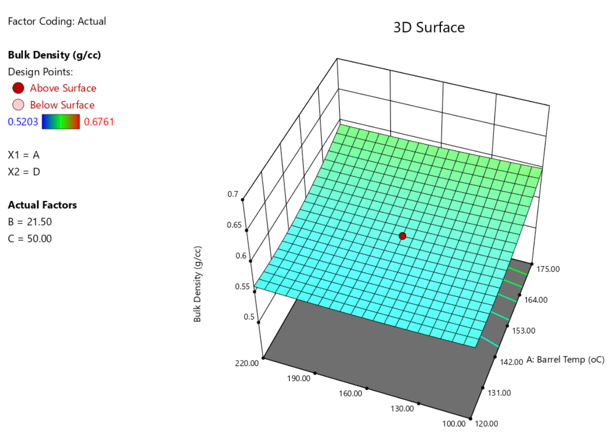


(a)

(a) Effect of feed moisture and barrel temperature on bulk density



(b) Effect of feed rate and barrel temperature on bulk density



(c) Effect of screw speed and barrel temperature on bulk density

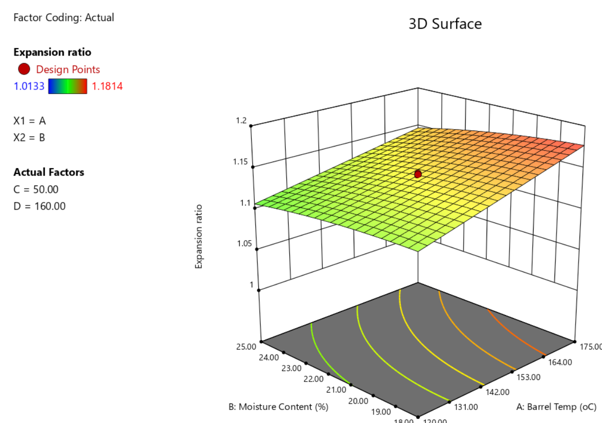
Fig. 1. Effect of Process parameters on bulk density of tur dal analogues

increased, the bulk density slightly reduced. Higher screw speeds have the tendency to reduce the melt viscosity of the mixture, which in turn increases the dough's elasticity and lowers the extrudate density. However, the statistical analysis showed that screw speed had no significant impact on density (P>0.05).

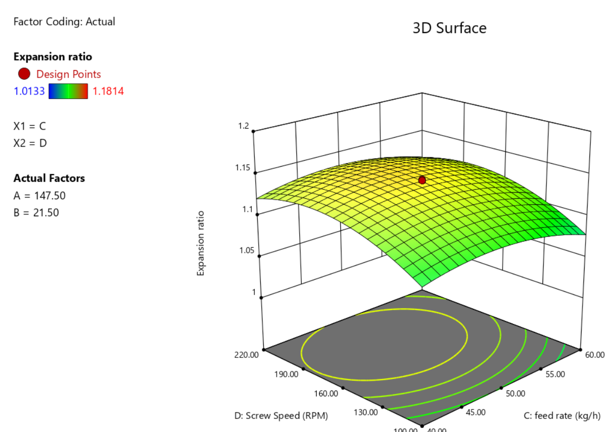
Effect of process parameters on Expansion ratio of extrudates

The expansion ratio values were found to vary in the range of 1.0133 to 1.1814. Regression equation representing the variation of expansion ratio with different independent parameters in terms of coded factor is shown in Eq (4).

Expansion ratio = +1.14+0.0243A-0.0106B-0.0044C+0.0173D-0.0043AB+0.0106AC -0.0245AD -0.0013BC -0.0106BD+0.0014CD+0.0002A^2-0.0041B^2-0.0162C^2-0.0248D^2 ... (4)



(a) Effect of feed moisture and barrel temperature on expansion ratio



(b) Effect of screw speed and feed rate on expansion ratio

Fig. 2. Effect of Process parameters on Expansion ratio of tur dal analogues

Response surface plots of expansion ratio of tur dal analogues in relation to the extruder barrel temperature, feed moisture, feed rate and screw speed are shown in Fig. 2. The results showed that the expansion ratio increased with increase in temperature. As the temperature increases, the starch was more thoroughly cooked and hence more capable of expanding. Additionally, it can be demonstrated that melt viscosity decreased with rising temperature, and that this impact would favor the formation of bubbles during extrusion. These results validated earlier findings on bean extrudates (Balandran *et al.* 1998).

The feed moisture exhibits a negative correlation with the product's expansion ratio. Increased feed moisture lowers feed material temperature, which results in a decreased expansion ratio. High mechanical energy dissipation, micro structural deterioration, and consequent high expansion are caused by the low moisture content and high temperature (Kirby *et al.*, 1988). Similar trends in the extrusion of whole pinto bean meal and Hard-To-Cook Beans (*Phaseolus vulgaris* L.) were observed by Balandran *et al.* (1998) and Martin *et al.*, (1999) respectively.

Increased feed rate has negative impact on expansion ratio of tur dal analogues. This may be attributed to higher feed rate cause less residence time resulting feed material absorbs less mechanical and thermal energy absorption.

The expansion ratio increased as screw speed rises; this could be because the material needs more shear to form better dough, which leads to better expansion. This outcome is consistent with Senol *et al.* (2006) research on the extrusion of gluten-free products using chickpea flour blended with rice flour and with Kothakota *et al.* (2013) report on the extrusion of byproducts made from red grams and chickpeas.

Effect of process parameters on Hardness of extrudates

The hardness values were found to vary in the range of 140.66 N to 433.123N. Regression equation representing the variation of hardness with different independent parameters in terms of coded factor is shown in Eq (5).

$$\text{Hardness (N)} = +218.48+20.86A+20.30B-11.61C+3.13D-44.79AB-20.63AC + 29.58AD + 20.10BC -43.52BD+1.60CD + 16.49A^2+ 23.94B^2+ 20.41C^2-21.76D^2 \quad ..... (5)$$

Response surface plots of hardness of tur dal

Table 2. Average experimental values of bulk density, expansion ratio and hardness tur dal analogues developed at various process conditions

Exp. No.	Barrel Temperature (^{0}C), A	Moisture content (%), B	Feed rate, (kg/h), C	Screw speed, (rpm), D	Bulk density (g/cc)	Expansion ratio	Hardness, N
T1	120	25	60	220	0.6612± 0.006	1.0844±0.033	261.35±9.70
T2	147.5	21.5	50	160	0.5647±0.004	1.1429±0.045	218.52±10.32
T3	147.5	21.5	50	160	0.5650±0.003	1.1440±0.032	220.62±11.82
T4	147.5	21.50	50	160	0.5654±0.004	1.1430±0.042	219.56±12.11
T5	193.75	21.5	50	160	0.6343±0.006	1.1814±0.039	298.75±11.93
T6	147.5	21.5	50	160	0.5658±0.002	1.1420±0.038	216.50±6.32
T7	175	18	60	220	0.6628±0.009	1.1502±0.047	327.20±6.62
T8	175	18	40	220	0.6466±0.016	1.1323±0.044	433.12±8.94
T9	147.5	21.5	33.18	160	0.5932±0.006	1.1019±0.033	289.04±6.14
T10	147.5	21.5	50	260.91	0.5681±0.008	1.0989±0.028	160.75±11.61
T11	147.5	21.5	50	59.09	0.5730±0.007	1.0408±0.019	150.22±7.46
T12	147.5	21.5	50	160	0.5654±0.004	1.1430±0.045	220.61±10.76
T13	120	18	40	100	0.5264±0.006	1.0432±0.021	170.45±5.05
T14	120	25	40	220	0.6104±0.005	1.1139±0.016	204.35±8.62
T15	175	25	60	100	0.6613±0.007	1.1296±0.051	249.79±8.14
T16	101.25	21.5	50	160	0.5740±0.004	1.0996±0.062	228.59±6.02
T17	147.5	27.4	50	160	0.6754±0.010	1.1104±0.035	318.89±10.65
T18	175	25	40	100	0.6761±0.014	1.1221±0.027	281.70±4.18
T19	147.5	15.6	50	160	0.5732±0.011	1.1460±0.047	250.60±5.35
T20	120	18	60	100	0.5203±0.012	1.0133±0.010	140.66±1.63
T21	147.5	21.5	66.82	160	0.6367±0.003	1.0863±0.040	260.53±16.78

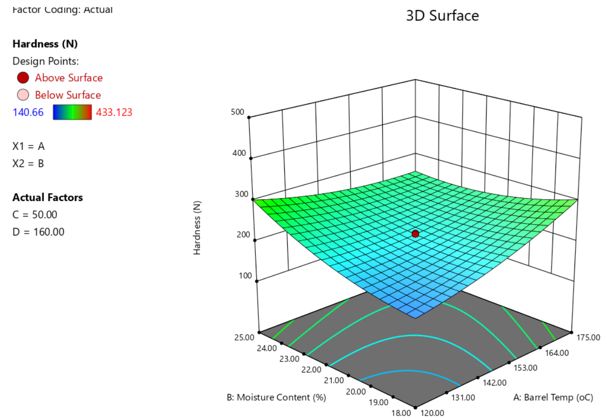
analogues in relation to the barrel temperature, feed moisture, feed rate and screw speed are presented in Fig. 3. The results showed that the hardness increased with the increase in feed moisture content during extrusion (Fig. 3a). It is obvious that at increasing feed moisture levels, plasticization of melt causes a reduction in dough elasticity and an increase in compact or less porous structure. Similar types of findings were also reported by Ding *et al.* (2006) for the production of extended snacks made of wheat and by Seth *et al.* (2015) for an extruded snack made of a yam-corn-rice mixture.

The barrel temperature increased the hardness at lower moisture content due to protein denaturation. The feed material has more crude fibre, which may not allow the vapour bubbles to grow inside the melt and the higher temperature will reduce the melt viscosity resulting produce harder tur dal analogues at higher temperature at lower moisture content. However at higher moisture content, the temperature slightly decreased hardness. This could be because the product is forming more bubbles due to a decrease in melt viscosity and the discharge of superheated steam at high barrel temperatures. Similar results have also been reported by Kothakota *et al*. (2013) in extrusion of chickpea and redgram based byproducts.

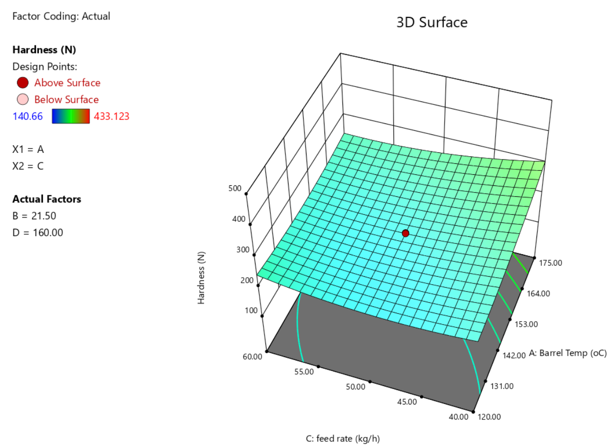
Hardness decreases as the feed rate increases (Fig. 3b) as the material residence time is less and less mechanical and thermal heat absorption takes place. Senol *et al.* (2006) observed comparable results in the extrusion of gluten-free snacks with chickpea flour incorporation in rice flour. Hardness increased with increase in screw speed (Fig. 3c). This may be possibly explained by the fact that the material inside the barrel is exposed to severe mechanical shear at higher screw speeds and lower feed rates, both of which would lead to a more sheared product with a harder texture. However, according to statistical analysis, the screw speed effect was not significant ($p>0.05$).

CONCLUSION

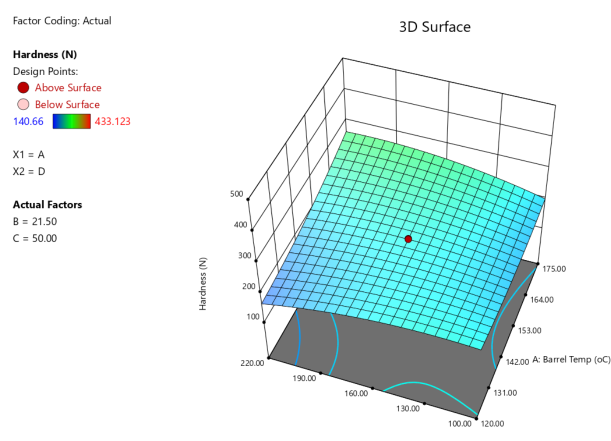
The bulk density varied from 0.5203 to 0.6761 g/cm3. It increased as the feed rate and moisture content increased. When the feed moisture content was lower, the bulk density increased as the barrel temperature increased; when the feed moisture content was higher, the bulk density reduced as the barrel temperature increased. The expansion ratio values were found to vary in the range of 1.0133 to



(a) Effect of feed moisture and barrel temperature on hardness



(b) Effect of feed rate and barrel temperature on hardness



(c) Effect of screw speed and barrel temperature on hardness

Fig. 3. Effect of Process parameters on hardness of tur dal analogues

1.1814. The expansion ratio increased with increase in barrel temperature and screw speed and decreased with increase in feed moisture content and feed rate. The hardness of Tur dal analogues were varied from 140.66 N to 433.123N. Lower feed rate and higher screw speed had a positive effect on hardness, where as feed moisture content had negative effect. When the feed moisture content was lower, the hardness increased as the barrel temperature increased; when the feed moisture content was higher, the hardness reduced as the barrel temperature increased.

REFERENCES

Balandrán, R.R.Q., Barbosa, G.V., Canovas, J.J., Zazueta, M., Anzaldua, A.M. and Quintero, R.A. 1998. Functional and Nutritional Properties of Extruded Whole Pinto Bean Meal (*Phaseolus vulgaris* L.). *Journal of Food Science*. 63(1): 113- 116.

Camire, M.E. and King, C.C. 1991. Protein and fiber supplementation: effects on extrudates cornmeal snack quality. *Journal of Food Science*. 56(3): 760-763.

Chandrahas. S., Shadanan, P.B and Tripathi, A.K. 2022. Effect of extrusion parameters on physical and functional quality of soy protein enriched maize based extruded snack. www.elsevier.com/locate/afres

Ding, Q., Paul, A., Gregory, T. and Hayley, M. 2005. The effect of extrusion conditions on the physicochemical properties and sensory characteristics of rice-based expanded snacks. *Journal of Food Engineering*. 66: 283–289.

Ding, Q., Paul, A., Gregory, T. and Hayley, M. 2006. The effect of extrusion conditions on the functional and physical properties of wheat-based expanded snacks. *Journal of Food Engineering*. 73: 142–148.

Fan, J., Mitchel, J.R. and Blanchard, J.M.V. 1996. The effect of sugars on the extrusion of maize grits: II. Starch conversion. *International Journal of Food Science.* 31:67-76.

Gamea, G.R. 2013. Effect of extrusion conditions on the physical properties of high protein snacks. *Misr J. Ag. Eng.* 30 (2): 425-446.

Harper, J.M. 1981. *Extrusion of Foods*. CRC Press Inc, Boca Raton, p 212

Iriti, M. and Varoni, E.M. 2017. Pulses, healthy, and sustainable food sources for feeding the planet. *International Journal of Molecular Sciences.* 18(2): 1-6.

Jennifer, A. W. 2017. Evaluation of Cooking Time in Pulses: A Review. *Cereal Chemistry*. 94 (1): 32-48.

Jin, Z., Hsieh, F. and Huff, H.E. 1994. Extrusion cooking of corn meal with soy fiber, salt and sugar. *Cereal Chemistry*. 71(3): 227-234.

Kirby, A. R., Ollett, A.L., Parker, R. and Smith, A.C. 1988. An experimental study of screw configuration effects in the twin-screw extrusion-cooking of maize grits." *Journal of Food Engineering.* 8(4): 247-272.

Kothakota, A., Navdeep, J. and Thimmaiah. 2013. A Study on evaluation and characterization of extruded product by using various by-products. *African Journal of Food Science.* 7(12): 485-497.

Mariotti, M., Iametti, S., Cappa, C., Rasmussen, P. and Lucisano, M. 2011. Characterisation of gluten-free pasta through conventional and innovative methods: Evaluation of the uncooked products. *Journal of Cereal Science*. 53 (3): 319–327.

Martin-Cabrejas, M.A., Jaime, L., Karanja, C., Downie, A.J., Parker, M.L., Lopez-Andreu, F.J., Maina, G., Esteban, R.M., Smith, A.C. and Waldron, K.W. 1999. Modifications to physicochemical and nutritional properties of hard-to-cook beans (*Phaseolus vulgaris* L.) by extrusion cooking. *Journal of Agricultural and Food Chemistry*. 47(3): 1174-1182.

Mendonça, Grossmann and Verhe, 2000. Development of extruded foods by utilizing food industry by-products. *Advances in Food Extrusion Technology.* 121-160.

Senol, I., Paul, A., Emir, A.O. and Andrew, P. 2006. Physical and sensory evaluation of a nutritionally balanced gluten-free extruded snack. *Journal of Food Engineering*. 75: 469–472.

Seth, D., Badwaik, L.S. and Ganapathy, V. 2015. Effect of feed composition, moisture content and extrusion temperature on extrudate characteristics of yam-corn-rice based snack food. *Journal of Food Science and Technology.* 52(3): 1830-1838.

Shruthi, V. H., Sharanagouda, H. and Udaykumar, N. 2019. Evaluation of textural properties of corn based extruded products. *Plant Archives*. 19(2): 2405-2410.

Sibel, Y. and Fahrettin, G. 2008. Response surface methodology for evaluation of physical and functional properties of extruded snack foods developed from food-by-products. *Journal of Food Engineering.* 86: 122–132.