International Journal of Basic and Applied Biology
Print ISSN: 2394-5820, Online ISSN: 2349-2539, Volume 2, Number 3; October-December, 2014 pp. 112-119

http://www.krishisanskriti.org/ijbab.html

The Effect of Added Pineapple Pomace Powder and Maize Flour on the Extrusion Cooking of Rice Flour and Process Parameter Optimization by using RSM

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Abstract: *Rice flour (75%) was added to equal amount of pineapple pomace powder (12.5%) and maize flour (12.5%) mixture. The formulation was extruded at different moisture content (8-14%), screw speed (80-120 rpm) & barrel temperature (100-140°C). The lateral expansion, bulk density, water absorption index, water solubility index, hardness and sensory characteristics were measured as responses. In the experiments, increase in barrel temperature resulted in extrudate with higher expansion, higher hardness, lower bulk density, lower WSI and higher WAI. Increasing in screw speed resulted in higher expansion, lower bulk density, higher overall acceptability and lower hardness; whereas, increasing level of moisture resulted in lower hardness, lower expansion and minimum bulk density and higher overall acceptability.*

1. INTRODUCTION

For the last decades, the demand for nutritional and health standards has increased considerably. This has been characterized by rising costs and often decreasing the availability of raw materials together with much concern about environmental pollution. Consequently there is a considerable emphasis on the recovery, recycling and upgrading of wastes. This is particularly valid for the food and food processing industry in which wastes, effluents, residues, and by-product can be recovered and can be upgraded to higher value and useful products.

Pineapple world production reached 21.8 million of tons in 2011 [5], and most of its production is used for processing as fruits salads, juices, concentrates, and jams. During processing, large amounts of by-products, consisting mainly of peel and pomace are generated, representing about 25–35% of the fruit weight[8]. Since most of these by-products have no specific destination, they may be inappropriately disposed causing environmental issues. Consequently, it is of vital importance to reuse industrial by-products in order to improve the process economics and its sustainability. The current way of life, which is characterized by limited free time and increased working hours, has turned consumers to the consumption of ready-to-eat products. In addition, children, worldwide, are attracted to several snack products which are particularly tasty and easy to be consumed. Therefore, food industries have increased the production of ready-to-eat products using several processes. Among these processes, extrusion is a high temperature-short time, well-established industrial technology, which is characterized by continuous cooking, mixing and forming processing and produces direct expanded materials with high quality [4]. Extrusion is flexible in the production of new products, such as cereal baby foods, breakfast cereals, snack foods, bakery products, pastas, etc. During extrusion food materials are thermo-mechanically cooked in a screw-barrel assembly by a combination of moisture, pressure and temperature in order to be mechanically sheared and shaped and they undergo many chemical and structural transformations. Final products' quality depends on the process conditions, such as the extruder type, the feed moisture, the temperature profile in the barrel sections, the screw speed and the feed rate. Additionally, nowadays, there is an increasing trend for the consumption of high-value food products. In order to combine the need for the production of ready-to-eat products with the need for the consumption of high-value products, beneficial ingredients are added to the extruded mixtures. These ingredients include legumes, beans, peas, tomato lycopene, apple pomace, herbs, cactus pear, grape seed, grape pomace etc. Ready-to-eat breakfast cereal is an ideal food for people’s modern-day lifestyle, where speed and convenience, as well as complete nutritional values, are desirable food characteristics.

Applications of extrusion technology to evaluate food industry by-products are relatively recent.Fruit and vegetable wastes are inexpensive, available in large quantities, characterized by a high dietary fibre content resulting to high water binding capacity and relatively low enzyme digestible organic matter [28]. A number of researchers have used fruits and vegetable by-products such as apple, pear, orange, peach, blackcurrant, cherry, artichoke, asparagus, onion, carrot pomace and pineapple waste pulpas sources of dietary fibre supplements in refined food.

Raw pineapple is an excellence source of manganese (45% DV in a 100g serving) and vitamin C (80% DV per 100g). Mainly from its stem, pineapple contains a proteolytic enzyme, bromelain, which breaks down important plant in the bromeliaceae. Pineapple may be cultivated from crown cutting of theprotein. If having sufficient bromelain content, pineapple juice can be used as a marinade and tenderizer for meat.

In India, north east India, cover Tripura, Manipur, Nagaland, Meghalaya and Assam. There is a lot of solid pineapple waste by the canned industries every year; it includes cellulose, hemicelluloses and other carbohydrates. This waste cannot be used for further process and also causes lot of environmental problems and pollution problems. That is why we planned to recycle the pineapple pulp waste in the form of incorporation extruded product. Besides, during pineapple processing, large amount of unusable waste material are generated. Reports have shown that 40-80% of pineapple fruit is discarded as waste having high biological oxygen demand and chemical oxygen demand values.

Pineapple pomace is good source of fiber, minerals so it can be utilize for ready to eat extruded products.The objective of this study was to incorporate pineapple by-products as a source of dietary fibre into ready-to-eat snacks.

2. MATERIAL AND METHODS

2.1 Raw Materials

Pineapple, Maize flour & Rice flour were procured from local market of Jabalpur, Madhya Pradesh, India.

2.2 Pineapple pomace powder preparation

Pineapple was washed in tap water to remove extraneous material. Peel was removed with a plane stainless steel knife and trimming was also done. A juice mixer grinder cum food processor was used to extract pineapple juice. The pomace was collected and blanched. After blanching pomace was cooled and dried. A hot air oven was used for drying pineapple pomace. The samples were spread over the trays and the temperature of the dryer was set at 60°C. The drying procedure continued till the moisture content of the sample was reduced to about 5 ± 1% (wet basis). The grinding was performed using the food processor with grinder attachment. The material was ground to pass through the sieve of 2 mm size. The pomace was stored in sealed polythene bag for further use.

2.3 Sample Preparation

The pineapple pomace powder (12.5%), maize flour(12.5%) and rice flour (75%) were mixed in a food processor with mixer attachment. The moisture content of the formulation was estimated by hot air oven method [10]. The moisture was adjusted by sprinkling distilled water in dry ingredients. All the ingredients were weighed and then mixed in the food processor for 10min .The mixture was then passed through a 2 mm sieve to reduce the number of lumps formed due toaddition of moisture. After mixing, samples were stored inpolyethylene bags at room temperature for 24 h. The moisture content of all the samples were againdetermined by hot air oven method [10] prior to extrusion experiments.

2.4 Development of extruded snacks

Formulation of blend was employed using response surface methodology. Flour samples of 200 g was then extruded through single screw food extruder at barrel temperature (100,120, and140°C), Screw Speed (80, 100, and120 rpm) and Moisture content (8,11 and 14,%). The extrudatesproduced were dried at 105^{0}C for 5-10 min and analyzed for various Product Quality Attributes viz., Expansion Index, Porosity, Bulk Density, Hunter Colour values (L, a and b), Water Absorption Index and Water Solubility Index, Hardness,Rupture energy.

2.5 Physical properties of extrudates

2.5.1 Expansion Index

The diameters of 5 pieces of random were measured with digital vernier calliper and SEI was calculated as the ratio of cross sectional areas of extrudate to that of slit die and averaged.

$$\text{SEI (\%)} = \frac{(\text{Diameter of extrudate})^2}{(\text{Diameter of die})^2}$$

5.2 Bulk Density

Bulk density (BD, g/cm^3) was calculated using the following expression. [31]

$$BD = \frac{4m}{\pi d^2 L}$$

Where m is mass (g) of length L (cm) of extrudate with diameter d (cm).

2.5.3 Hunter colour values

The colour of the raw material and the ground extrudates were measured in a Hunter Lab LabScan XE (Hunter Associates Laboratory Inc., Reston, Virginia, USA) as lightness (L), redness (a) and yellowness (b). The extrudates were ground in laboratory grinder and passed through a 20 mesh sieve prior to colour analysis. For each sample, four measurements were taken and averaged. The total color change (ΔE) was calculated as

$$\Delta E = \sqrt{(L - L_0)^2 + (b - b_0)^2 + (a - a_0)^2}$$

Where, the subscript '0' indicates initial colour values of the raw material.

2.5.4 Water Absorption Index (WAI) and Water Solubility Index (WSI)

The extrudates were milled to a mean particle size of approximately 180-250 µm. A 2.5 g sample was dispersed in 25 g of distilled water, using a rod to break up any lumps. After stirring for 30 min using magnetic stirrer, the dispersions were rinsed in to tared 50 ml centrifuge tubes, made up to 32.5 g and then centrifuged at 3000xg for 10 min. The supernatant was decanted for determination of its solids and sediments were weighed.

$$WAI\ (g/g) = \frac{\text{Weight gain by gel}}{\text{Dry weight of extrudate}}$$

$$WSI\ (\%) = \frac{\text{Weight of Dry Solid in Supernatan t}}{\text{Dry weight of extrudate}} x100$$

2.5.5 Hardness

The textural evaluation of the extrudates was performed with texture analyzer (TA-HD*i*). The extrudates was conditioned at warm temperature and low relative humidity, to remove the effect of moisture sorption during storage or between the times it takes from extrusion to texture analysis [15, 16]. The hardness of extrudates was determined as the maximum force offered by extrudates during compression test in a texture analyzer (model TA-HDi).

2.5.6 Rupture energy

The rupture energy was calculated using the following formula.

$$Breaking\ Strength = \frac{Peak\ breaking\ force,\ N}{Cross\ sec\ tional\ area,\ M^2}$$

2.5.7 Porosity

Porosity was calculated using the following formula:

Porosity= Particle density-Bulk Density/particle Density *100

2.6 Experimental design

In order to ascribe the effect of factors on response surface, a central composite rotatable design (CCRD) with three factors were performed. 20 experiments were conducted as per central composite rotatable design (CCRD) (Table 3). The independent variables affecting the quality of the product were the varied levels of moisture content (X_1), barrel temperature (X_2), and screw speed (X_3). (Table 2).

2.7 Analysis of data

The second order polynomial response models were fitted foreach response variables (Y) with the independent variable (x):

$$Y_K = \beta o + \sum_{i=1}^{m} \beta_i X_i + \sum_{i=1}^{m-1} \sum_{j=i+1}^{m} \beta_{ij} X_I X_j + \sum_{i,j=1}^{m-1} \beta_{ij} X_i^2 X_j^2$$

Where Y_k is response variable, $\beta_0$is value of the fitted response at the centre point of design, β_i, β_{ij}, : linear, quadratic and interactive regression coefficients, X_i&X_j *is* Coded independent variable. The mathematical models were evaluated for each response by means of multi linear regression analysis. The significant terms in the model were found by Analysis of Variance (ANOVA) for each response with 95% of confidence ($p<0.05$). Significance was judged by determining the probability level that the F-statistic calculated from the data is less than 5%. The adequacy of the model was determined using model analysis, lack of fit test, coefficient of determination R^2 . The model generally considered adequate when the calculated F-value is more than significant value. Maximization and minimization of the polynomials thus fitted was performed by desirability function method and mapping of the fitted response was achieved using Design-Expert 6.0 software.

3. RESULTS AND DISCUSSION

3.1 Raw material Analysis

Raw materials used for the development of extrudates preparation such as rice flour, maize flour,and pineapple pomace powder (PPP) were analyzed for their physicochemical properties.The results from the analysis were shown in table 1.

Table 2: Proximate analysis of raw materials

Raw material	Moisture%	Ash%	Protein (mg/g)
Rice Flour	11.58±0.3	0.5±0.05	0.52±0.01
Maize Flour	8.98±0.05	1.21±0.02	.70±0.01
Pineapple pomace powder	8.89±0.01	0.45±0.02	0.54±0.00

Table 2: Coded and non-coded values of independent variables for extrudates preparation

Independent variables	Symbols		Levels	
	Uncoded	Coded	Uncoded	Coded
Moisture content (%)	t1	X1	5.95	-1.4142
			8	-1
			11	0
			14	1
			16.5	1.1442
Barrel temperature	t2	X2	86.36	-1.4142
			100	-1

(0C)			120	0
			140	1
			153.64	1.1442
Screw speed (rpm)	t3	X3	66.368	-1.4142
			80	-1
			100	0
			120	1
			133.64	1.4142

3.2 Levels and codes of the independent variables

Coded and non-coded values of variables and their levels for preparation of beverage are shown in table 2.

3.3 Diagnostic checking of the fitted models

The actual values of the test variables and the experimental results are shown in Table 3.All main, linear, quadratic and interactive effects were calculated for each model.The correlation coefficients for the responses are shown in Table 4 The calculated F-values were more than the table F-value indicating the adequacy of the models.Allnine responses were considered adequate to describe the effect of variables on the quality of extruded products.

3.4 Effect of process variables on product colour (L Value, a value, b value)

Response surface plot for L, a, and b as a functions of moisture content, barrel temperature and screw speed are given in (fig 1, fig.2, fig.3).The L-values of extrudate wasfound between 57.7 to 64.44,a-values ranged between 0.8 to 2.74 and b-values were ranged between 12.53 to 13.98 respectively.

Table 3: The central composite rotatable experimental design for development of Pineapple pomace based extrudates and the responses of developed extrudates.

Independent Variables				Dependent Variables									
S.NO	Moisture Content (%) X1	Temperature (0C)X2	Screw speed (rpm) X3	Colour L Value	Colour a Value	Colour b Value	Bulk density g/cm3	WAI (g/g)	WSI (%)	Hardness (N)	RE	Porosity	EI
1	11	120	100	59.1	2.20	12.88	.457	2.612	5.6	19.67	.89	82.7	4.4
2	14	100	80	59.2	2.10	12.85	.502	2.590	5.5	40.79	.72	85.34	4.2
3	11	120	100	64.2	2.70	12.86	.687	2.605	5.4	23.67	2.1	97.3	4.5
4	11	120	100	63.9	2.52	13.27	.335	2.627	7.1	30.07	1.9	89.2	4.9
5	11	120	100	63.7	1.40	13.20	.526	1.228	6.9	28.50	1.5	95.7	4.7
6	11	120	133.64	60.8	1.20	12.47	.395	2.163	7.2	22.78	.71	123.6	5.3
7	14	140	120	60.0	1.11	12.94	.451	2.290	8.1	29.80	.20	132.3	4.5
8	8	100	120	59.9	0.80	12.53	.814	2.546	5.6	10.36	2.1	98.9	5.5
9	8	100	80	60.5	1.71	12.80	.490	2.580	7.3	15.21	2.4	138.3	4.7
10	11	120	100	59.2	2.70	13.98	.232	1.328	12.6	12.71	1.3	88.6	4.9
11	5.95	120	100	59.3	0.72	12.92	.521	2.578	5.6	28.91	1.1	94.4	4.1
12	14	140	80	59.3	2.35	12.88	.538	2.580	10.3	30.49	1.9	121.2	4.3
13	8	140	120	57.7	2.39	13.02	.321	2.678	7.5	30.74	2.4	135.8	5.1
14	16.05	120	100	58.6	1.35	12.95	.440	2.551	9.1	28.78	2.2	132.2	5.3
15	11	153.64	100	58.0	1.20	12.81	.502	2.665	5.7	31.21	1.8	130.1	4.6
16	11	86.36	100	59.8	1.45	12.82	.721	2.615	6.5	27.51	1.2	111.7	5.4
17	8	140	80	57.5	2.74	11.95	.339	2.582	6.9	25.45	2.5	92.4	4.8
18	11	120	100	64.4	1.65	13.29	.415	2.578	5.6	13.71	2.1	86.5	5.2
19	11	120	66.36	62.2	1.42	12.82	.529	2.352	8.9	29.8	2.3	119.2	5.3
20	14	100	120	61.5	1.40	12.85	.667	2.621	6.8	32.69	1.1	131.9	4.9

F value was 7.63 and the p-value was 0.0019 which was significant in L value.F value was 6.30 and the p-value was 0.0041 which was significant in a value.F value was 6.73 and the p-value was 0.0031 which was significant in b value.ANOVA for color suggests that linear model has significant effect with the value of p is 0.0019($P \leq 0.01$).Value of R^2 is 85% of a value and value of color changes from 0.8 to

2.74. ANOVA for color suggests that linear model has significant effect with the value of p is 0.0041(P≤0.01). Value of R^2 is 85.84% of b value and value of color changes from 12.53 to 13.28.ANOVA for color suggests that linear model has significant effect with the value of p is 0.0019(P≤0.01).

Table 4: Regression coefficients for response variables

PARAMETER	L	a	b	BD	WAI	WSI	h	RE	POROSITY	EI
CONSTANT	1.0149601	-9.88699	13.66289	4.51829	-2.07401	91.77671	-108.598	11.32642	-143.3293	-0.430599
X1	-0.46592	0.56002	-0.32705	-0.2193	-1.1694	-4.30549	019.1181	-0.4444	-8.66583	-0.70276
X2	-0.50539	0.16807	0.043084	-0.0358	0.12397	-0.69156	0.23430	0.049320	2.644440	0.10158
X3	-0.26690	-0.01541	-0.03142	-0.0208	0.0626882	-0.52527	0.23430	-0.20973	2.43023	0.15648
X12	0.0097420	-0.00314253	-0.012618	-0.00194248	-0.000725317	0.011256	-0.025669	-0.029668	0.41449	0.00665750
X22	0.0009439	-0.0000707068	-0.000266225	0.000013557	-0.000319492	0.000871969	0.000306556	-0.000764767	-0.0086785	-0.000283309
X32	0.0021283	-0.0000751339	-0.000142481	0.000000649439	0.0000039807	0.00025325	0.000258256	0.000034926	0.000644074	-0.000433569
X1*X2	0.016146	-0.00856	0.00135417	0.00140833	0.0055833	0.021875	-0.071771	0.00054166	0.031271	0.00304167
X1*X3	-0.018562	0.00618750	0.00439583	0.00003	0.00515833	0.016042	0-0.098438	0.00043333	-0.076396	0.00145833
X2*X3	0.0011093	-0.00067185	0.000103125	0.000168813	-0.00103812	-0.00290652	0.00356562	0.000737500	-0.00729062	-0.000718750
R2	0.8729	0.85	0.8584	0.75089	0.9147	0.73	0.8366	0.8264	0.8602	0.8546

Table 5: Analysis of variance of Responses

RESPONSES	REGRESSION	SUMOFSQUARE	FVALUE	P>F
L	LINEAR	0.5249	5.89	.066
	QUADRATIC	0.8729	7.63	.0019
	2FI	0.7403	6.18	.030
	TOTAL MODEL	88.25		
a	LINEAR	0.3288	2.56	.0949
	QUADRATIC	0.85	6.30	.0041
	2FI	0.8446	11.78	.0001
	TOTAL MODEL	7.24		
b	LINEAR	0.0882	.52	.6773
	QUADRATIC	0.0031	6.73	.0031
	2FI	0.0419	3.09	.0419
	TOTAL MODEL	1.25		
Bulk density	LINEAR	0.0810	.47	.7071
	QUADRATIC	0.7508	3.35	.0367
	2FI	0.7199	5.57	.0047
	TOTAL MODEL	0.15		
WAI	LINEAR	0.046	.26	.8551
	QUADRATIC	0.9147	11.91	.0003
	2FI	0.8494	12.22	.0001
	TOTAL MODEL	3.79		
WSI	LINEAR	0.4162	3.80	.0017
	QUADRATIC	0.8757	7.93	.132
	2FI	0.8504	12.31	.0001
	TOTAL MODEL	689.45		
HARDNESS	LINEAR	0.1683	1.08	.3859
	QUADRATIC	0.8366	5.69	.0060
		0.8119	9.35	.0004
	TOTAL MODEL	689.45		
RE	LINEAR	0.0179	40.097	.9605
	QUADRATIC	0.8264	5.29	.0078
	2FI	0.3698	1.27	.03350
	TOTAL MODEL	5.92		
POROSITY	LINEAR	0.7200	13.71	.0001
	QUADRATIC	0.8602	6.84	.003
	2FI	0.7744	7.44	.0013
	TOTAL MODEL	4856.46		
EI	LINEAR	0.1597	1.01	.027
	QUADRATIC	0.8546	6.53	.015
	2FI	0.5725	2.90	.342
	TOTAL MODEL	2.40		

3.5 Effect of process variables on product bulk density

Bulk density is a major physical property of the extrudate products. The coefficients of the model and other statistics are given in Table 3, 4 & 5.

It is perceived from fig.4 that bulk density initially decreased with moisture content, whereas further increases. However bulk density decreased initially with screw speed whereas further increase with screw speed.The contour plot in fig.4 demonstrate the initial increase in bulk density with the increase in temperaturewhereas further decreases with the increase in temperature.

3.5 Effect of process variables on product water absorption index

The water absorption index of extrudates varied in the range of 1.328 to 2.678 g/g. The coefficients of the model and other statistics are given in Table 3,4 &5. It was observed from fig.5 that increase in temperaturecontent resulted in quadratic decrease in water absorption index. Water absorption index increased with increase in screw speed, may be attributed to high mechanical shear and higher expansion due to gelatinization. Whereas further decrease water absorption index may be because of plasticization of melt at higher moisture content**.**

3.6 Effect of process variables on product water solubility index

Water solubility index of extrudates ranged from 5 to 12.9%. The coefficients of the model and other statistics are given in Table 3, 4 & 5. The Model F-value of 7.83 indicates that the model is significant (P <0.05.Analysis of variance of equation show that F values for X_1 ,$X_2$and X_3were within 5 and p value more than 0.0017 (P < 0.05), indicating no direct significance on water solubility index.It is evident from fig 6.that water solubility index decreased initially and increased further with increase in temperature**.**Water solubility index increases with increase screw speed due to high mechanical shear exerted on extrudates. It was observed from fig.6 that water solubility index decreased initially with the increase in moisture content.

3.7 Effect of process variables on product hardness

Hardness of rice flour, maize flour and pineapple pomace extrudate varied between 10.36 and 31.21 N. Table 3,4 &5. shows the coefficient of the model and other statistical attributes of hardness. The Model F-value of 5.69 implies the model is significant. It is evident from fig.7 that the hardness increase with the increase in moisture content& temperature.It may be observed from fig. 7that hardness decreased with the increase in screw speed.

3.8 Effect of process variables on product rupture energy

Response surface plot for breaking force as a function of screw speed and moisture content is given in Fig. 8. From experimental data it is clear that breaking force showed decreasing trend with increasing screw speed. The breaking force was found in the range of 0.2 to 2.53. Based on the data and response surface plot.Analysis of variance results showed that for linear, quadratic and interaction models has significant effect on rupture energy at p values of 0.0078,0.097 and 0.033 respectively.Value of R^2 is 0.0078 and value of adjacent $R^2$is 0.097 and rupture energy of extruded products ranges from 0.2 to 1.52.

3.9 Effect of process variables on product porosity

Analysis of variance results showed that for linear, quadratic and interaction models has significant effect on porosity at p values of 0.001,0.001 and 0.003 respectively**.**All the processing parameters have negative effect on porosity except interaction of pineapple pomace powder with feed moisture. Positive sign represents increase in porosity with increase in process variables. Value of R^2 for porosity is 0.7744.Porosity of extruded products ranges from 85.34 to 138.34.

3.10 Effect of process variables on product expansion index

From experimental data it is clear that EI ranges between 4.2 and 5.55. Expansion index showed increasing trend with increasing screw speed, increases up to certain level and then decreases with increasing screw speed. .Value of $R^2$for EI is 0.8546 and the value of EI ranges from 4.2 to 5.55**.**

4. CONCLUSION

Response Surface Methodology (RSM) was applied successfully for the optimization of feed formulation for production of extruded snacks, using pineapple pomace powder as base material. The moisture content (8-14%), screw speed (80-120 rpm) & barrel temperature (100-140°C) were taken as process parameters and Colour values (L, a and b), bulk density, water absorption index, water solubility index, hardness, rupture energy, porosity and expansion index, were taken as response parameters. The effect of moisture content, screw speed & barrel temperature on response parameters were also analyzed through Design-Expert 6.0 software. The second order polynomial response models were fitted for each response variables, RSM and ANOVA tests were performed.

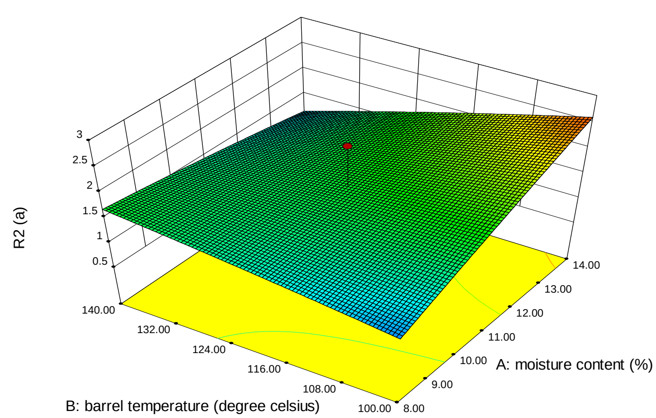


Fig. 1: Effect of Moisture content, screw speed and barrel temperature on L value

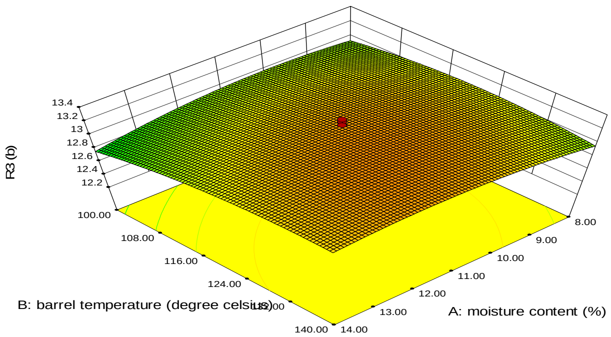


Fig. 2: Effect of Moisture content, screw speed and barrel temperature on a value

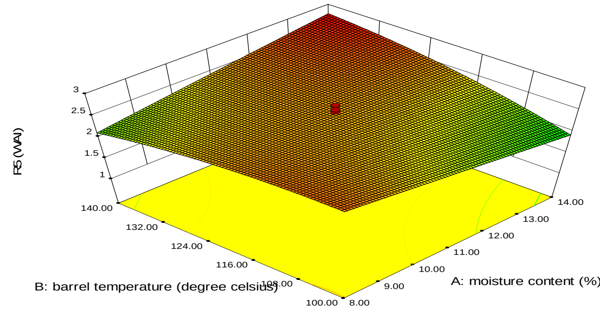


Fig. 5: Effect of moisture content, screw speed and barrel temperature on WAI

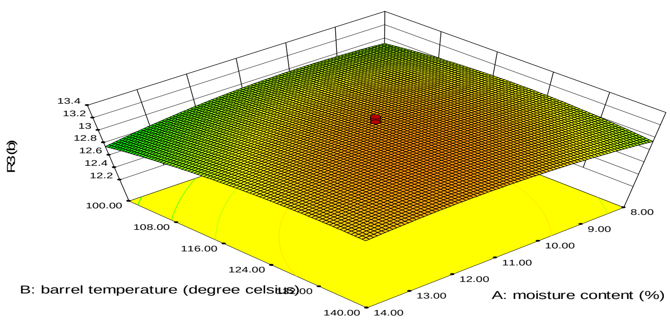


Fig. 3: Effect of Moisture content, screw speed and barrel temperature on b value

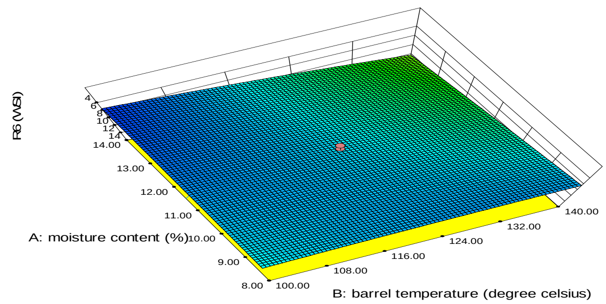


Fig. 6: Effect of moisture content, screw speed and barrel temperature on WSI

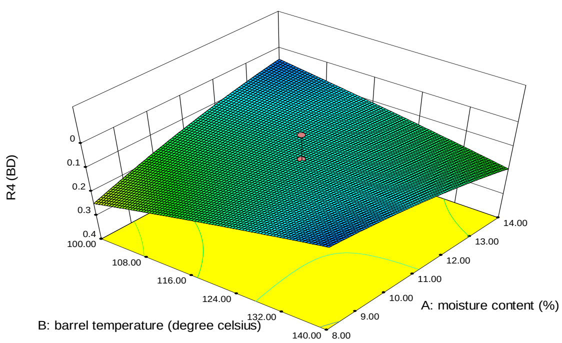


Fig. 4: Effect of Moisture content, screw speed and barrel temperature on Bulk density

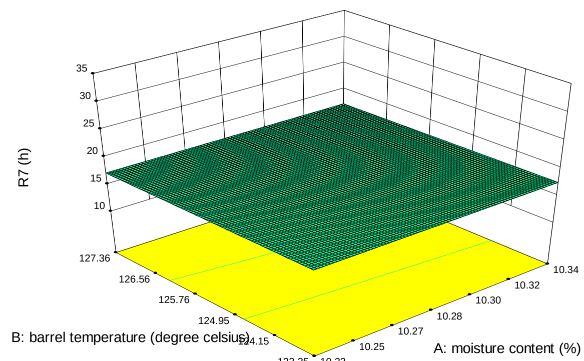
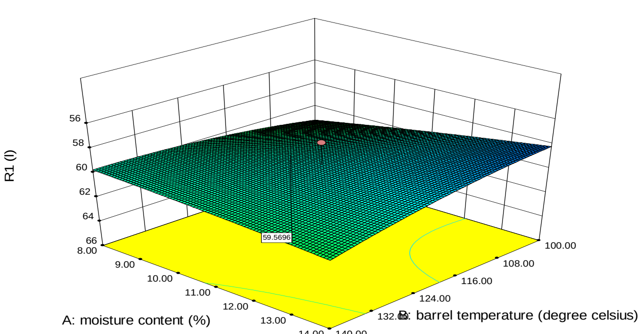


Fig. 7: Effect of moisture content, screw speed and barrel temperature on Hardness



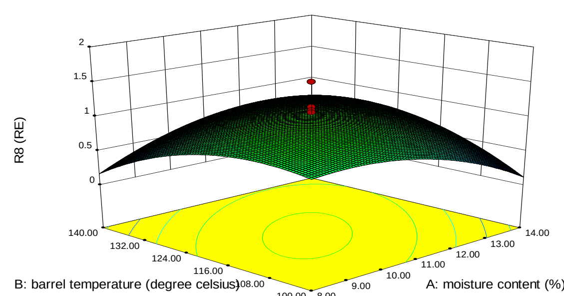


Fig. 8: Effect of moisture content, screw speed and barrel temperature on Rupture energy

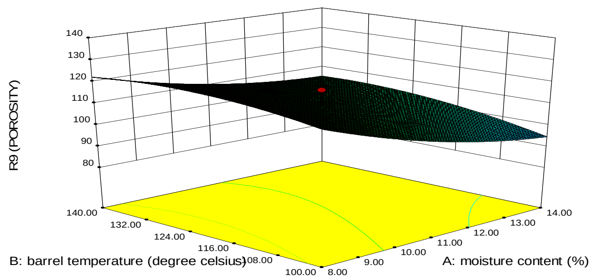
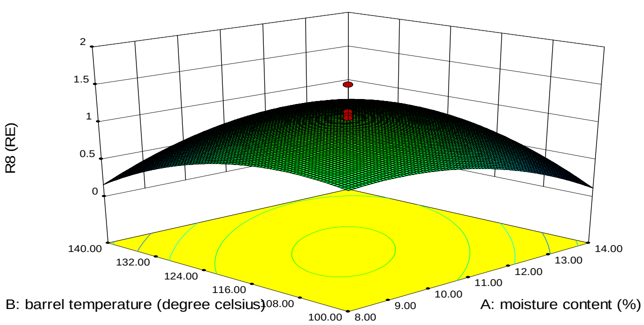


Fig. 9: Effect of moisture content, screw speed and barrel temperature on Porosity



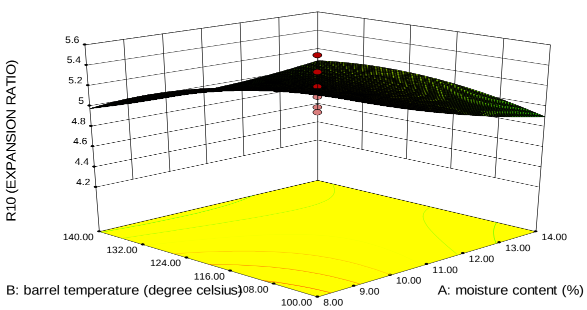


Fig. 10: Effect of Moisture content, screw speed and barrel temperature on Expansion index

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