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Research Article

Modification of Techno-Functional Properties of Rice by Extrusion

Prabhjeet Kaur*, Hanuman Bobade and Baljeet Singh

Department of Food Science and Technology, Punjab Agricultural University, Ludhiana, India

*Corresponding Author's E-mail: bhullarprabh025@gmail.com

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Abstract

This research aimed at modifying the end-use properties of broken rice flour through extrusion processing for its intended application in beverage preparation. The broken rice grains were processed in a twin screw co-rotating extruder to produce the modified rice flour. The experiments of extrusion were planned according to central composite rotatable design to study the effects of extrusion process variables, feed moisture (14%-18%), extrusion temperature (120°C-160°C) and screw speed (300 rpm-450 rpm) on techno-functional properties, bulk density, water absorption index, water solubility index, wettability, dispersibility and oil absorption index, which are of most significance in beverage processing. Polynomial equations were developed by fitting the data and numerical optimization was done by assigning the specific goals. The results of the study indicated that increased extrusion temperature and screw speed caused a reduction in bulk density and water absorption whereas increased the solubility, wettability and dispersibility of the modified rice flour. Extrusion at higher feed moisture increased the bulk density, water absorption and wettability. The desirable end-use properties of rice flour required for the development of beverage can be achieved by extrusion at 14% feed moisture, 156.76°C extrusion temperature and 450 rpm screw speed as the optimum process variables.

Keywords: Extrusion, Modification, Beverage, Broken rice, Optimization

INTRODUCTION

Rice is one of the most cultivated (164.19 million ha) and produced (756.74 million tonnes) food grains in the world. Rice is the staple food and main source of carbohydrate for many parts of the population across the globe (Bhatnagar, et al., 2014). The brown and white rice are obtained by milling of rough rice or paddy which constitutes husk and bran as outer coverings (Das, et al., 2019). The milling process produces approximately 64% head rice (Giraldo-Gomez, et al., 2019). Besides, husk and bran, paddy milling also produces about 15% broken rice, which is considered a by-product of the rice milling industry (Hagenimana, et al., 2006). The broken rice is primarily used for cattle feed, as a thickening agent, brewing adjunct and in cosmetics and textile industries (Hoan, et al., 2010). Rice beverages (rice milks) have recently gained importance as an alternative to bovine milks and are preferred by consumers with allergy or vegan approaches. Contemporary methods of rice milk production consisted of subjecting head rice to colloidal milling or enzymatic treatment, both of which are techno-economically less efficient (Jinapong, et al., 2008). Alternatively, broken rice and extrusion process could be suitably used for this purpose (Kulkarni et al., 1991). The native properties such as density, solubility and dispersibility of broken rice flour that limit its application in beverage processing could be modified by thermomechanical action of extrusion process performed at specific conditions of moisture, temperature and screw speed of extruder (Kraithong, et al., 2017). The extrusion process variables could be effectively optimized by the response surface methodology (Ma, et al., 2018). The present investigation was, therefore, undertaken to optimize the extrusion process variables for modifying the end-use properties of broken rice flour suitable for its application in beverage processing (Nguyen, et al., 2017).

MATERIALS AND METHODS

Raw material

The clean broken rice (v. PR 121) was ground in Torrento Flour Mill (Tech Electric Enterprise, 50 Ahmedabad, India) to obtain flour and sifted through 60 mesh sieve size which resembles to 250 µ.

Experimental design

The experiments of extrusion were planned according to central composite rotatable design using Design Expert (Statease Inc, Minneapolis, MN, USA). Preliminary trials were performed to select the appropriate levels and range of the extrusion processing variables such as feed moisture (FM, 14-18%), extrusion temperature (ET, 120℃-160℃) and screw speed (SS, 300 rpm-450 rpm) which were varied to five different levels (Table 1). The Bulk Density (BD), Water Absorption Index (WAI), Water Solubility Index (WSI), wettability, dispersibility and Oil Absorption Index (OAI) were selected as response variables since these are the properties of most importance in beverage processing (Ogunsina, et al., 2010).

Table 1. Effect of extrusion processing conditions on the physicochemical and rehydration properties of modified rice flour.

Sr. No.	Feed moisture (%)	Extrusion temperature (°C)	Screw speed (rpm)	Density (kg/m^3)	WAI (g/g)	WSI (%)	Wettabi -lity (s)	Dispersibi -lity (%)	Oil absorption (g/g)	HR	CI
1	14	120	300	415	5.8	50.37	318	84.55	1.72	1.2289	18.63
2	18	120	300	425	6.09	45.91	329	84.15	1.84	1.2118	17.48
3	14	160	300	375	4.44	66.03	150	89.1	1.21	1.2267	18.48
4	18	160	300	395	4.65	63.42	194	87.8	1.32	1.2278	18.56
5	14	120	450	385	4.78	62.07	242	88.1	1.58	1.2338	18.95
6	18	120	450	400	5.26	56.28	280	86.7	1.66	1.225	18.37
7	14	160	450	365	3.76	74.02	39	95.3	0.84	1.2329	18.89
8	18	160	450	380	3.98	71.69	62	93.2	1.03	1.2368	19.15
9	12.64	140	375	385	4.52	65.18	142	88.15	1.38	1.2338	18.95
10	19.36	140	375	405	5.38	54.84	176	86.15	1.62	1.2222	18.18
11	16	106.36	375	425	5.88	48.37	368	85.7	1.93	1.211	17.48
12	16	173.64	375	390	3.86	74.58	90	96.4	0.87	1.2308	18.75
13	16	140	248.87	385	5.54	52.83	295	84	1.69	1.2338	18.95
14	16	140	501.13	355	4.18	69.28	110	90.15	1.28	1.2535	20.22
15	16	140	375	370	5.09	58.31	214	86.4	1.47	1.2432	19.57
16	16	140	375	365	5.05	58.81	205	86.7	1.43	1.2466	19.78
17	16	140	375	375	5.1	58.13	210	86.55	1.52	1.2533	20.21
18	16	140	375	370	5.13	57.84	217	86.8	1.55	1.2568	20.43
19	16	140	375	365	5.01	59.29	222	87	1.45	1.2466	19.78
20	16	140	375	375	5.03	59.06	209	86.9	1.5	1.24	19.35

Extrusion processing

Extrusion of broken rice flour was performed using a co-rotating twin-screw extruder (BC21, Clextral, Firminy, France). The extrudates produced were dried in a convective hot air dryer at 50℃ ± 5℃ (Opalinski, et al., 2012). The dried extrudates were grounded using grinder to obtain the Modified Rice Flour (MRF) and passed through 60 mesh sieve size (Pardhi, et al., 2016).

Techno-functional properties

The techno-functional properties, BD, WAI and WSI, wettability, dispersibility and OAI, HR and CI of MRF were measured by procedures described in the previous studies (Savlak, et al., 2016).

Statistical analysis

Response variables (BD, WAI, WSI, OAI, Wettability, Dispersibility, CI and HR) of MRF was developed in the second-order polynomial equation which were subjected to regression analysis to check the effects of FM, SS and ET. Data was considered based on the F-value and p-value of lack-of-fit obtained by Analysis of Variance (ANOVA). Further, coefficient of determination (R2), adjusted R2, predicted R2, Coefficient of Variation (CV) and adequate precision were determined to test the response surface methodology of independent variables (Suksomboon, et al., 2011).

Optimization

The numerical optimization was performed by assigning the specific goals to the response variables (Schefer, et al., 2021). The process variables were kept in range and response variables BD, WAI and wettability were considered minimized while the WSI, dispersibility and OAI were considered maximized to preparation of rice beverages (Sethi, et al., 2016).

RESULTS AND DISCUSSION

BD

The ingredients with low density are desired in beverage processing as low-density materials have more void spaces and thus provide higher wettability and dispersibility (Sharma et al., 2012). All the extrusion process variables in linear terms and interaction of ET and SS had a significant ($p<0.05$) effect on BD of MRF (Singh et al., 2015). The lowest BD (355 kg/m^3) of the MRF was noticed at 16% FM, 140°C ET, 85 and 375 rpm SS (Table 1). The negative coefficients of regression models of ET and SS and the positive coefficient of FM (Table 2) indicated that the BD of MRF decreased with an increase in ET and SS, however, FM caused an increase in BD. Further, FM and ET with their significant quadratic terms had a curvilinear effect on BD (Figure 1), depicting that BD increased at a higher level of FM and ET. The density of material decreases due to puffing caused by a sharp pressure drop at the die end section of the extruder (Wang et al., 2020). However, as high moisture content inhibits this puffing effect, the BD of MRF increased at higher levels of FM as the higher level of water produced denser extrudates than the low-level moisture. The ET and SS at higher levels cause increased superheating of water and structural breakdown which was responsible for producing an expanded and puffed product with subsequent lower density. Similarly, ET and SS decreases bulk density of extruded rice flour because increase in ET decrease the viscosity of melt which favour the growth of bubbles during extrusion and thus BD is decreased.

Table 2. Coefficient of regression models of dependent variables of modified rice flour.

Actor	Density	WAI	WSI	Wettability	Dispersibility	Oil absorption	Hausner ratio	Carr index
Intercept	369.98	5.07	24.57	212.64	86.72	1.49	1.25	19.86
A-Feed moisture	6.86*	0.19*	-2.39*	12.68*	-0.63*	0.07*	-0.0029	-0.20*
B-Extrusion temperature	-12.36*	-0.62*	7.66*	-87.25*	2.92*	-0.31*	0.0042*	0.28*
C-Screw speed	-9.55*	-0.40*	4.83*	-49.73*	2.05*	-0.12*	0.0049*	0.32*
A × B	1.25	-0.04	0.66*	2.25	-0.2	0.012	0.0039	0.26*
A × C	0.1	0.03	-0.13	0.75	-0.22	0.005	0.0014	0.09
B × C	3.75*	0.06*	-0.73*	-14.75*	0.69*	-0.042*	-0.0036	-0.03
A^2	8.92*	-0.05*	0.56*	-17.79*	0.17	-0.0079	-0.0074*	-0.48*
B^2	13.34*	-0.08*	1.08*	6.96*	1.55*	-0.043*	-0.0099*	-0.64*
C^2	0.09	-0.08*	0.93*	-2.41	0.14	-0.013	-0.018	-0.12
C.V. (%)	1.0446	1.5811	3.1558	5.2028	0.4294	3.4272	0.4039	1.6754
R^2	0.979	0.9927	0.9944	0.9924	0.9935	0.9848	0.9192	0.9223
Adj. R^2	0.9602	0.9861	0.9894	0.9856	0.9877	0.9711	0.8465	0.8524
Pred.R^2	0.9179	0.9515	0.9654	0.9473	0.9576	0.9219	0.7766	0.7871
Adeq. precision	26.1308	44.2197	50.6721	46.3351	46.1915	29.4281	11.2726	11.5779

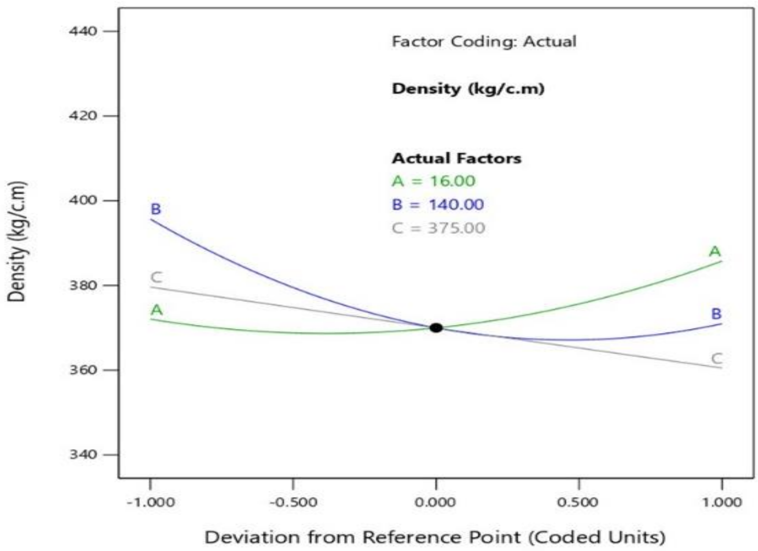

Figure 1. Perturbation graph of bulk density.

WAI

The materials after absorbing water swell causing an increase in volume and thereby viscosity. Therefore, the raw material for beverages is preferred with lower water absorption characteristics. The lowest WAI of MRF was observed at a higher level of ET (160℃) and SS (450 rpm) and a lower level of FM (14%). The FM has a positive coefficient of WAI regression model (Table 2) suggesting that FM aided in increasing the WAI of MRF. This increase could be linked to the plasticizer function of moisture at a higher level which prevents degradation of starch and other polymers and hence promotes more water absorption. Similarly, some studies found that higher FM led to less starch gelatinization during the extrusion process, which increased the ability of starch granules and undamaged polymer chains to absorb water thereby increasing the WAI value. The WAI of MRF significantly ($p<0.05$) reduced with an increase in ET and SS. The interaction term of ET and SS also significantly affected the WAI of MRF (Table 2). ET had a more profound effect in lowering the WAI of MRF compared to SS (Figure 2). The ET and SS foster increased degradation of starch and therefore suppressed the WAI of MRF.

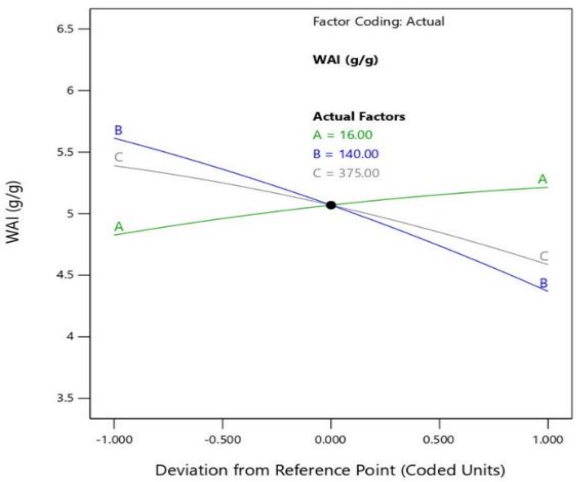

Figure 2. Perturbation graph of Water Absorption Index (WAI).

WSI

Water solubility is one of the desired parameters of materials used in beverage preparation. Solubility of materials prevents phase separation which relatively occurs in suspensions prepared from high molecular weight compounds like starch. MRF with maximum WSI was obtained by extrusion at the highest ET. All extrusion processing variables studied had a significant ($p<0.05$) effect on WSI with FM having a negative coefficient and, ET and SS having positive coefficients of the regression model. The ET and SS increased the WSI of MRF while FM lowered it. Similar to WAI, ET strongly influenced the WSI of MRF compared to SS (Figure 3). This is also reflected in the interactive effect as the interaction of ET with FM and that of SS had a significant effect on the WSI of MRF. The effects of these processing variables were, however, not linear at all the levels as indicated by their respective quadratic terms. The moisture in feed acts as lubricant resulting in reduced friction during extrusion and thus produces a lesser degree of polymer disintegration. Moreover, high moisture during extrusion reduces starch degradation that led to a reduced shear rate and residence duration and a higher material flow rate inside the barrel. These effects attributed to lower WSI of MRF extruded at relatively higher FM. The screw speed is responsible for generating shear and friction and thereby causes fragmentation of feed material at the molecular level. This could result in MRF with higher WSI on increase in SS during extrusion. Similarly, the WSI values rise as the extrusion cooking temperature rises, indicates the development of water-soluble compounds with reduced molecular weights. ET at a higher level accelerates polymer breakdown and starch dextrinization which led to increased WSI of MRF (Figures 3 and 4).

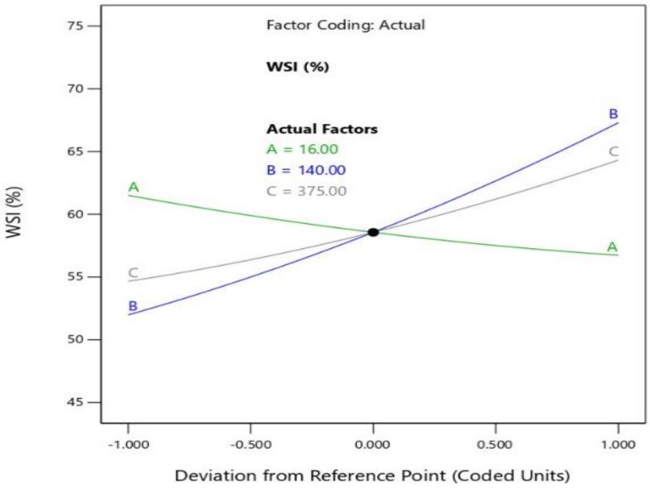

Figure 3. Perturbation graph of Water Solubility Index (WSI).

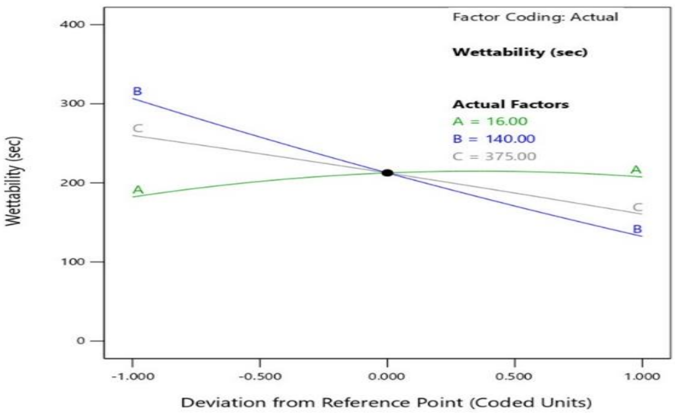

Figure 4. Perturbation graph of dispersibility.

Wettability

Wettability is the amount of wetness that occurs when solid and liquid phases interact. The material used for beverage preparation is desired to have high wettability in a short time. The MRF with less time is considered to have more wettability. The least time of wettability was noticed in MRF extruded at a lower level of FM and a higher level of ET and SS. The wettability of MRF was desirably influenced by ET and SS while it was negatively affected by FM. The undesirable effect of FM on wettability subsided when extrusion was performed at a higher level of ET and SS. The FM at a higher level produced a lesser adverse effect on the wettability of MRF (Figure 5). The changes in wettability of MRF as a function of process variables could be linked to BD as it has been observed that material with high BD hinders water penetration and reduces wettability. Similarly, some studies suggested that wettability of flour increased with increase in particle size and due to significant adhesion forces, tiny particles tended to aggregate on the liquid surface more readily. Therefore, high FM, which resulted in MRF with more BD, decreased the wettability whereas higher levels of ET and SS, which produced MRF with lower BD, increased the wettability of MRF.

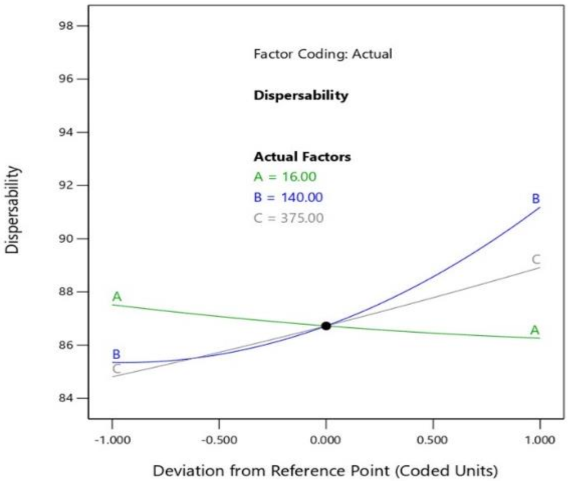

Figure 5. Perturbation graph of dispersibility.

Dispersibility

The food material used for beverage processing is expected to have high dispersibility. The extrusion performed at an intermediate level of FM and SS and extreme ET produced MRF with the highest dispersibility. The ET and SS had a linear positive significant (p<0.05), effect while FM had a negative effect on the dispersibility of MRF. The interaction of ET and SS also had a significant positive effect on dispersibility. Further, ET has shown a significant positive quadratic effect on the dispersibility of MRF. Figure 6 indicated that the effect of ET and SS escalated strongly at higher levels of these process variables and though FM augmented in decreasing the dispersibility, its effect has been feeble at all the levels. The materials with low density, less water absorption and more water solubility have high dispersibility. The increased dispersibility at higher ET and SS could be attributed to low WAI and high WSI of MRF due to the high amount of polymer breakdown while FM resisted these changes and resulted in lowering the dispersibility of MRF (Figure 6).

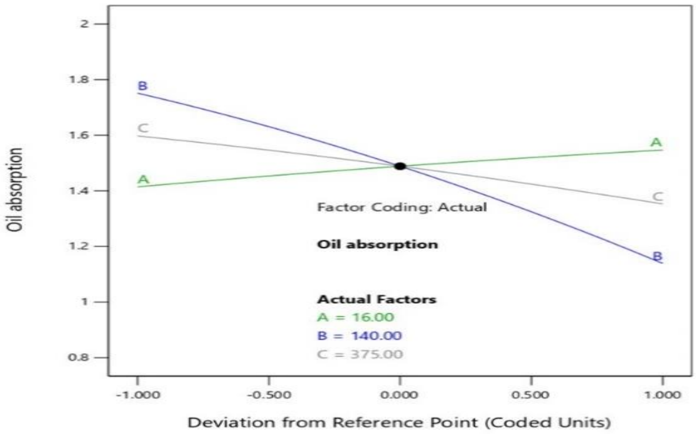

Figure 6. Perturbation graph of Oil Absorption Index (OAI).

OAI

The oil absorption and binding capacity of food material support emulsion formation and 156 impart improved stability. Therefore, the food material used in beverage processing should 157 have a higher OAI. The extrusion process hampered the OAI of MRF. The MRF with highest 158 OAI was obtained at higher level of FM and lower levels of ET and SS. All the 159 process variables in linear terms had a significant (p<0.05) effect on the OAI of MRF. The ET 160 and SS had a significant negative interactive effect on OAI. The quadratic term of ET also significantly and negatively affected the OAI of MRF. The negative coefficients of ET and SS suggested that these variables decreased the OAI whereas the positive coefficient of FM indicated that it enhanced the OAI of MRF, however, this enhancing effect of FM on MRF is relatively weak (Figure 7). Amongst all the process variables, ET had shown a strong and profound effect on OAI. Oil interacts and is absorbed relatively more by macromolecules than low molecular hydrolysis compounds like sugars and dextrin's. The low OAI of MRF produced at harsh extrusion processing conditions (low FM, high ET and SS) could be due to depolymerization and disintegration of large molecular weight compounds leading to the formation of water-soluble substances as observed by Heredia-olea, et al.

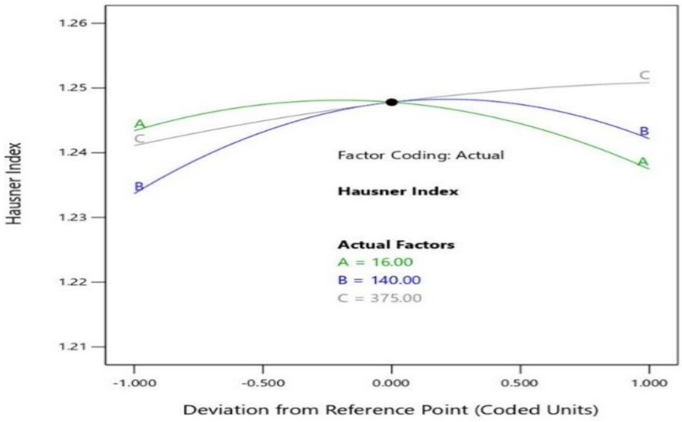

Figure 7. Perturbation graph of Hausner Ratio (HR).

Haunser Ratio (HR)

The highest HR (1.253) of modified rice flour was observed at 140°C extrusion temperature,16 per cent feed moisture and 501.13 rpm screw speed as depicted in Table 1. It is explained in Table 2 that HR of modified rice flour had significant effect on extrusion temperature and screw speed in linear form whereas feed moisture and extrusion temperature in quadratic form. HR of modified rice flour reduced with reduction in feed moisture and maximized with increase in extrusion temperature and screw speed as given in Figure 7. The increase in HR due to compressible nature of obtained product. HR of modified rice flour increased with increase in extrusion temperature and screw speed. This might be due to higher compressibility as has been observed by Nguyen et al., for soya milk powder. Observations of his study indicated that evolution of soya milk powder due to its compressible nature and its HR ranged from 1.2-1.4 after spray drying of fermented soya milk powder.

Carr Index (CI)

The lowest CI (18.18) was recorded at 140°C extrusion temperature, 19.36% feed moisture and 375 rpm screw speed as given in Table 1. From the regression coefficient Table 2, it is displayed that CI of modified rice flour significantly affect the feed moisture, extrusion temperature and screw speed in linear form. Additionally, feed moisture and extrusion temperature in indirective form while feed moisture and extrusion temperature in quadratic form.

CI of modified rice flour reduced with reduction in feed moisture and raised with increase in extrusion temperature and screw speed as shown in Figure 8. The decrease in CI of modified rice flour might be due to poor flowability Opalinski, et al., discovered that the moisture content of sample was responsible for decreasing or increasing mechanical strength of the food powder, whether excellent or poor flowability of the powder (Figure 8).

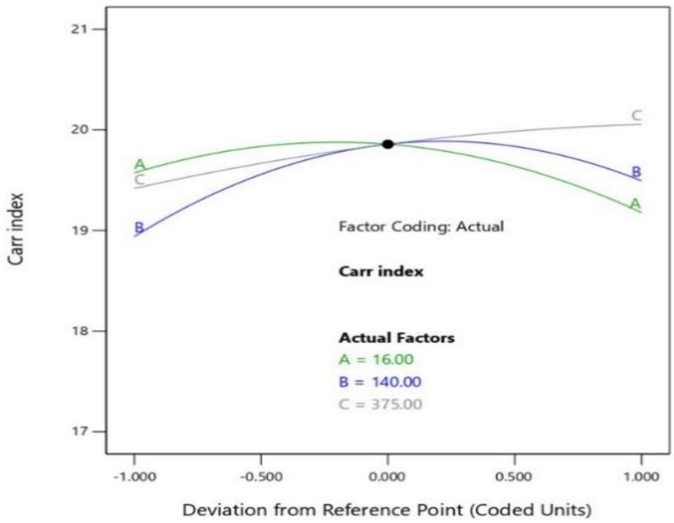

Figure 8. Perturbation graph of Carr Index (CI).

Optimization

The optimum values of process variables obtained consisted of 14% FM, 156.76℃ ET and 450 rpm SS with the desirability value of 0.67. The predicted values of functional properties of MRF at these optimized extrusion processing conditions consisted of 362.92 kg/m^3 BD, 3.83 174 g/g WAI, 73.41% WSI, 46.79 s wettability, 94.13% dispersibility and 0.94 g/g OAI. The coefficient of variation between predicted values and that of actual values of response variables of MRF obtained at optimized extrusion process parameters was less than 5%. The results suggest that extrusion should be performed at lower FM and higher ET and SS to obtain the MRF with desirable techno-functional properties that could be effectively used for the development of rice-based beverages **(Figure 9)**.

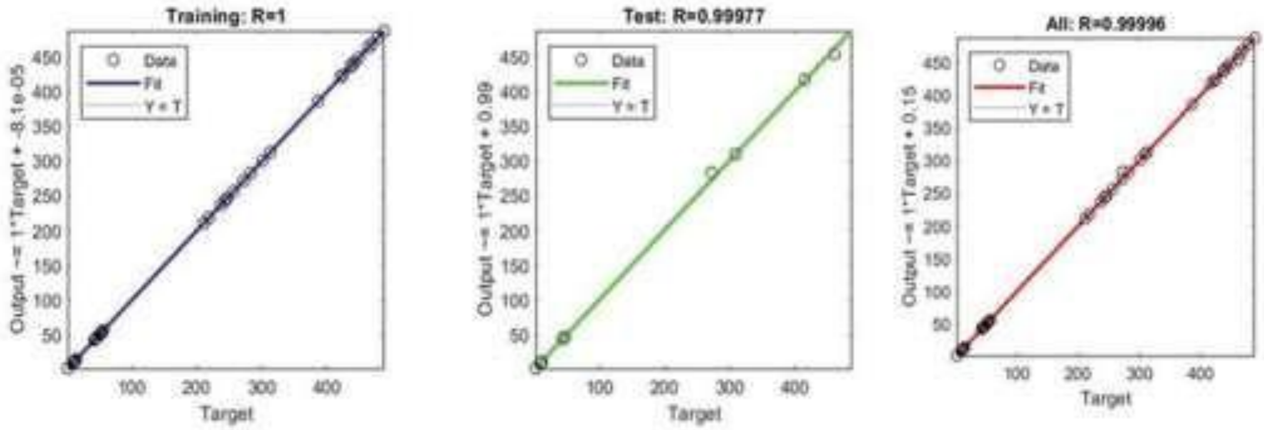

Figure 9. Correlation coefficient for the developed ANN model.

CONCLUSIONS

The higher level of feed moisture in extrusion has produced undesirable changes in the quality characteristics of extruded modified rice flour. The extrusion temperature and screw speed were the most dominant extrusion process variables that caused major changes in the technical and functional attributes of broken rice flour. The extrusion process resulted in significant modification of broken rice flour properties. The extrusion process variables are, however, required to be meticulously optimized to achieve desired properties in the extruded material. The broken rice flour modified with extrusion processing possesses desirable end-use properties that can be effectively utilized in the development of rice flour-based beverages.

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