International Journal of Chemical Studies

P-ISSN: 2349–8528
E-ISSN: 2321–4902
IJCS 2017; 5(6): 1657-1662

Received: 19-09-2017
Accepted: 20-10-2017

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Effect of process and machine parameters on physical properties of extrudate during extrusion cooking of rice, ashwagandha powder and spinach powder blends

Shraddha Bhople, Mohan Singh and Satyendra Thakur

Abstract
Extrusion cooking of rice (*Oryza sativa* L.), ashwagandha (*Withania somnifera*) and spinach (Spinacia oleracea) flour blends was done to prepare snacks by using a Brabender single screw laboratory extruder. The combined effect of moisture content, blend ratio of feed, barrel temperature, die head temperature and screw speed of extruder on physical parameters of extrudate was studied. It was observed that 18% moisture content of feed, 80:15:5 (rice flour: ashwagandha: spinach powder) of blend ratio, 180 °C barrel temperature and 100 rpm of screw speed gave the highest Mass flow rate and sectional expansion index of extrudate, while 15% moisture content, 80:15:5 of blend ratio of feed, 140 °C of barrel temperature and 80 rpm of screw speed gave lowest bulk density of extrudate. A central composite rotatable design (CCRD) of response surface methodology was used to develop prediction model.

Keywords: Rice, Ashwagandha, Spinach, Extrusion cooking, Bulk density, Sectional expansion index and Mass flow rate.

Introduction

In recent years, there has been an increasing interest in the production of extruded foods such as snacks, pastas, breakfast cereals, baby foods and pet foods. Extrusion cooking has advantages, including versatility, high productivity, low operating costs, energy efficiency and shorter cooking times [1]. Inside the extruder the cereal mixture is heated above the starch gelatinization temperature leading to a cooked product that may be directly enrobed and flavored, or may need further processing such as frying or roasting. In the blend of flours made from starch and iron, the selection of machine and process parameters for extrusion becomes more important as the starch gets gelatinized at different process parameters. Chemical and physical characteristics of products strongly depend upon process variables such as extrusion temperature, screw speed and moisture content [2]. In cereal-based products, the degree or proper processing of starch is important for major quality aspects such as taste, digestibility, texture, puffing and appearance. Extrusion operational parameters such as barrel temperature, and screw speed affect the snack quality. In addition to these, processing parameters like feed moisture content, blending ratio also play important role on the quality of extrudate. Therefore, the effects of various operational and processing parameters and their interaction on quality of extrudate has to be studied and established. In the present study, rice (oriza sativa), Ashwagandha (withania somnifera) and spinach (spinacia oleracea) flour were used to develop an extruded snack which is iron enrich, has good textural properties due to the incorporation of rice and also has some medicinal properties which are attributed to ashwagandha. The main objective of this study is to develop a nutritionally rich snack at an affordable price and was to examine the effect of extrusion conditions (temperature, feed moisture content, blending ratio and screw speed) on physical properties of extrudate.

Materials and Methods

Rice, Ashwagandha and Spinach were used for the preparation of iron rich product. In the preparation of this product different level of die head temperature, barrel temperature and screw speed were taken for each set of moisture content and blend ratio. Overall 32 sets of samples were prepared. Effect of their variable on mass flow rate, Bulk Density and sectional expansion index were analyzed.

The moisture content of flour of different blend ratios was measured by hot air oven method. After getting the moisture content of blends, water was added to maintain desired moisture content levels in the blends i.e. 9, 12, 15, 18 and 21%, kept for conditioning for 24 h, calculated by using the formula:

$$W\ w = Wd\ \{\frac{[M2-M1]}{[1-M1][1-M2]}\}$$

W where
W w Wt of water to be added
Wd Bone dry wt. of raw flour
M1 Initial moisture content of flour% wb in decimal
M2 Desired moisture content of flour% wb in decimal.

The laboratory—scale single—screw extruder (model Kompakt E 19/25 D Brabender Duisburg, Germaney) (length-to-dia 20:1; compression ratio 2:1 and die opening 5 mm) was used for extrusion cooking.

Experiment design and analysis Response surface methodology (RSM) was used in designing the experiment [3]. Independent variables such as moisture content, blend ratio of feed, barrel temperature and screw speed were coded as X1, X2, X3 and X4 respectively. Five levels of each of the four variables were chosen according to a central composite rotatable design (CCRD). The coded and actual parameter values are presented in Table 1.

Determination of physical properties low Mass flow rate, Sectional expansion index and Bulk density of extrudate was calculated by standard method [4, 5]. The data obtained from the experiments for different combinations (Table 1) were analyzed by using multiple regression and second order polynomial model and fitted to the experimental data with coded values of independent variables and inter- treated with the help of models and graphs. From the tabulated values, three-dimensional graphs were prepared treating two independent variables to be constant and showing the effect of other two variables on physical properties i.e. bulk density, sectional expansion index and longitudinal expansion index of extrudate.

S. No	Variable Parameters	Code	Code levels				
			-2	-1	0	1	2
1	Moisture content of feed (w.b.) (%)	MC_f	9	12	15	18	21
2	Blend Ratio	B_R	80:15:5	80:12:8	80:9:11	80:6:14	80:3:17
3	Die head temperature	T_{die}	130	150	170	190	210
4	Barrel Temperature (Zone III ^{0}C)	T_{brl}	120	140	160	180	200
5	Screw Speed	S_s	60	70	80	90	100

1. Mass Flow Rate (MFR)

It is the rate at which extrudate come out of the die expressed in grams per second. It was measured by collecting the extrudates in polyethylene bags for a specific period of time (usually counting 20 seconds) as soon it came out of the extruder and the weight was taken instantly.

$$\text{Mass Flow Rate (MFR), g/sec} = \frac{\text{Weight of Sample collected in,,(g)}}{\text{Time taken to collect the sample (s)}}$$

2. Sectional Expansion Index

It is measure of degree of puffing of extrudates, it is an important property from the point of view of quality of extrudate to yield a soft porous and crispy extrudate. Samples of extrudate ware collected randomly from the extruded mass of each batch and their diameter was measured along three mutually orthogonal axes using screw guage (least count 0.01mm) from the average value of three data observed was determined to give the diameter at the section, and then from the diameter of extruded and the given diameter of die the sectional expansion index was calculated as below.

$$\text{Sectional Expansion Ind ex (SEI)} = \left[\frac{\text{Diameter of extrudate}}{\text{Diameter of Die}}\right]^2$$

3. Bulk Density (B.D.)

Bulk density is the mass per unit bulk volume where the volume is calculated including the volume of void spaces, it is calculated by tapping method. The extrudates are filled in a measuring cylinder of capacity 100 ml and tapped, the extrudates are filled in a measuring cylinder of capacity 100 ml and tapped, the extrudates are allowed to settle thoroughly inside the cylinder and when there is no more setting observed further the tapping of the cylinder is stopped and it is weighed and the mass of 100 ml sample is recorded. Now the bulk density is calculated by :

$$\text{Bulk Density} = \frac{\text{Mass of extrudate}}{\text{Volume of extrudae}} (g/cm^3)$$

Results and Discussion

Mass Flow Rate (MFR) of Extrudates

The polynomial model in coded terms generated by multiple regression analysis using CCRD and fitting of second degree polynomial equation for representative response surface of data between mass flow rate of extrudate (MFR) verses different coded levels of feed moisture content (A), blend ratio (B), blend ratio (B), barrel temperature (C), die head temperature (D) and screw speed (E), resulted following model.

The polynomial model in coded value is:

MFR (g/sec) = + 4.31 -0.11 × A - 0.21 × B - 3.20 × C - 1.81 × D + 5.82 × E + 7.712E – 004 × A × B + 0.066 × A × C + 0.027 × A × D + 3.438E – 004 × A × E + 0.17 × B × C - 4.984E – 003 × B × D - 0.12 × B × E + 0.11 × C × D - 1.46 × C × E - 0.90 × D × E - 1.718E - 003 × A2 -7.787E – 005 × B2 + 0.37 × C2 + 0.61× D2 - 0.3 × E2 ……...……………………………………...………......….(a)

A strong association between the different variables under study was endorsed by a fairly good value of R^2 i.e 0.74. The second order model was adequate in describing the mass flow rate of extrudates. The result of analysis of variance (ANOVA) for model 1 (Table 1).

Table 1: Analysis of variance for mass for rate of extrudates (MFR)

Source	DF	SS	MSS	F-Value	P
Regression	20	0.55	0.02	1.02	0.42
Residual	11	0.36	0.033		
Total	31	0.91			

The positive coefficient at linear level indicated that there was increase in response with increase in level of selected parameters and vice versa. Negative quadratic terms indicated that the maximum value of response was at the center point while positive quadratic term represents the minimum response at center point.

The standard deviation, coefficient of variation mean and predicted residual error sum of square (PRESS) values, coefficient of determination and predicted R^2 and adequate precision are given (fig 1 to 4). The response surface analysis graphs for the mass flow rate as a dependent variable against combinations in pair of two different independent variables.

Response surface graphs given in fig.1, 2, 3 and 4 shows the interactive effect of blend ratio and screw speed, effect of die head temperature and barrel temperature, effect of die head temperature and screw speed and effect of barrel temperature and screw speed on mass flow rate of extrudate.

Mass flow rate decreases with increase in bled ratio. Mass flow rate decreases with increase in die head temperature. It is increases with increase in barrel temperature at zone III which shows that the effect of barrel temperature is more pronounced on mass flow rate and also shows that screw speed is directly proportional to mass flow rate i.e. with increase in screw speed the mass flow rate initially increase due to increase in screw speed the discharge through the die increases later at greater discharge there occurs choking of stock in die head assemble and a minor decrease was observed in mass flow rate, increasing screw speed and barrel temperature improve the expansion of extruded ultimately high screw speed and barrel temperature resulted in high mass flow rate and moisture content of feed plays key role in variation of mass flow rate of extrudates. The maximum and minimum values shown from mass flow rate were 1.15 to 0.5581 g/s with mean value of 0.88 g/s.

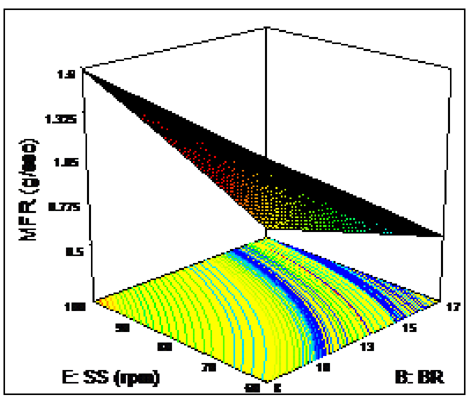

Fig 1: Effect of blend ratio and Screw speed on mass flow rate of extrudates

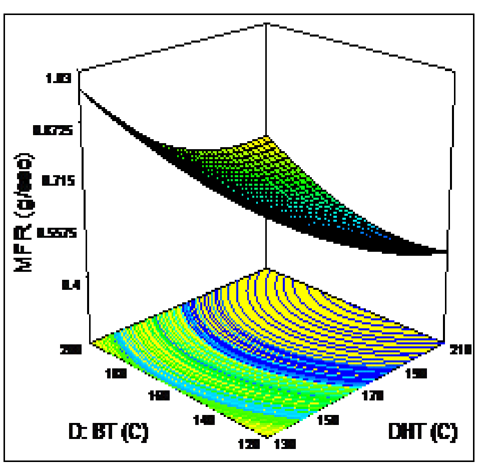

Fig 2: Effect of die head temperature and barrel temperature on mass flow rate of extrudates.

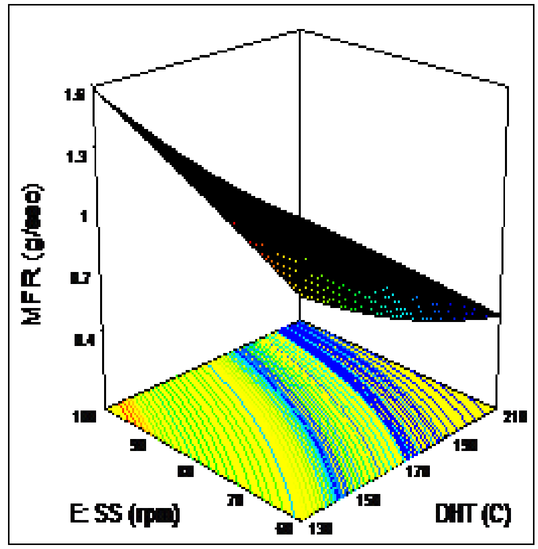

Fig 3: Effect of die head temperature and screw speed on mass flow rate of of extrudates

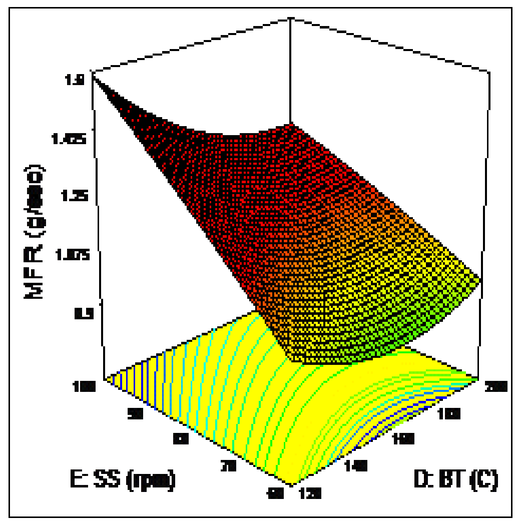

Fig 4: Effect of barrel temperature and screw speed on mass flow rate extrudates

Sectional Expansion Index (SEI) of Extrudates

The polynomial model in coded terms generated by multiple regression analysis using CCRD and fitting of second degree polynomial equation for representative response surface of data between sectional expansion index of extrudate (SEI) verses different coded levels of feed moisture content (A), blend ratio (B), blend ratio (B), barrel temperature (C), die head temperature (D) and screw speed (E), resulted following model.

The polynomial model in coded terms is:

$$SEI= - 3.95 + 0.56 \times A - 0.071 \times B - 5.71 \times C + 2.58 \times D + 15.28 \times E + 4.478E - 003 \times A \times B -0.093 \times A \times C - 0.031 \times A \times D - 0.14 \times A \times E + 0.17 \times B \times C - 0.21 \times B \times D + 0.099 \times B \times E + 3.70 \times C \times D - 0.040 \times C \times E - 3.60 \times D \times E - 0.010 \times A2 - 2.700E - 003 \times B2 - 0.24 \times C2 - 1.20 \times D2 - 5.63 \times E2 \qquad (b)$$

A strong association with different variables under study was endorsed by fairly good value of R^2 i.e. 0.7403. the second order model was adequate in describing the moisture content of extrudates with analysis of variance (ANOVA) for model 2 are presented in Table 2.

Table 2: Analysis of variance for sectional expansion index of extrudates (SEI)

Source	DF	SS	MSS	F – Value	P
Regression	20	2.02	0.10	1.62	0.2072
Residual	11	0.69	0.062		
Total	31	2.71			

The positive coefficient at linear level indicated that there was increase in response with increase in level of selected parameters and vice versa. Negative quadratic terms indicated that the maximum value of response was at the center point while positive quadratic term represent the minimum response at center point.

The standard deviation, coefficient of variation, mean and predicted residual error sum of square (PRESS) values, coefficient of determination and predicted R^2 and adequate precision are The response surface graphs for the SEI as a dependent variable against combination in pair of two different variables of the model 2 are represented by fig 5 to 8.

Response surface graphs given in 5, 6, 7 and 8 shows the interactive effect of moisture content of feed and blend ratio, effect of moisture content of feed and die head temperature, effect of moisture content of feed and effect of blend ratio and barrel temperature on sectional expansion index of extrudates.

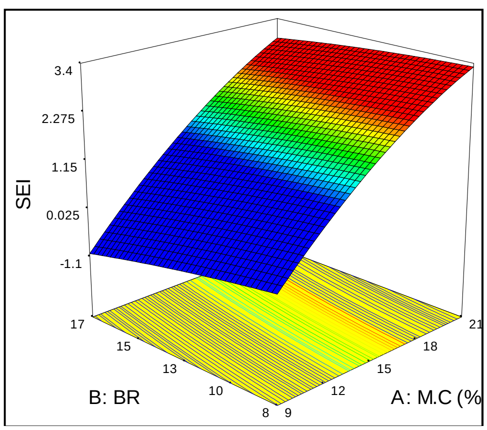

Fig 5: Effect of moisture content and blend ratio on sectional expansion index of extrudates**.**

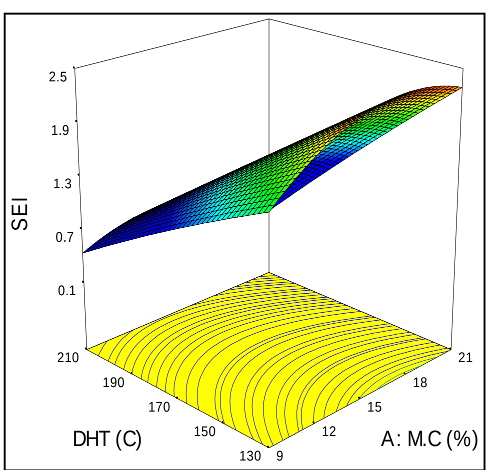

Fig 6: Effect of moisture content and die head temperature on sectional expansion index of extrudates.

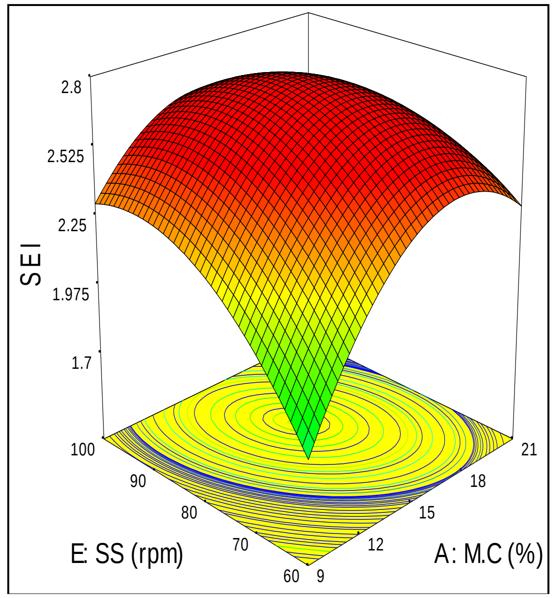

Fig 7: Effect of moisture content and screw speed on sectional expansion index of extrudates.

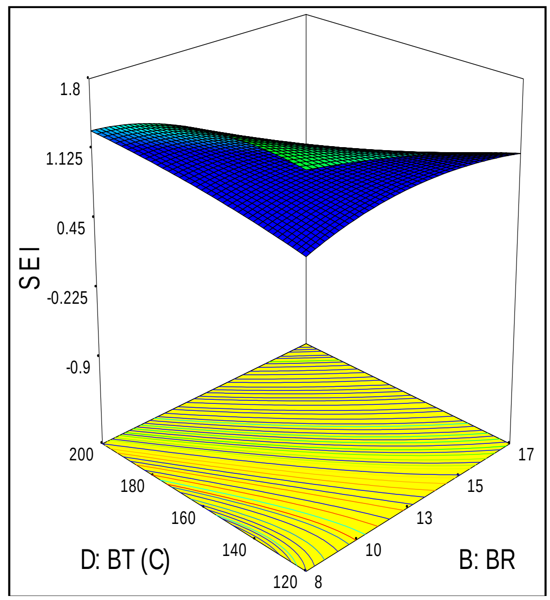

Fig 8: Effect of blend ratio and barrel temperature on sectional expansion index of extrudates

As the value of feed moisture content increases the value of sectional expansion index also increases, the increase in sectional expansion index may be because of due to high percent of rice flour present in blend it is high starch content which is responsible for puffing and the reason being also be that increasing moisture content could be evaporated thus formation of bubbles and air pocket got resulting in higher expansion index. The value of blend ratio increases the sectional expansion index decreases may be because percentage of spinach and ashwagandha in blend i.e. due to high fiber content expansion rate decreases. As increase in die head temperature the sectional expansion index of extrudates decrease. The curvilinear graph between barrel temperature and sectional expansion index, as the value of barrel temperature increases with moisture content, the value of sectional expansion index increases up to center value and beyond that the value of sectional expansion index decreased.

This may be due to the fact that ashwagandha doesn't have good sectional expansion index compared to rice flour causing the reduction in sectional expansion index. As screw speed increases the sectional expansion index of extrudates decrease this is because of retention time increases. The maximum value of sectional expansion index was found to be 2.5 times where minimum value of was 1.12 times and it had mean value of 1.81 times

Bulk Density (BD) of Extrudates

The polynomial model in coded terms generated by multiple regression analysis using CCRD and fitting of second degree polynomial equation for representative response surface of data between bulk density of extrudate (BD) verses different coded levels of feed moisture content (A), blend ratio (B), blend ratio (B), barrel temperature (C), die head temperature (D) and screw speed (E), resulted following model.

The polynomial model in coded value is:

BD = - 3.19 - 0.042 × A + 0.017 × B + 1.23 × C + 2.70 × D + 2.21 × E + 2.083E – 004 × A × B + 0.066 × A × C - 0.043 × A × D - 0.031 × A × E - 0.018 × B × C + 0.011 × B × D - 6.250E -003 × B × E - 0.77 × C × D - 0.72 × C × E + 0.28 × D × E + 9.657E – 004 × A2 - 1.383E – 005 × B2 -0.070 × C2 - 0.35 × D2 - 0.63 × E2…………………………….. (c)

A strong association with different variables under study was endorsed by fairly good value of R^2 i.e. 0.5956. The second order model was adequate in describing the bulk density of extrudates. The results of analysis of variance (ANOVA) for model 3 the brief information are presented in Table 3.

Table 3: Analysis of variance for bulk density of extrudates (BD)

Source	DF	SS	MSS	F – Value	P
Regression	20	0.084	4.188E-003	0.81	0.6722
Residual	11	0.057	5.171E-003		
Total	31	0.141			

The positive coefficient at linear level indicated that there was increase in response with increase in level of selected parameters and vice versa. Negative quadratic terms indicated that the maximum value of response was at the center point while positive quadratic term represents the minimum response at center point.

The standard deviation, coefficient of variation, mean and predicted residual error sum of square (PRESS) values, coefficient of determination and predicted R^2. The response surface graphs for the BD as a dependent variable against combination in pair of two different variables of the model 3 are represented by fig 9 to 12.

Response surface graphs given in 9, 10, 11 and 12 shows the interactive effect of moisture content of feed and blend ratio, effect of moisture content of feed and die head temperature, effect of moisture content of feed and barrel temperature and effect of moisture content of feed and screw speed on bulk density of extrudates respectively.

Fig 9, 10, 11 and 12 shows moisture content increases the bulk density of extrudates also increases and from graph blend ratio increases the bulk density also increases may be due to the percentage of spinach and ashwagandha powder in the blend increase and it contain high percent of moisture. As die head temperature increases the bulk density of extrudate also increases. Also the bulk density increased with the increase in barrel temperature. Fig 12 shows the effect of screw speed and moisture content on bulk density of extrudates. Increase in screw speed increases the bulk density. In increase in screw speed bulk density increases.

Interactive response of pairs of two different independent variables taken together is seen on bulk density of extrudates in figure 4.55 to 4.60 show. The bulk density ranged from 0.85 g/mm to 0.61 g/mm and its mean value was 0.73 g/mm.

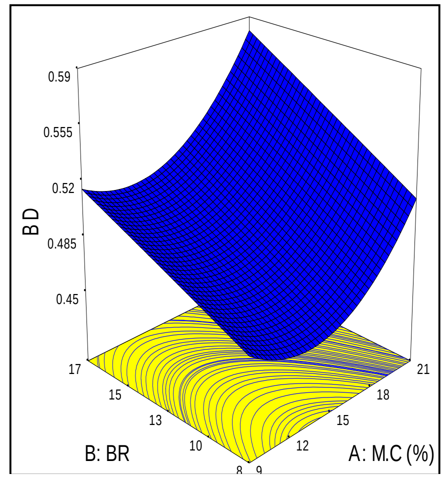

Fig 9: Effect of moisture content and blend ratio on bulk density of extrudates.

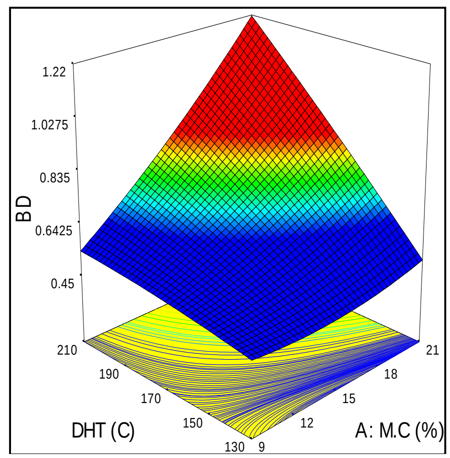

Fig 10: Effect of moisture content and die head temperature bulk density of extrudates.

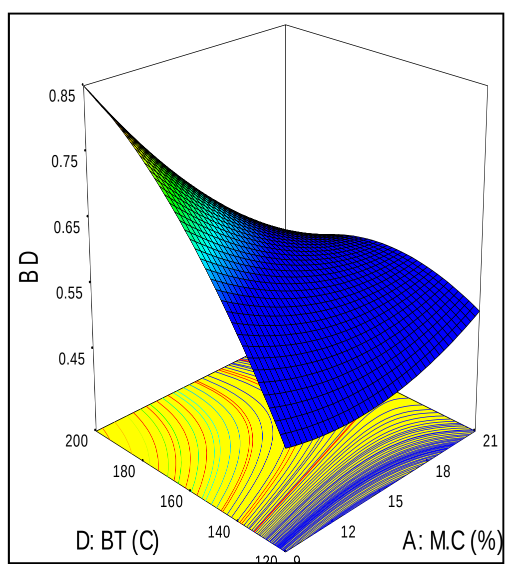

Fig 11: Effect of moisture content and barrel temperature on bulk density of extrudates.

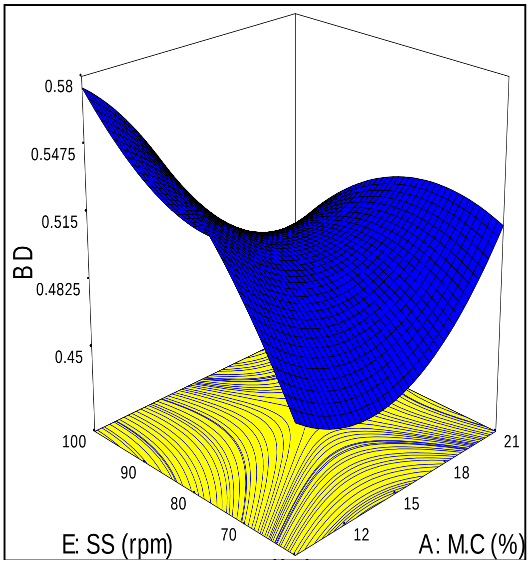

Fig 12: Effect of moisture content and screw speed on bulk density of extrudates.

Conclusion

It was observed that 18% moisture content of feed, 80:15:5 (rice flour: ashwagandha: spinach powder) of blend ratio, 180 °C barrel temperature and 100 rpm of screw speed gave the highest Mass flow rate and sectional expansion index of extrudate, while 15% moisture content, 80:15:5 of blend ratio of feed, 140 °C of barrel temperature and 80 rpm of screw speed gave lowest bulk density of extrudate.

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