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ORIGINAL ARTICLE

Modeling of coconut milk residue incorporated rice-corn extrudates properties using multiple linear regression and artificial neural network

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Abstract

The effect of extrusion screw speed (200, 250, and 300 rpm), barrel temperature (100, 120, and 140 °C), and formulation (Coconut milk residue [CMR] 10–20%, corn flour 20–30% and rice flour 60%) on product characteristics like expansion ratio, bulk density, water solubility and water absorption index, compression force, and cutting strength were investigated using multiple linear regression (MLR) and artificial neural network (ANN). The coefficient of determination (R^2) of MLR ranged between 0.34 and 0.84, and the sum of squared error (SSE) ranged between 0.0009 and 292.51. Whereas, the R^2 of ANN ranged between 0.41 and 0.94, and SSE ranged between 0.0001 and 214.81. This indicates its superior performance over MLR in the present study. The extrusion condition of 15% CMR, 25% corn flour, and 60% rice flour, at 220 rpm screw speed, and 140 °C barrel temperature were determined as optimum conditions for development of coconut milk residue incorporated rice-corn based extrudates with a desirability value of 0.95 using MLR with optimum responses of expansion ratio 3.19, bulk density 0.08 g/cm^3, water absorption index 5.69 ml/g, compression force 20.80 N, and cutting strength 10.81 N.

Practical applications

Coconut milk residue, which is rich in dietary fiber and polyphenols, is the main underutilized co-product of virgin coconut oil, coconut milk powder, coconut milk yogurt, and flavored coconut milk processing industries. It can be incorporated into the rice-corn mixture to produce a healthy snack food by extrusion. Hence, this study was focused on optimizing the extrusion conditions and flour ratio using multiple linear regression and artificial neural network to obtain a desirable extruded product. The promising results suggest that CMR can be incorporated with rice and corn to produce extrudates with improved nutrition.

1 | INTRODUCTION

Extrusion technology is the most economical and adaptable method to formulate new cereal-based snacks in a variety of textures and shapes (Kowalski, Medina-Meza, Thapa, Murphy, & Ganjyal, 2016). The desirable ingredients (raw materials) are mixed in an established proportion and passed through the extruder where the ingredients undergo high shear, friction, drag, and compression forces. The action of these forces produces viscous dough due to the presence of moistened starchy and fibrous components in the ingredients, which is passed through the die at high pressure (Lazou & Krokida, 2010). Examples of extruded foods include ready-to-eat snacks, textured vegetable protein, dry pet foods, and pasta etc. (Rajesh, Thirupathi, Eyarkai Nambi, & Pandiselvam, 2014).

Altering the extrusion process conditions such as barrel temperature, feed rate, ingredient composition, screw rotating direction, speed, and die shape will directly have impact on thermal energy of extruder (Godavarti & Karwe, 1997). Suitability of the extruded product depends on their physical properties—bulk density and expansion ratio; functional properties—water absorption index (WAI) and water solubility index (WSI), oil absorption index (OAI); and textural properties—hardness, compression force, and cutting strength (Hernandez-Diaz, Quintero-Ramos, Barnard, & Balandran-Quintana, 2007).

Generally, extruded products are developed from rice, wheat, and corn flours. They tend to be low in essential amino acid contents with a meager biological value (Prinyawiwatkul, McWatters, Beuchat, Phillips, & Uebersak, 1996). In any case, the base ingredient has to be any starch rich material which gets gelatinized during extrusion cooking. The starch sources play a vital role in extrudate quality like expansion ratio and hardness. The extrudates from rice starches containing 20% and 32% amylose exhibited the highest expansion ratio, while, extrudates from corn starch containing 55% amylose exhibited the lowest expansion ratio (Vanier et al., 2016). But corn flour is gluten free and contains abundance of antioxidants, protein, fiber, and resistant starch. Incorporation of dietary fiber and polyphenols into the ingredients formulation enhances the nutritional value of the extruded snacks; fiber incorporation through different sources in extruded snacks has been done in the past (Soy Fiber by Jin, Hsieh, & Huff, 1995; Corn Fiber by Mendonca, Grossmann, & Verhé, 2000 and Pai, Blake, Hamaker, & Campanella, 2009; Wheat Fiber by Onwulata, Konstance, Smith, & Holsinger, 2001 and Yanniotis, Petraki, & Soumpasi, 2007; Yam Fiber by Seth, Badwaik, & Ganapathy, 2015; and Quinoa by Kowalski et al., 2016). But till-date, incorporation of coconut milk residue in the development of extrudates is not reported, even though they have several health benefits.

Coconut milk residue (CMR) is a byproduct in coconut processing industries obtained after processing of virgin coconut oil, coconut milk powder, coconut milk yogurt, and flavored coconut milk. The crude fiber and total dietary fiber present in CMR flour are 25.51% and 46.50%, respectively (Manikantan, Ambrose, & Alavi, 2015). Besides a rich source of dietary fiber and polyphenols, CMR has remained an underutilized byproduct so far and is either used as animal feed or thrown as waste (Manikantan, Arivalagan, Mathew, & Hebbar, 2015; Trinidad et al., 2003). Incorporation of coconut milk fiber enhances the physiological and nutritional value of food (Raghavendra et al., 2006). It has been reported that food products with high fiber coconut flour have potential to lower the serum cholesterol and increased fecal bulk (Gunathilake, Yalegama, & Kumara, 2009). Further, CMR has numerous healing benefits like anti colon cancer, anti diabetic and is good for cardiac disease patients (Trinidad et al., 2003). Hence, there is a huge potential to utilize the CMR for the development of ready-to-eat food products. Therefore, the present study with following objectives was conducted.

1. To investigate the effect of composition and different extrusion conditions (screw speed and barrel temperature) on some selected physical, functional, and textural properties of the extrudates for optimizing the processing conditions for development of desirable extrudates.
2. Development and evaluation of prediction models using multiple linear regression and artificial neural network to predict the extrudate properties.

2 | MATERIALS AND METHODS

2.1 | Raw materials

Coconut milk residue (CMR) was procured from Indian Council of Agricultural Research (ICAR)-Central Plantation Crops Research Institute (CPCRI), Kasaragod as a byproduct after processing of virgin coconut oil. CMR flour used in the study had crude fiber (25.51%) and dietary fiber (46.50%), respectively (Manikantan, Ambrose, & Alavi, 2015). The rice flour and corn flour of commercial brand were purchased from Shipyard Supermarket, Cochin, Kerala.

2.2 | Blending of flours

The right levels of CMR that produces extrudate with high expansion ratio and low bulk density were investigated during preliminary evaluation. The extrudates obtained with CMR proportion > 20% and moisture content >16% (dry basis) were unsuitable because they had less expansion ratio and high bulk density. Similarly, burning or charring of extrudates was observed for the formulation with less than 16% dry basis moisture. Sadik (2015) also reported that 16% (dry basis) feed moisture would produce an acceptable snack product from chick pea. Therefore, the CMR level was fixed between 10% and 20% with three levels of variation, 10%, 15%, and 20%. And, the experiments were undertaken at 16% dry basis moisture level.

The raw materials (CMR, corn flour, and rice flour) were sieved through a 40 mesh screen (425 μm pore size). The ratios of CMR, corn flour, and rice flour were 10:30:60, 15:25:60, and 20:20:60. A laboratory ribbon blender mixer (Basic Technology Pvt., Ltd., India) was used to homogeneously mix the raw materials. The required amount of moisture to be added onto the flour blend to achieve 16% (dry basis) moisture content was calculated based on the initial moisture content of the blend (6–8%) (AOAC, 2005).

2.3 | Extruder and processing conditions

A co-rotating twin screw extruder (Basic Technology Private, Ltd., Kolkata, India) was used to extrude the prepared homogenous CMR, corn, and rice mixture. The L/D ratio of extrusion screws and die diameter was 16:1 and 3 mm, respectively.

From the observations of preliminary study, expansion ratio decreased at higher temperatures (>140 °C) which was due to the weakening of internal structure and increased dextrinization of corn fiber based expanded snacks (Mendonca et al., 2000). Increasing the screw speed (>300 rpm) resulted in neither cohesive nor gelatinized product, consequently, resulting in lower expansion ratio (Della Valle, Tayeb, & Melcion, 1987). The extrudates require an optimum amount of shear to expand its full capacity. If the shear is less than optimum (200 rpm), the cells will not be formed properly. Thereby, in this study extrusion temperature ranging between 100 and 140 °C with three variation levels, 100, 120, and 140 °C and screw speed ranging between 200 and 300 rpm with three variation levels, 200, 250, and 300 rpm were used.

After 5 min of initial run, the extrudates were collected and dried in a coating machine (M/s Pharma Fab Industries, Mumbai, India) at 120 °C for 15 min. Metallized polyester and polyethylene laminated bags (50 μm thickness) were used to store the extrudates until used for further analysis.

2.4 | Proximate composition

The proximate composition of CMR and optimized level of blended flour before and after extrusion was determined by the standard methods of the AOAC (2005)—moisture (AOAC, 934.01), crude protein (AOAC, 2001.11), fat (AOAC, 920.58), and ash (AOAC, 938.08). The carbohydrate content of CMR and blended flour (before and after extrusion) was determined by Anthrone method (Osborne & Voogt, 1986).

2.5 | Scanning electron micrographs

The effect of CMR addition on the internal structure of the extrudate was examined through scanning electron microscopy. The internal structures of extrudates obtained from the optimized level of composition and control samples (60% rice flour +40% corn flour) were compared. Internal structure of the extrudates was observed in a scanning electron microscope (SEM). Extrudates were frozen in liquid nitrogen and fractured before the SEM observation. Cross-sections of the samples were coated with silver colloidal paste and sputter-coated using V Sputter coater. Samples were mounted on SEM studs (Manufacturer-FEI, Czech republic; Model-Quanta 250; Detector-Everhart thornley detector; Electron source-Tungsten) operated at 60 Pa pressure, 10 kV, and 75 X magnifications to observe the differences in cell size and shape among the extrudates.

2.6 | Effect of extrusion conditions on extrudate properties

2.6.1 | Expansion ratio

A digital vernier caliper (Mitutoyo Inc, Tokyo, Japan) was used to measure the diameter of the cylindrical extrudates. The expansion ratio (ER) was determined as the ratio of the mean diameter of the dried extrudates to the die diameter (3 mm) (Onwulata et al., 2001),

$$\mathrm{ER} = \frac{\text{Mean diameter of extrudates (mm)}}{\text{Die diameter (mm)}} \tag{1}$$

2.6.2 | Bulk density

The bulk density (BD) of coconut milk residue incorporated rice-corn extrudates was measured following the method of Pardhi, Singh, Nayik, and Dar (2016).

2.6.3 | Water absorption index

The water absorption index (WAI) was measured using the method described by Anderson, Conway, and Peplinski (1970) for corn grits with minor modifications. Few pieces of extrudates weighing about 0.5 g were mixed with 15 ml distilled water and mixed on a vortex mixer (Riviera Glass Pvt., Ltd., Mumbai, India) for 2 min. The mixture was left to stand for 30 min, and centrifuged (M/s Hermle Labortechnik GmbH, Germany) at 5,000 *g* for 30 min. The supernatant liquor was poured carefully into a tared evaporating dish. The remaining gel was weighed and the WAI was calculated from its weight.

2.6.4 | Water solubility index

Water solubility index (WSI) is the ability of the polysaccharides release from the granule on the addition of excess of water (Anderson, 1969). Higher value of WSI is good for digestion. It was calculated as the ratio of weight of dry solids recovered by evaporating the supernatant from the WAI test to the weight of initial sample (0.5 g) and is expressed as percentage.

2.6.5 | Texture analysis

The hardness of the extrudate was measured based on compression force (CF) and cutting strength (CS) using a TA Plus Texture Analyzer (Lloyd Instruments, UK; Range: 0–500 N; Accuracy: 0.1 N), equipped with a 50 kg load cell along with a compression probe and V-cutting edge. For compression test, a 15 mm length extrudate was compressed to 50% of its original diameter at 2 mm/s. This generated a force vs distance curve in which the compression force was identified as a peak and expressed as Newton (N).

The extrudate piece of about 30 mm length was placed on a Texture Analyzer and a V-cut probe was used to cut the extrudate samples. A calibrated load cell of 50 N was used at a speed of 2 mm/s. The cutting strength was identified as the peak cutting force and recorded in N. Extrudates were replicated at 10 times and average value was reported.

2.7 | Experimental design

The effect of the different levels of CMR and corn flour on the physical, functional, and textural properties was studied. An experimental design was developed using response surface methodology (RSM), which used a combined mixture process design with mixture component (corn flour and CMR) and process factors (screw speed and barrel temperature).

The independent variables—corn flour (X_1, %), CMR (X_2, %), screw speed (Z_1, rpm), and temperature (Z_2, °C) were selected at three levels based on values obtained in preliminary experiments. These independent variables were fitted to the mixture-process design and the goodness of fit was determined. This comprised of 23 extruder runs as shown in Table 1.

A mixture-process design for dependent variables shown in Equation (2) was followed:

$$\begin{aligned} Y = {} & \beta_1 X_1 + \beta_2 X_2 + \beta_{11} X_1 Z_1 + \beta_{12} X_1 Z_2 + \beta_{21} X_2 Z_1 + \beta_{22} X_2 Z_2 \\ & + \beta_{112} X_1 Z_1 Z_2 + \beta_{212} X_2 Z_1 Z_2 + \beta_{111} X_1 Z_1^2 \\ & + \beta_{122} X_1 Z_2^2 + \beta_{211} X_2 Z_1^2 + \beta_{222} X_2 Z_2^2 \end{aligned} \tag{2}$$

where, Y is the predicted response, β_1 and β_2 are linear coefficients, β_{12}, β_{21}, β_{22}, β_{112}, and β_{212} represent interaction coefficients, β_{111}, β_{122}, β_{211}, and β_{222} are the quadratic coefficients and X_1 and X_2 are the coded values of the mixture variables and Z_1 and Z_2 are the process parameters. In the current study, β_1 and β_2 are the coefficients of corn flour and CMR level. The responses studied were ER, BD, WAI, WSI, CF and CS. The ANOVA were carried out using Design Expert 7.1 (State-Ease, Inc., Minneapolis) to determine the significance at 0.01%, 0.1%, 1%, and 5% for the linear, interaction, and quadratic effects of the independent variables and goodness of fit. The regression coefficients evaluated for the actual values are presented in Table 2.

The most commonly used quality parameters for extruded products are ER and BD. Extruded foods with high ER and low BD are desirable for the consumers (Luyten, Plijter, & Van Vliet, 2004). In addition to these properties, low CF and CS are also desirable for an extruded product. Keeping these characteristics as primary importance, the optimization of the extrusion conditions were carried out and reported.

TABLE 1 Mixture-process experimental design and properties of extrudates

	Independent variables					Dependent variables					
Run	Rice flour (%)	Corn flour (%)	CMR (%)	Screw speed (rpm)	Extrusion temperature (°C)	Expansion ratio	Bulk density (g/cm^3)	WAI (ml/g)	WSI (%)	Compression force (N)	Cutting strength (N)
1	60	30	10	300	140	3.57	0.0630	4.32	29.92	16.68	10.65
2	60	20	20	300	140	2.93	0.0826	5.67	22.20	21.69	13.31
3	60	30	10	200	140	3.58	0.0688	4.38	22.24	14.25	10.13
4	60	27.5	12.5	200	120	3.17	0.0864	4.66	28.34	20.71	15.61
5	60	25	15	300	140	3.21	0.0810	5.47	27.80	21.04	11.20
6	60	25	15	300	100	3.13	0.0820	3.90	24.20	22.80	19.73
7	60	25	15	200	140	3.22	0.0851	5.70	21.94	19.86	12.73
8	60	22.5	17.5	250	140	2.90	0.0900	6.14	27.30	26.94	13.94
9	60	22.5	17.5	300	120	2.87	0.0993	5.38	25.24	24.01	18.06
10	60	27.5	12.5	275	110	3.30	0.0885	4.86	31.80	22.77	11.01
11	60	25	15	250	120	3.08	0.0933	5.21	25.40	19.94	15.94
12	60	20	20	300	100	2.83	0.0902	5.00	21.42	27.21	18.90
13	60	30	10	300	100	3.55	0.0796	3.60	25.04	22.98	21.36
14	60	20	20	200	100	2.87	0.1195	5.65	17.92	27.27	23.83
15	60	25	15	200	100	3.11	0.1148	4.70	22.20	23.69	23.41
16	60	20	20	200	120	2.79	0.1186	5.60	25.04	20.92	22.36
17	60	20	20	250	100	3.03	0.0958	5.27	24.94	27.56	12.96
18	60	25	15	250	100	3.20	0.0888	4.61	29.70	26.71	11.30
19	60	30	10	300	120	3.28	0.0857	4.10	28.44	26.43	12.90
20	60	30	10	200	100	3.53	0.0956	3.92	23.46	18.51	21.16
21	60	30	10	250	100	3.35	0.0830	3.79	32.62	24.38	11.25
22	60	20	20	200	140	2.96	0.0980	7.95	20.54	22.34	13.88
23	60	30	10	250	140	3.32	0.0739	4.59	33.34	20.44	12.44

CMR = Coconut milk residue; WAI = Water absorption index; WSI = Water solubility index.

TABLE 2 Coefficients of regression equation for the physical, functional, and textural properties of extrudates

Source	Expansion ratio	Bulk density (g/cm^3)	Water absorption index (ml/g)	Water solubility index (%)	Compression force (N)	Cutting strength (N)
Intercept	1.25***	3.98×10^{-3}***	18.90****	304.52**	217.75*	323.90
X_1	0.57***	3.91×10^{-4}****	−25.80****	−3.26***	−12.82**	11.14
X_2	−0.38***	4.10×10^{-3}****	32.79****	−4.78***	21.01**	−9.54
X_1Z_1	-1.94×10^{-3}	2.45×10^{-5}	−0.0637***	0.04	0.02	−0.02
X_1Z_2	-3.99×10^{-3}	-2.05×10^{-5}**	5.87×10^{-3}***	−0.02	0.17*	−0.15*
X_2Z_1	2.90×10^{-3}	-1.19×10^{-4}**	8.88×10^{-4}	-9.51×10^{-3}	-9.51×10^{-3}	−0.04
X_2Z_2	1.33×10^{-3}	2.65×10^{-4}*	0.51*	0.10	−0.32	0.26
$X_1Z_1Z_2$	-8.15×10^{-7}	7.41×10^{-8}	-2.11×10^{-3}	8.92×10^{-5}	-1.11×10^{-5}	-1.96×10^{-5}
$X_2Z_1Z_2$	8.96×10^{-7}	1.68×10^{-7}	3.08×10^{-3}	-1.05×10^{-4}	1.84×10^{-5}	7.41×10^{-5}
$X_1Z_1^2$	4.09×10^{-6}*	-6.30×10^{-8}	5.05×10^{-4}	-1.03×10^{-4}**	-4.03×10^{-5}	3.93×10^{-5}
$X_1Z_2^2$	1.75×10^{-5}*	-5.20×10^{-8}	2.69×10^{-3}	-1.90×10^{-6}	-7.33×10^{-4}	6.10×10^{-4}
$X_2Z_1^2$	-6.07×10^{-6}	1.73×10^{-7}	-6.06×10^{-4}	4.30×10^{-5}	1.04×10^{-5}*	5.29×10^{-5}
$X_2Z_2^2$	-6.40×10^{-6}	-1.27×10^{-6}	-5.54×10^{-3}	-3.29×10^{-4}	1.30×10^{-3}	-1.15×10^{-3}
R^2	0.93	0.91	0.94	0.84	0.79	0.72
Adjusted R^2	0.86	0.82	0.88	0.67	0.58	0.45
Predicted R^2	0.68	0.51	0.67	0.31	0.03	0.01
SSE	0.43	2.14	6.57	252.59	267.10	639.80

The asterisks near the coefficient value indicates significance at ****($P < .0001$), ***($P < .001$), **($P < .01$), *($P < .05$).
X_1 = Corn flour (%); X_2 = Coconut milk residue (%); Z_1 = Screw speed (rpm); Z_2 = Extrusion temperature (°C); R^2 = coefficient of determination; SSE = sum of squared error.

2.8 | Model fitting

2.8.1 | Multiple linear regression

The significant variables that influences the response variables (ER, BD, WAI, WSI, CF, and CS) were selected from the RSM output (Table 2) and used for developing multiple linear regression (MLR) equations using MATLAB's "*fitlm*" function. The model performances evaluated were coefficient of determination (R^2), and sum of squared error (SSE).

2.8.2 | Artificial neural network

A feed forward single layer artificial neural network (ANN) was developed to train a model for predicting the physical, functional, and textural properties of extrudates. Individual ANN models were developed for each property (ER, BD, WAI, WSI, CF, and CS). The network architecture of the developed ANN model consisted of four neurons in input layer—corn flour, CMR, screw speed, and barrel temperature; three neurons in hidden layer; and one neuron in output layer. The scheme of the developed ANN model is shown in Figure 1. The decision of choosing three neurons in the hidden layer is based on the thumb rule reported by Heaton (2008). The data from 23 extruder runs was replicated thrice and the entire data set of 69 entries were used for developing ANN model as carried out by Shankar and Bandyopadhyay (2007). The whole data set (69 data) was split into three portions—80% for training (55 data), 10% for validation (7 data), and 10% for testing (7 data). A user-coded MATLAB (Ver. R2016a, Mathworks, Massachusetts) program was written to automatically run and validate the ANN model.

An ANN algorithm in general runs several iterations by fixing random weights at the initial point. This random weight at each run results in different performance measures when the model is run again. To resolve this, the initial random weight was fixed by setting the seed for random number generation using *rng* function in MATLAB. In this study, the seed was set to "2017." Thus, for training the network model, the input variables (corn flour, CMR, screw speed, and barrel temperature) are passed through three hidden neurons, then the algorithm runs several iterations, and the ANN models predicts the best performing weights and bias values and optimize the model. The model performances such as R^2, SSE were calculated to evaluate the suitability of each model.

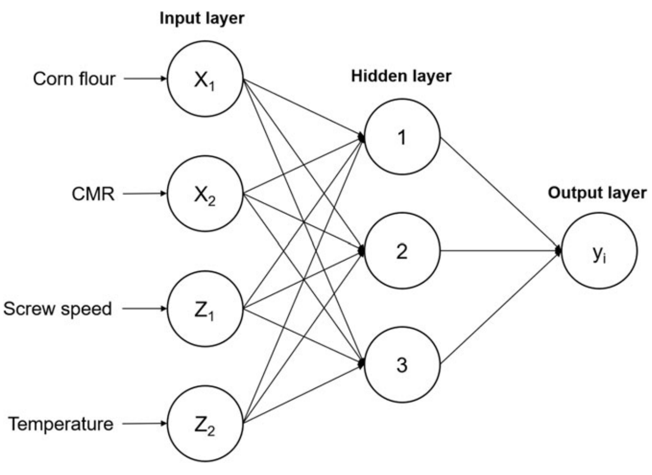

FIGURE 1 The scheme of artificial neural network with four input neurons, three hidden neurons, and one output neuron

3 | RESULTS AND DISCUSSION

3.1 | Proximate analysis

Proximate analysis results of CMR and mixed flour before and after extrusion are presented in Table 3. The moisture content of CMR was 6.52 ± 0.04%, carbohydrate content was 23.46 ± 0.16, protein content was 4.80 ± 0.08%, fat content was 43.19 ± 0.19%, and ash was 0.96 ± 0.02%.

The protein concentration was higher owing to decreased moisture content of mixed flour after extrusion. This increase in protein content from 5.03% to 7.85% might be due to the lower degree of denaturation of proteins by which minimal changes in secondary and tertiary structures of amino acids. Gui, Gil, and Ryu (2012) also observed similar result. The fat content of mixed flour after extrusion (5.95%) was lower than flour before extrusion (7.55%), which may be due to lipid degradation and formation of different types of amylose–lipid complexes due to high temperature as explained by De Pilli et al. (2008). The ash content of the mixed flour before extrusion was less (0.74%) than after extrusion (1.93%). The increase in ash content may be due to the fact that some biological macromolecules were accumulated during extrusion and increase of dry matter yields (Yagoub & Abdalla, 2007).

3.2 | Scanning electron microscopic investigation

The internal structure of the control extrudate and CMR enriched extrudates are shown in Figure 2. The extrudates containing 15% CMR (Figure 2b) resulted in a dense networks forming more compact texture. The numbers of cells per unit area were more, and the cell size was apparently smaller compared to extrudates from corn and rice flour (Figure 2a). Also, the cell size in the center of the extrudates (15% CMR, 25% corn flour, and 60% rice flour) was larger than that of edges (Figure 2b). Yagoub and Abdalla (2007) also observed similar effect on extruded products with wheat bran fiber. It is evident from micro graphs that incorporation of CMR resulted in premature rupture of cells which lead to thick cell wall (Moore, Sanei, Hecke, & Bouvier, 1990).

3.3 | Extrudate properties

3.3.1 | Expansion ratio

The values obtained for expansion ratio (ER) of extrudate samples are shown in Table 1. The ER ranged from 2.79 to 3.58. The highest value of ER was observed at a barrel temperature and screw speed combination of 140 °C, and 200 rpm, respectively, whereas the lowest value was found at 120 °C, and 200 rpm, respectively. These values are high compared to many other fiber based extrudates, such as 1.19 to 1.67 for quinoa based extrudates (Kowalski et al., 2016). The highest value of recorded ER (3.58) was low compared to the ER of 4 in case of commercial corn starch (Chinnaswamy & Hanna, 1988). The lower expansion may be attributed to higher fat and fiber content in

TABLE 3 Proximate analysis of CMR and mixed flour composition

Material	Moisture (%)	Carbohydrate (%)	Protein (%)	Fat (%)	Ash (%)
CMR	6.52 (0.04)	23.46 (0.16)	4.80 (0.08)	43.192 (0.19)	0.960 (0.02)
Flour before extrusion	14 (0.14)	71.92 (1.13)	5.03 (0.06)	7.550 (0.08)	0.744 (0.04)
Flour after extrusion	3.31 (0.06)	76.31 (1.22)	7.85 (0.14)	5.951 (0.11)	1.927 (0.05)

Values in parenthesis represent the standard deviation.
CMR = Coconut milk residue.

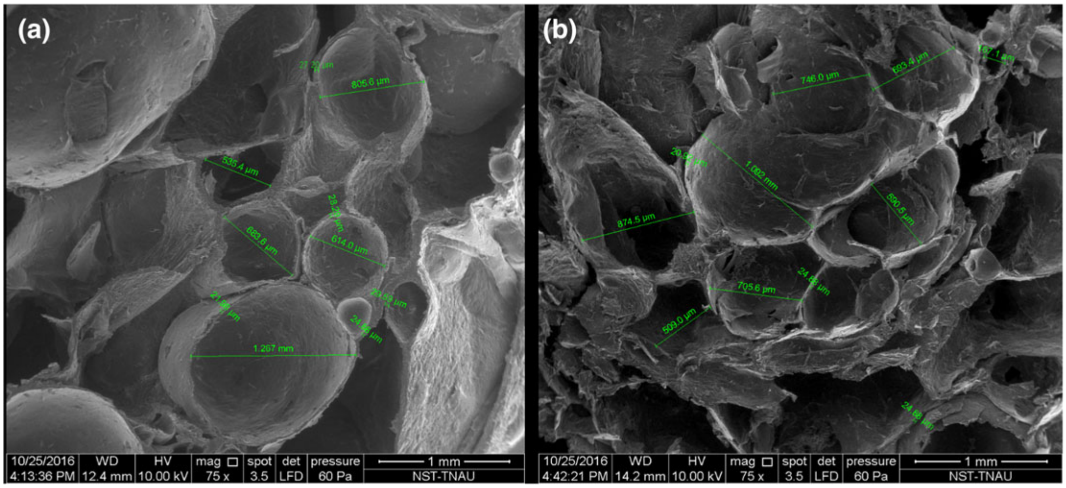

FIGURE 2 Internal structure of extrudates observed through scanning electron micrographs, (a) control: 60% rice flour and 40% corn flour; (b) CMR enriched extrudates: 15% CMR, 25% corn flour, 60% rice flour

CMR as compared to cereal grains. The fibers are rigid compared to starch- and protein-based polymers, which leads to premature rupture of cells and causes reduction in expansion (Ganjyal, Reddy, Yang, & Hanna, 2004; Yanniotis et al., 2007).

The effect of barrel temperature and screw speed (direct and interaction) on ER of extrudates can be observed in Figure 3a. An ER is slightly increased at higher screw speed and exhibits a positive parabolic trend with temperature. The increase in ER at higher screw speed is due to increase in shear and pressure which causes more gelatinization. ER depends on the starch gelatinization elasticity and melts viscosity of feed composition during extrusion cooking (Ali, Hanna, & Chinnaswamy, 1996). There was a significant linear effect of CMR and corn flour on ER ($p < .001$) and quadratic effect ($p < .05$) of screw speed and barrel temperature with corn flour level (Table 2).

3.3.2 | Bulk density

The BD is a vital quality parameter of extruded products. The observed value for BD varied between 0.063 and 0.1195 g/cm^3 (Table 1). These values are 86% lower compared to quinoa enriched extrudates (0.45 to 1.02 g/cm^3) as reported by Kowalski et al. (2016).

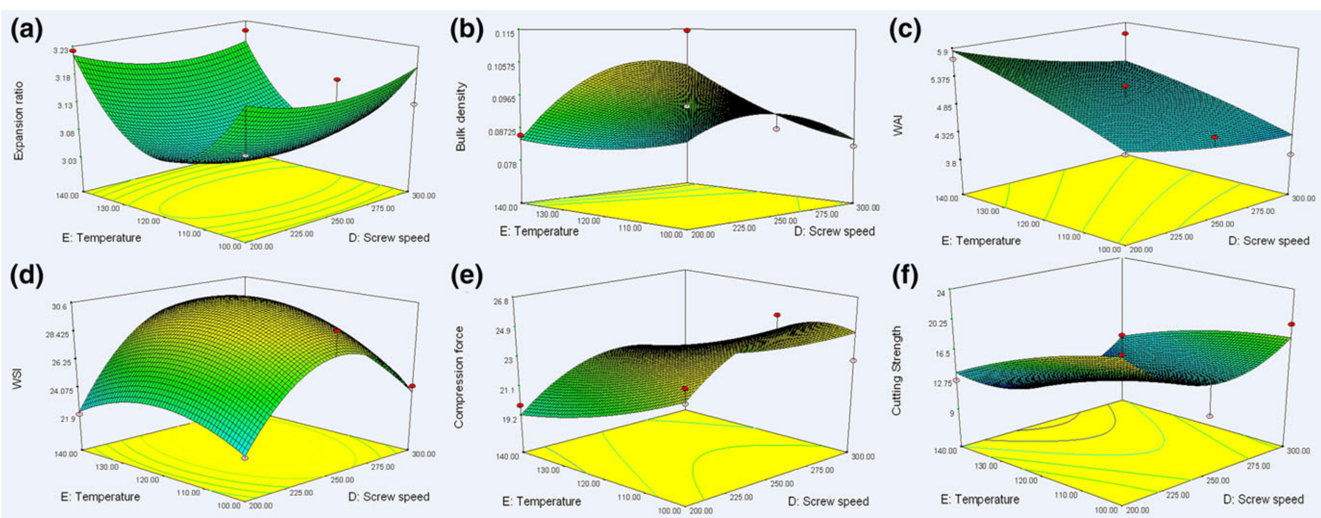

FIGURE 3 Response surface diagrams illustrating the effects of temperature and screw speed on (a) expansion ratio (b) bulk density (c) WAI, (d) WSI, (e) compression force and (f) cutting strength of CMR enriched extruded snack at 15% CMR, 25% corn flour and 60% rice flour

Regression analyses showed that BD had significant effect ($p < .001$) on CMR and corn ratio (Table 2). The positive effect of CMR level on BD is explained by rupture of external surface of extrudates as well as the walls of gas cells, thereby, preventing the expansion of the air bubbles. The amylose content present in corn flour produced compact viscous matrix in extrudates, and an almost total absence of pores, resulting in a lower expansion ratio and greater density (Vanier et al., 2016).

The 3D response surface plot also provides useful insights on observing the effect of extrusion conditions on BD (Figure 3b). The lowest BD value was obtained at a screw speed of 200 rpm, and barrel temperature of 140 °C, whereas the highest BD value was obtained at a screw speed of 200 rpm, and barrel temperature of 100 °C, respectively. Even at same screw speed, the decrease in BD values with increase in temperature might be due to degree of gelatinization of starch particles (Ding, Ainsworth, Tucker, & Marson, 2005). According to Case, Hamann, and Schwartz (1992), gelatinization increases the volume of puffed products, thereby reducing BD. Corn flour and CMR had significant linear effect ($p < .001$) on the BD, and screw speed and temperature had significant interaction effect ($p < .01$) with CMR and corn flour, respectively, (Table 2).

3.3.3 | Water absorption index

The response of WAI on feed composition and extrusion condition are shown in Table 1. The WAI of extrudates was found in the range of 3.60 and 7.95 ml/g. The maximum WAI was recorded at 200 rpm screw speed, 140 °C barrel temperature, and 20% CMR content. Increasing CMR content from 10% to 20% produced higher WAI. Onwulata et al. (2001) also observed similar trend with incorporation of wheat bran fiber and corn meal flour. The WAI of extrudates had significant effect ($p < .0001$) on CMR and corn flour composition ratio (Table 2).

WAI decreased with screw speed and increased with temperature (Figure 3c). Jin et al. (1995) observed similar effect on soy fiber-based extrudates. Increase in screw speed increases shear rate, which reduced WAI and resulted in modification of starch structure (Fletcher, Richmond, & Smith, 1985). At low shear rate, the hydrophilic groups were highly available to bind more water molecules (Gomez & Aguilera, 1983; Jin et al., 1995). At higher extrusion temperature, the increase in WAI is due to the disruption of starch particle, which in turn absorbs more water. The corn flour and screw speed had negative interaction effect, while corn flour and barrel temperature had positive interaction effect ($p < .001$) on WAI of extrudates (Table 2).

3.3.4 | Water solubility index

WSI can be used as an indicator for measuring the degree of starch conversion and the degradation of molecular compounds during extrusion. The values of WSI for CMR-based extrudates ranged from 17.92% to 33.34% (Table 1). The increase of CMR proportion of extrudates led to decrease in WSI. The main components of CMR are cellulose, lignin, hemicellulose, and starch components (Wolthuis et al., 1980). In general, cellulose, lignin, and retrograded starch are insoluble in water. Therefore, WSI decreased with increased CMR content. The corn flour contains high amylose content resulted in reaction between amylose-amylose and amylose-amylopectin interactions after starch gelatinization form crystalline structure, thereby, reduces the solubility (Vanier et al., 2016).

An increasing trend was observed in WSI up to 120 °C barrel temperature and 250 rpm screw speed (Figure 3d). The degree of gelatinization increase with increase in temperature, which consequently raised the solubility of starch molecules, thus increased WSI (Sobukola, Babajide, & Ogunsade, 2013). The decreasing trend of WSI has been observed at the extrusion operating condition of >250 rpm screw speed and 120 °C barrel temperature. The higher screw speed decreases the degree of gelatinization, hence WSI decreased. At high corn flour and CMR levels had most significant negative linear effect ($p < .001$), and screw speed with corn flour had significant quadratic effect ($p < .01$) on WSI responses (Table 2).

3.3.5 | Compression force and cutting strength

For extruded snacks, low values for compression and cutting strength are desirable. CMR content increased compression and cutting strength, while corn flour decreased compression strength (Table.1). Moore et al. (1990) reported that increase in fiber content increases the hardness of extrudates. Compression force and cutting strength of extrudates are directly related to the microstructure of extrudates. High dietary fiber content in the CMR creates fiber-protein interaction which imparts structural integrity to the extrudates and increases their hardness (Chiu, Peng, Tsai, & Lui, 2012). Analysis of variance shows that corn flour had a negative linear effect ($p < .01$), and CMR had positive linear effect ($p < .01$) on the compression force (Table 2).

TABLE 4 Linear regression models developed using selected variables from mixture process design

Properties	Model	R^2	SSE
Expansion ratio	$y = 1 \times 10^{-4}X_1 - 0.05X_2 - 1.1 \times 10^{-8}X_1Z_1^2 + 7.29 \times 10^{-8}X_1Z_2^2 + 3.991$	0.84	0.21
Bulk density (g/cm^3)	$y = 7 \times 10^{-4}X_1 + 0.002X_2 - 1.6 \times 10^{-5}X_1Z_2 - 9.8 \times 10^{-6}X_2Z_1 + 4.3 \times 10^{-6}X_2Z_2 + 0.135$	0.77	0.0009
WAI (ml/g)	$y = 4 \times 10^{-4}X_1 - 0.1195X_2 - 1.7 \times 10^{-4}X_1Z_1 - 1.3 \times 10^{-6}X_1Z_2 + 0.002X_2Z_2 + 4.695$	0.84	3.07
WSI (%)	$y = 2 \times 10^{-4}X_1 - 0.437X_2 + 2.02 \times 10^{-6}X_1Z_{12} + 28.85$	0.40	216.32
Compression force (N)	$y = 4 \times 10^{-4}X_1 - 0.171X_2 - 0.004X_1Z_2 + 2.03 \times 10^{-6}X_2Z_1^2 + 34.99$	0.52	132.17
Cutting strength (N)	$y = -0.00403X_1Z_2 + 27.64$	0.34	292.51

WAI = Water absorption index; WSI = Water solubility index;
R^2 = coefficient of determination; SSE = sum of squared error; X1 = Corn flour (%),
X2 = Coconut milk residue (%); Z1 = Screw speed (rpm); Z2 = Extrusion temperature (°C).

TABLE 5 Performance measures of artificial neural network models

Parameters	Observed range	Predicted range	R^2	SSE
Expansion ratio	2.76–3.64	2.83–3.55	0.92	0.26
Bulk density (g/cm^3)	0.06–0.12	0.07–0.12	0.89	0.0001
WAI (ml/g)	3.58–8.03	3.68–7.31	0.94	2.61
WSI (%)	16.84–34.01	19.59–33.30	0.78	214.81
Compression force (N)	13.97–28.39	14.27–27.96	0.86	101.08
Cutting strength (N)	9.73–24.55	9.25–22.53	0.41	203.80

WAI = Water absorption index; WSI = Water solubility index.

The effect of screw speed and barrel temperature on compression and cutting strength are shown in Figure 3e,f. As discussed earlier, increasing screw speed or decreasing temperature produced a compact extrudate with small air cell size and thick cell walls; hence, a high compression force was observed. The increase in temperature causes increase in expansion, thus, decreases compression force. More expanded extrudates could be easily broken. For the compression force, linear terms (corn flour and CMR) and interactive effect (corn flour and temperature) from the regression model were significant at ($p < .01$) and ($p < .05$), respectively, as were the quadratic effect of screw speed with CMR also had significant ($p < .05$) effect. However, only the interactive effect, Corn flour × Temperature (X_1Z_2) was statistically significant ($p < .05$) for cutting strength (Table 2).

3.4 | Model performances

The results of RSM models developed using second order response equation (Equation (2)) are presented in Table 2 which had R^2 ranging between 0.01 and 0.68, and SSE ranging between 0.43 and 639.80. Those models were developed including all 12 variables and one intercept term. The results also provide the significant variables which are influencing each model in predicting its corresponding responses. For example, predicting expansion ratio is mostly influenced by the linear terms X_1 and X_2, and quadratic terms $X_1Z_1^2$, and $X_1Z_2^2$. Therefore, such significant variables were used to develop the linear regression equation for predicting corresponding responses. The models developed using only the significant variables from Table 2 was redefined by MATLAB's "*fitlm*" function are shown in Table 4. It can be observed that, the new linear equations are compact with only the significantly influencing variables and the performances are improved. The R^2 and SSE were ranging between 0.34 and 0.84, and 0.0009 and 292.51, respectively. Therefore, the new regression models (Table 4) are preferred for predicting the extrudate properties rather than the models shown in Table 2.

An artificial neural network model was also developed to compare the performance with MLR models. The ranges of observed and predicted values were almost in the same range (Table 5). The relationship between observed values and predicted values are plotted in Figure 4. Unlike the previous study (Shihani, Kumbhar, & Kulshreshtha, 2006) consisting of more than eight hidden neurons, a single hidden layer with three neurons was sufficient to produce good performance in the present study. The performance of all the ANN models was better than the MLR models presented in Table 4. The R^2 values of the ANN models ranged from 0.41 to 0.94, and SSE values ranged from 0.0001 to 214.81. Both (ANN and MLR) models were suitable for predicting WAI and recorded highest R^2 values of 0.94 and 0.84, respectively for WAI. At the same time, both the models yielded lowest R^2 in predicting cutting strength (0.41 and 0.34), which indicates the model could be still improved to make it suitable for predicting cutting strength. Rests of the other models were acceptable. However, the ANN models could be improved using more hidden neurons for each model, but there are chances of model overfitting. Hence, with the decision on number of neurons by Heaton (2008), the developed models were performing well. Comparing ANN and MLR, the performance of ANN was better and hence can be used for predicting extrudate characteristics in future studies as well.

3.5 | Optimization of feed composition and processing conditions

The independent variables were optimized using Design Expert (Ver. 7.1., Stat-Ease, Inc.). Five important responses were taken for

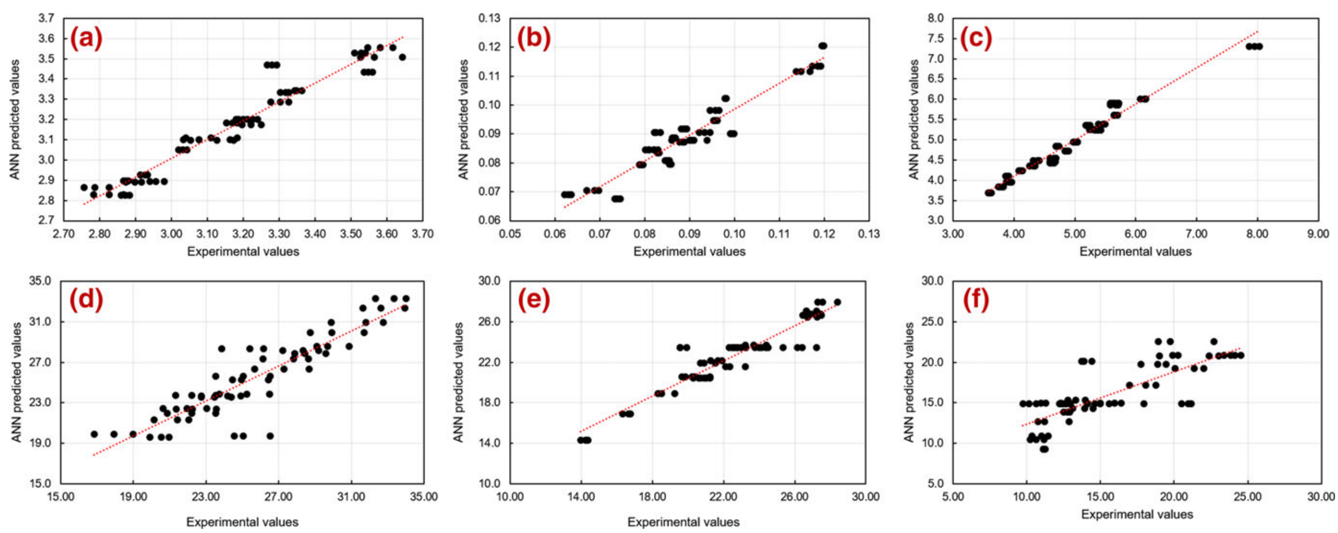

FIGURE 4 The relationship between experimental values and predicted values for the models developed using artificial neural network. (a) Expansion ratio, (b) bulk density, (c) water absorption index, (d) water solubility index, (e) compression force, (f) cutting strength

optimization. Desired goals were assigned to each response to obtain numerical optimum values. The ER and BD were kept ≥3.2 and 0.06 to 0.09, respectively. Because, the commercial extrudates brand available in the market has the expansion ratio of 3.2 and bulk density of 0.06–0.09. Remaining variables (CF, CS, and WAI) were kept in range during optimization.

It was observed that 15% CMR flour, 25% corn flour, 220 rpm screw speed, and 140 °C barrel temperature resulted in an optimized product of 95% desirability. The rice flour percentage was fixed at 60% for the optimized blend. The respective optimized response values of ER, BD, WAI, CF, and CS, were 3.19, 0.08 kg/cm^3, 5.69 ml/g, 20.80 N, 10.81 N, respectively.

4 | CONCLUSIONS

Coconut milk residue (CMR) has several nutritional benefits and desirable attributes. Increased CMR level decreased the expansion ratio significantly ($p < .001$). The extrudate's bulk density varied between 0.06 and 0.12 g/cm^3 and it was positively correlated with CMR level ($p < .001$), however, increase of screw speed and extrusion temperature decreased the bulk density. Higher coconut milk residue content increased the compression force and cutting strength of extrudates. The developed models demonstrated adequate information regarding the extrudates characteristics upon variation of feed composition and process variables. Prediction models developed using MLR and ANN performed well. Both models (MLR and ANN) were well suited for prediction of water absorption index, and least suited for cutting strength.

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CONFLICT OF INTEREST

The authors declare that they have no conflicts of interest.

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