Optimization of Iron Rich Extruded *Moringa oleifera* Snack Product for Anaemic People Using Response Surface Methodology (RSM)

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Abstract

*Moringa oleifera*, a multiuse tree has numerous medicinal properties. Most parts of the *Moringa* tree are edible among these leaves are the most nutritious part of the tree and are having good quantity of iron content. Incorporation of nutritional properties via addition of natural components present in fruits and vegetables is a relatively novel concept. One of the most effective ways of achieving this is via extrusion technology. The present study deals with the development of extruded snacks by incorporation of *Moringa oleifera* leaf powder in finger millet using a lab-scale twin screw extruder. The main aim of this study is to optimize the extrusion process using Response Surface Methodology (RSM). The effect of feed moisture, blend ratio and barrel temperature on product responses viz. mass flow rate (MFR), expansion ratio (ER), bulk density (BD), water absorption index (WAI) and sectional expansion index (SEI) of the extruded product were studied. The blend of *Moringa* and finger millet was extruded at different moisture content (19% to 25%), barrel temperature (120°C to 140°C) and blend ratio (0% to 15%). Increase blend ratio had showed increase in WAI, MFR but decrease in ER, SEI and BD. The optimized sample was obtained at 25% M.C, 5% blend ratio, and 140°C barrel temperature and it has iron content of 5 ± 0.10 mg/100 g.

**Keywords:** *Moringa oleifera*; Physico-chemical properties; Extrusion technology; Optimization; RSM

Introduction

Extrusion is one of the important processing techniques in food processing industries i.e. snack food industries [1]. Indian snack market has been increasing rapidly with an annual growth rate of about 15% to 20% [2]. Extruded snacks were generally made from the grain based materials. Grains have an excellent swelling and binding power with the *Moringa* leaves powder because of the starch content in grains. The high temperature and short time extrusion (HTST) cooking has many benefits over low temperature and long-time (LTLT) cooking, because of inactivation of anti-nutritional factors [3]. HTST provides better quality extruded products and also found to be efficient in terms of energy. It was widely used to produce expanded snacks, modified starches, Ready to Eat (RTE) cereals, baby foods, pasta and pet foods [4]. The use of extrusion cooking has unique advantages includes versatility, low cost, consumer acceptable product shapes, high product quality and product of new food with no or negligible effluents. Expansion of starchy products by extrusion was widely studied by Colonna et al. [5]. Extrusion cooking used in this study was accomplished through the application of heat directly by means of steam injection to the blend. Various changes have observed in ingredients during the extrusion cooking process were the gelatinization of starch, destruction of natural toxic substances, denaturation of proteins and the diminishing of microbial counts in the final product [6].

*Moringa* tree (*Moringa oleifera*) is a multipurpose tree native to the foot hills of Himalayas in north western India and is cultivated throughout the tropics [7]. *Moringa* leaves are considered to be an important source of several nutrients [8]. It consists of 17 g (28% RDA/Day) protein, 24.65 mg iron (230% RDA/Day) and 48.23 g carbohydrates (34% RDA/Day) because of the high nutritional value these leaves were used in blend with finger millet for preparing extruded snack [3,9,10].

Finger millet (*Eleusine coracana*) is considered as an annual plant widely grown as a cereal in the arid areas of Asia and Africa. It is an important minor millet crop of India. It is a rich source of many major nutrients such as protein, fibre, iron and calcium. It contains of significant number of micronutrients [11]. The state of Karnataka is the leading producer of ragi, accounting for 58% of India's ragi production Ministry of Agriculture Report-November [2]. Since finger millet is abundantly available and is also a rich source of iron (3.2 mg/100 g) it was used as a base material of extrudate. The proximate analysis value of *Moringa oleifera* leaf powder, finger millet powder and extruded product were mentioned in the (Table 1). The present study deals with the development and dissemination of expanded snacks based on *Moringa* leaf powder using a lab-scale twin screw-extruder (SYSLG-IV, China) for industrial and nutraceutical applications in order to fully exploit the nutritional potential of *Moringa oleifera* leaves for the benefit of mankind and also enhance the consumption of iron in diet thereby eliminating iron deficiency and providing the right nutritional supplement to anaemic people and to find out the best suitable proposition for consumer consumption. Therefore, objective of this study is to optimize the extrusion process of *Moringa oleifera* leaves-finger millet powder in terms of feed moisture, blend ratio and barrel temperature for evaluating the physico-chemical properties (MFR, ER, BD, WAI and SEI) under optimum conditions.

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Materials and Methods

Sample preparation

Preparation of Moringa leaf powder and feed for extrusion: Moringa leaves were collected from Indian Institute of Crop Processing Technology (IICPT) campus and sorted for infected and damaged leaves. The leaves were washed with tap water and surface dried. Then they were dried in hot air oven at 55°C for 6 hours and ground using a food mixer grinder (Philips, HL1632). The Moringa leaf Powder was packed in polyethylene (PE) bags and stored at 30°C for further studies.

Preparation of ragi powder: Finger millet was obtained from the local market and impurities were removed using sieves manually. It was then powdered using hammer mill in IICPT. 0.1 mm sieve was used for obtaining fine powder. Ground ragi was packed and stored at 30°C in polyethylene (PE) bags for further studies. Pure ragi extrudate is shown in Figures 1 and 2.

Preparation of blend: Both the finger millet and Moringa powder were mixed in the batch flour mixer (las -PM-1945) to various proportion i.e. 5%, 10% and 15% of Moringa powder in 95%, 90% and 85% of finger millet powder were made. Moringa oleifera leaf based snack product (10-95%) is shown in Figure 3.

Chemical analysis

Proteins, Carbohydrates, fibre, fat, iron and Moisture analysis of raw materials and extruded snack was carried out using standard procedures of AOAC. All analysis is expressed as the mean (± SD) of triplicate analysis and shown in Table 1.

Extruder conditions

The extruder used for the study was co-rotating and intermeshing twin screw extruder (SYSLG-IV, China) as shown in Figure 2. The barrel diameter of the extruder was 5 mm and its length to diameter (L/D) was 18:1. The extruder had four barrel zones. Temperature of the 1st, 2nd and 3rd were maintained at 40°C, 70°C and 100°C respectively throughout the experiment while the 4th zone was adjusted according to the experimental design. The die with 2.25 mm was used for the extrusion. Raw material fed into the extruder with a volumetric single screw feeder (Modena, Italy) which was attached on top of the extruder. The feed rate and screw speed was kept constant throughout the experiment at 150 rpm (Table 2).

Processing conditions

Moringa leaves and finger millet were used to make iron rich extruded product. In the preparation of this expanded product, moisture content in the blends was 19%, 22% and 25%. Moringa leaves powder to Finger millet blend ratio (BR) were 0: 100, 5: 95, 10: 90 and 15: 85 and temperature levels of 120°C, 140°C and 160°C were taken for each set of moisture content and blend ratio shown in Table 3. Once cooked, the product is forced through a die at the extruder discharge end where it expands rapidly with some loss in moisture. After expansion, cooking and drying the extrudate develops a rigid structure and maintains a porous structure. The Overall effects of independent variables on mass flow rate, sectional expansion index (SEI), expansion ratio was studied. The effects of independent variable on responses were analyzed with RSM–Three level factorial models to check the significance of responses at p<0.05. The different Independent variables used in this study are shown in Table 2.

| Parameters | Moringa leaf powder (/100 g) | Ragi powder (/100 g) | Extruded product (/100 g) |
|------------|-------------------------------|----------------------|--------------------------|
| Carbohydrate | 48.23 ± 0.18 g | 71.94 ± 0.21 g | 68.10 ± 1.45 g |
| Protein | 17 ± 0.08 g | 7.1 ± 0.21 g | 10.03 ± 0.17 g |
| Fiber | 15.33 ± 0.06 g | 3.982 ± 0.09 g | 6.410 ± 0.22 g |
| Fat | 7.6 ± 0.5 g | 3.6 ± 0.21 g | 4.60 ± 0.10 g |
| Iron | 24.65 ± 0.12 mg | 3.71 ± 0.05 mg | 6.91 ± 0.18 mg |
| Moisture | 9.5 ± 0.01 g | 8.5 ± 0.02 g | 7.65 ± 0.01 g |

Table 1: Proximate analysis of extrudate.

Figure 1: Extruded snack product based on (a) Ragi extrudate; (b) Moringa oleifera leaf.

Figure 2: Twin screw extruder (SYSLG-IV, China).

Figure 3: Response surface graph of blend ratio (br), feed moisture content (m) and expansion ratio (er)of extrudates at Barrel Temperature 140°C.

| S. no. | Parameters                                      |
|--------|------------------------------------------------|
| 1      | Moisture content in blend, (% wb)              |
| 2      | Blend ratio of MLP in finger millet (%)        |
| 3      | Barrel temperature (°C)                        |

Table 2: Independent variables.
Determination of product responses

Expansion ratio (ER): The ratio of diameter of extrudate and the diameter of die was used to express the expansion of extrudate [12]. The diameter of extrudate was determined as the mean of 10 random measurements made with Vernier callipers. The extrudate expansion ratio was calculated using the following equation.

\[ ER = \frac{\text{Extrudatediameter}}{\text{Die diameter}} \]

Sectional expansion index (SEI): Sectional expansion index was measured by taking the ratio of the square of diameter of extrudate to the square of diameter of the die [13]. Random samples were selected from the extruded mass and their diameter was measured using screw gauge. For SEI was calculated using the following equation.

\[ SEI = \frac{\text{Diameter of the extrudate}}{\text{Diameter of the dye}}^2 \]

Mass flow rate (MFR): It is defined as the ratio of the weight of the sample collected to the time taken to collect the sample [9]. It was measured by collecting the extrudate in polyethylene bags for a specific period as soon as it came out of the extruder and its weight was taken instantly and calculated using the following equation.

\[ \text{MFR (gm/sec)} = \frac{\text{Weight of the sample collected}}{\text{Time taken to collect the sample}} \]

Bulk density (BD): The bulk density was determined by the volumetric displacement method. Volume was measured using the 100 ml measuring cylinder. It is the ratio of the weight of the sample to the volume of the replaced sample was measured using the following equation [14].

\[ \text{BD (kg/cc)} = \frac{\text{Weight of the sample}}{\text{Volume replaced}} \]

Water absorption index (WAI): It measures the volume occupied by the starch after swelling in excess water, which maintains the integrity of the starch in aqueous dispersion. It can also be used as an index of starch gelatinization. Water Absorption Index was calculated using the following method [15].

\[ \text{WAI} = \frac{W_2 - W_1}{W_1} \]

Where,

- \( W_1 \) is the weight of ground extrudate sample.
- \( W_2 \) is the weight of ground extrudate sample after keeping in water.

Experimental design

Three level factorial designs were performed for three independent variables using design of experts 6.0.8. The independent variables considered were (1) Moisture content (2) Blend ratio (BR) and (3) Barrel temperature and the dependent variables were (1) ER (2) SEI (3) MFR (4) BD and (5) WAI. The coded and the responses for the three-level factorial model between levels and variables were given in the Table 4. Coded levels of each independent variables taken for Moisture content (19% to 25%), BR (5% to 15%) and Barrel temperature (120°C to 160°C) are shown in Table 3.

Results and Discussion

Physical properties of extrudates were calculated with different percentage of Moringa and finger millet in blend at different temperature (120°C, 140°C, 160°C) and moisture content (10%, 15% and 20%) and found operating condition for maximum and minimum value of physical properties and the effects of independent variables on each parameter was analysed using response graph at 140°C as shown in Figures 3-7.

Expansion ratio

The multiple regression analysis of the expansion ratio versus feed moisture content (A), blend ratio (B), and barrel temperature (C) yielded following polynomial model.

\[ ER = 2.84 + 0.74 A - 0.077 B - 0.022 C + 1.64 A^2 + 0.12 B^2 - 0.044 C^2 - 0.20 AB - 0.021 AC + 0.566 BC \]

In this case moisture content of feed, blending ratio, and barrel temperature were found highly influencing variables on the ER of the extrudates. The results showed that the expansion ratio increases

| Exp no. | \( x_1 \) | \( x_2 \) | \( x_3 \) | BD | ER | SEI | WAI | MFR |
|---------|--------|--------|--------|-----|----|-----|-----|-----|
| 1       | 1      | -1     | 1      | 346.97 | 5.42  | 23.079 | 71.82 | 92.52 |
| 2       | 0      | -1     | 0      | 178.9 | 2.67  | 15.203 | 45.14 | 93.2  |
| 3       | 0      | 1      | 1      | 172.03 | 3.28  | 14.297 | 59.57 | 91.62 |
| 4       | -1     | 0      | 1      | 149.058 | 3.98  | 17.9734 | 60.92 | 95.09 |
| 5       | 0      | 0      | 0      | 159.25 | 2.8  | 14.2991 | 59.57 | 91.62 |
| 6       | 0      | 0      | 0      | 159.25 | 2.8  | 14.2991 | 59.57 | 91.62 |
| 7       | 0      | -1     | -1     | 178.9 | 2.63  | 14.2071 | 54.1 | 87.67 |
| 8       | 1      | -1     | -1     | 342.85 | 5.75  | 23.088 | 71.66 | 55.6 |
| 9       | 0      | 1      | -1     | 171 | 3.28  | 14.2298 | 68.55 | 89.6 |
| 10      | 0      | 0      | 1      | 160.02 | 2.81  | 14.2753 | 60.91 | 86.02 |
| 11      | 0      | 0      | 0      | 159.25 | 2.8  | 14.2991 | 59.57 | 91.62 |
| 12      | -1     | -1     | -1     | 150.352 | 3.96  | 15.4711 | 63.65 | 83.6 |
| 13      | 1      | 1      | 1      | 339.14 | 5.27  | 23.318 | 72.76 | 114. |
| 14      | -1     | 0      | 0      | 138.702 | 4.12  | 16.7601 | 64.73 | 97.15 |
| 15      | 1      | -1     | 0      | 152.368 | 3.35  | 17.1285 | 56.25 | 87.65 |
| 16      | 1      | 1      | 0      | 321.56 | 4.51  | 23.501 | 76.11 | 105.99 |
| 17      | 1      | 0      | 0      | 324.12 | 4.87  | 23.026 | 71.91 | 102.87 |
| 18      | 1      | 0      | 1      | 325.1 | 4.87  | 23.169 | 72.14 | 112. |
| 19      | 0      | 1      | -1     | 171 | 3.3  | 14.8102 | 62.91 | 89.78 |
| 20      | 1      | -1     | 0      | 368.58 | 6.64  | 23.901 | 74.71 | 52.98 |
| 21      | -1     | -1     | 0      | 157.006 | 3.41  | 15.5612 | 65.74 | 93.65 |
| 22      | 0      | 0      | 0      | 159.25 | 2.8  | 14.2991 | 59.57 | 91.62 |
| 23      | -1     | -1     | 1      | 156.672 | 3.8  | 15.8152 | 62.59 | 98.5 |
| 24      | 1      | 0      | -1     | 358.21 | 4.89  | 23.153 | 72.1 | 106. |
| 25      | 0      | 0      | 0      | 159.25 | 2.8  | 14.2991 | 59.57 | 91.62 |
| 26      | -1     | 0      | -1     | 138.915 | 4  | 16.5322 | 60 | 102.15 |
| 27      | 0      | 0      | 0      | 159.25 | 2.8  | 14.2991 | 59.57 | 91.62 |
| 28      | 1      | 1      | -1     | 340.95 | 5.15  | 23.365 | 72.8 | 108. |
| 29      | -1     | 0      | 1      | 141.561 | 4.03  | 16.5935 | 61.08 | 102.52 |
| 30      | -1     | 1      | 1      | 153.81 | 3.41  | 17.418 | 57.52 | 87.53 |
| 31      | 0      | -1     | 1      | 179.48 | 2.63  | 14.2001 | 54.39 | 84.82 |
| 32      | 0      | 0      | -1     | 159.25 | 2.8  | 14.2359 | 61.75 | 87. |

x₁: Feed moisture (%), x₂: Blend ratio (Moringa leaf powder: finger millet powder) x₃: Temperature (°C), BR: Blend Ratio; ER: Expansion Ratio; SEI: Sectional Expansion Index; WAI: Water Absorption Index; MFR: Mass Flow Rate.
Sectional expansion index

The multiple regression analysis of the sectional expansion index versus feed moisture content (A), blend ratio (B), and barrel temperature (C) yielded the following polynomial model.

\[
\text{SEI} = 14.41 + 3.35A + 0.30B + 0.037C + 5.59A^2 + 0.20B^2 - 0.30C^2 - 0.46AB - 0.061AC - 9.417E-003BC
\]

In this case, all the independent variables gave positive effect on the SEI. The combined effect of barrel temperature with high feed moisture content decreased the SEI and increase with the blend ratio [12]. Sectional Expansion Index of extrudate was studied at different feed moisture contents, barrel temperature and blending ratios shown in Figure 4. It was observed that the SEI increases with feed moisture and increase with decrease in blend ratio but concluded that the SEI decreases with increase in feed moisture content and blend ratio [20]. The maximum value of SEI was achieved at 15% blend ratio for 25% moisture content and minimum at 22% moisture content.
moisture content whereas the minimum value was obtained for 0% blend ratio for 19% moisture content shown in Figure 4. SEI followed almost increasing trend for moisture content with maximum value at 25% moisture content and minimum at 19% moisture content but SEI decreased with the increase in moisture content as reported by Badrie and Mellowes [21]. SEI with respect to variations in barrel temperature followed almost increasing trend. Maximum values for 140°C barrel temperature and minimum values at 120°C barrel temperature. Borah et al. [15] had also reported positive effect of barrel temperature on the SEI of rice extrudates. With respect to Barrel temperature, it was observed that the maximum value (16.86) obtained at 140°C and minimum (16.53) at 120°C. With respect to Blend ratio maximum value (18.43) at 15% and minimum (12.4) at 0%. With respect to feed moisture content, maximum value (20.86) at 25% and minimum (14.34) at 22%. The design gives the Model f-value of 456.32 and R² value of 99.47% which implies the model is significant (p<0.05).

**Mass flow rate**

The multiple regression analysis of the mass flow rate versus feed moisture content (A), blend ratio (B), and barrel temperature (C) yielded following polynomial model.

\[
\text{MFR} = 93.35 - 3.00 A + 8.23 B + 0.23 C + 5.44 A^2 - 9.86 B^2 + 0.97 C^2 + 15.73 A B + 0.73 AC + 0.79 BC
\]

It was observed that MFR increases with the increase in blend ratio and barrel temperature but decreases with the decrease in feed moisture but Medeni [22] showed that the MFR decreases with the increase in feed moisture content. Mass Flow Rate of extrudate was studied at different feed moisture contents, barrel temperature and blending ratios shown in Figure 5. Model equation showed that moisture content gave negative effect on MFR. MFR quantifies the processing performance of the extruder [23]. The maximum value of mass flow rate was achieved at 15% blend ratio for 25% moisture content whereas the minimum value was obtained for 5% blend ratio for 25% moisture content shown in Figure 5. Mass flow rate with respect to variations in barrel temperature followed almost increasing trend with maximum values for barrel temperature 140°C and minimum values at barrel temperature 120°C. The design gives the Model f-value of 8.20 and R²-value of 77.04% which implies the model is significant (p<0.05).

With respect to Barrel temperature maximum value (108) at 120°C and minimum (55) at 140°C with respect to Blend ratio maximum value (102.15) at 15% and minimum (80) at 5% with respect to feed moisture content maximum value (98.10) at 19% and minimum (78.20) at 25%.

**Bulk density**

The multiple regression analysis of the bulk density versus feed moisture content (A), blend ratio (B), and barrel temperature (C) yielded following polynomial model.

\[
\text{BD} = + 159.72 + 95.56 A - 5.43 B - 1.00 C + 74.56 A^2 + 12.00 B^2 + 2.99 C^2 - 4.75 AB - 3.43 AC - 0.86 BC
\]

Model equation showed that moisture content gave positive effect on BD, blend ratio and barrel temperature showed the negative effect over the bulk density shown in Figure 6. Bulk Density of extrudate was studied at different feed moisture contents, barrel temperature (140°C) and blend ratios. It was observed that the trend was increasing for 25% moisture content and gradual decreasing trend has been seen for 19% and 22% moisture content for all blend ratios shown in Figure 6. As the Screw Speed increases bulk density decreases [24]. Extrudates fortified with the cabbage powder shows no significant increase in the bulk density with increase in feed moisture content [25]. The maximum value of BD was achieved at 15% blend ratio for 25% moisture content whereas the minimum value was obtained for 0% blend ratio for 25% moisture content (Figure 6). BD followed decreasing trend for moisture content with maximum value at 19% moisture content and minimum at 25% moisture content. Bulk Density with respect to variations in barrel temperature followed a decreasing trend with maximum values for 120°C barrel temperature and minimum values at 160°C barrel temperature. The design gives the Model f-value of 327.79 and R²-value of 99.26% which implies the model is significant at p<0.05. Values of "Prob>F" less than 0.050 indicate model terms are significant. Values greater than 0.100 indicate the model terms are not significant. By comparing mean values it was noted that maximum values were obtained at 15%, followed by 10%, 5% and 0%, with respect to blend ratio. With respect to moisture content the mean values indicated that maximum values were obtained for 19%, followed by 22%, then 25%. Similarly, with respect to barrel temperature, maximum values were achieved at 120°C, then 140°C, and finally 160°C. With respect to Barrel temperature, maximum value (202.77 kg/m³) at 120°C and minimum (187.25 kg/m³) at 160°C. With respect to Blend ratio maximum value (217.99 kg/m³) at 15% and minimum (148.84 kg/m³) at 0%. With respect to feed moisture content, maximum value (278.67 kg/m³) at 25% and minimum at 19% (153.37 kg/m³).

**Water absorption index**

The multiple regression analysis of the water absorption index versus feed moisture content (A), blend ratio (B), and barrel temperature (C) yielded following polynomial model.

\[
\text{WAI} = + 59.62 + 5.64 A - 1.87 B - 0.11 C + 7.84 A^2 - 0.37 B^2 + 0.042 C^2 + 1.56 AB + 0.073 AC - 0.092 BC
\]

WAI found to be increased with the increase in feed moisture content and blend ratio while WAI decreases with the increase in barrel temperature shown in Figure 7. Water Absorption Index of extrudate was studied at different feed moisture contents, barrel temperature (140°C) and blend ratios. It was observed that the trend was increasing for all blend ratios and moisture content of extrudates. The maximum value of WAI was achieved at 15% blend ratio for 25% moisture content whereas the minimum value was obtained for 0% blend ratio for 25% moisture content shown in Figure 7. WAI decreases due to degradation of starch [26]. Water absorption index increases with the feed moisture content [27]. Water Absorption Index with respect to variations in barrel temperature followed an almost decreasing trend with maximum values for 140°C barrel temperature and minimum values at 160°C barrel temperature. The design gives the Model f-value of 6.70 and R²-value of 73.27% which implies the model is significant (p<0.05). By comparing mean values, it was noted that maximum values were obtained at 15%, followed by 10%, 5% and 0%, with respect to blend ratio. With respect to moisture content the mean values indicated that maximum values were obtained for 25%, followed by 19%, then 22%. Similarly, with respect to barrel temperature, maximum values were achieved at 140°C, then 120°C and finally 160°C. With respect to Blend ratio maximum value (217.99 kg/m³) at 15% and minimum (148.84 kg/m³) at 0%. With respect to feed moisture content, maximum value (278.67 kg/m³) at 25% and minimum at 19% (153.37 kg/m³).

**Optimization of the extrusion cooking condition**

The optimized sample was obtained by numerical optimization from design of expert 6.0.8, which gives a desirability function of 0.64. Equal importance of 3 was given to all the 3 independent variables (Feed moisture, Blend ratio and Barrel temperature). Based on their
relative contribution to quality of final product importance of 5 was given to ER, SEI, WAI and importance of 3 was given to BD and MFR shown in Table 5. As shown in Table 6 at the optimal condition feed moisture, blend ratio and barrel temperature was found to be 25%, 5.95 and 140°C, respectively. Balasubramanian et al. [19] had reported better physico chemical properties for millet based extrudates developed at 120°C having 14% moisture content.

**Conclusion**

It was concluded that the best quality extrudate was obtained at 25% M.C, 5% blend ratio, and 140°C barrel temperature. RSM – Three level factoril designs were used for optimizing the extrusion process for simplified understanding of individual operating variables. There is a huge variation in the effect of feed moisture content and blend ratio on the various physico-chemical parameters like Sectional Expansion Index, Mass Flow Rate, and Expansion Ratio of extruded *Moringa oleifera* snack product. It was observed that the bulk density of extrudate lower was the expansion ratio. Expansion ratio increases with increase in feed moisture and decreases with increase in blend ratio and barrel temperature. Bulk density increases with the increase in moisture and decreases with increase in blend ratio and barrel temperature. The maximum value of Expansion ratio was achieved at 0% blend ratio for 25% moisture content. As the moisture content increases expansion ratio increases. Sectional expansion index increases with the feed moisture content, blend ratio and barrel temperature. It was also concluded that the mass flow rate of the extrudate was also decreases with increase in feed moisture content and increases with increase in blend ratio and barrel temperature. Water absorption index increases with the increase in feed moisture content, blend ratio and barrel temperature.

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Table 5: Optimized parameter in the response optimizer.

| Response | Goal | Lower limit | Upper limit | Lower weight | Upper weight | Importance |
|----------|------|-------------|-------------|--------------|--------------|------------|
| BD       | minimize | 138.702 | 368.58 | 1 | 1 | 3 |
| ER       | maximize | 2.63 | 6.64 | 1 | 1 | 5 |
| SEI      | maximize | 14.2001 | 23.901 | 1 | 1 | 5 |
| WAI      | maximize | 45.14 | 76.1 | 1 | 1 | 5 |
| MFR      | minimize | 52 | 114 | 1 | 1 | 3 |

Table 6: Optimized solution obtained using the response optimizer.

| Feed moisture (%) | Blend ratio (%) | Temperature (°C) | ER | SEI | BD (g/cc) | WAI | MFR (g/l) |
|-------------------|-----------------|------------------|----|-----|-----------|-----|-----------|
| 25                | 5.95            | 140              | 5.31 | 22.65 | 333.584 | 67.99 | 63.25     |
| BR: Blend Ratio; ER: Expansion Ratio; SEI: Sectional Expansion Index; WAI: Water Absorption Index; MFR: Mass Flow Rate

Table 7: Optimized solution for predicted responses.