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Effect of Operating Parameters on Physical Properties of Kodo Based Soy Fortified Ready to Eat Extruded Snacks

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A B S T R A C T

Response surface methodology (with central composite rotatable design) was used to investigate the physical properties of extruded kodo-defatted soy flour-water chestnut blends in a Brabender single screw extruder. The effect of extrusion operating parameters mainly moisture content in blend, barrel temperature, die head temperature, screw speed and blend ratio on quality of extruded products were determined. The properties of product were evaluated on the basis of moisture content of extrudates (MCE), sectional expansion index (SEI), bulk density (BD) and water absorption index (WAI). CCRD based prediction model were developed by CCRD base optimization to relate the product responses to process variable as well as to obtain the response surface plots.

Introduction

During the recent years quite a number of technologies in food processing have been emerged and made an impact on the availability and variety of food products. Food extrusion is one of these latest multidimensional food processing techniques.

Great possibilities are offered in food processing field by the use of extrusion technology to modify physicochemical properties of food components. The extruded food, besides its preserved and frequently even enhanced biological value, can be characterized by physicochemical properties superior to the original raw material (Riaz *et al.*, 2007). The extensive development of extrusion technology represents one of the most significant achievements in field of food processing in the last fifty years. The expansion of food extrusion technology has been accompanied by considerable research activity that has generated an impressive volume of new knowledge as to the physics and chemistry of the process. The thermo-mechanical action during extrusion brings about starch gelatinization and inactivation of enzymes, microbes and anti-nutritional factors. All this occurs in a shear environment, resulting in a plasticized continuous mass (Bhattacharya and Prakash, 1994). The product properties are influenced by extruder operating parameters, such as barrel and die temperature, screw speed, screw configuration and die shape, as well as raw material formulation, namely moisture, protein, starch, lipid contents etc (Moraru and Kokini, 2003). Extrusion cooking is defined by Berk (2009) as a thermo-mechanical process in which heat transfer, mass transfer, pressure changes and shear are combined to produce effects such as conveying, mixing, kneading, melting, cooking, sterilization, drying, texturizing, puffing, cooling, freezing, forming, conching (chocolate) etc.

Snack, defined as a light meal eaten between regular meals include a broad range of products that can take many forms (Sajilata and Singhal, 2004). Snack foods are designed to be less perishable, more durable and more appealing than natural foods. Different types of snack foods are available of which the new generation snacks fall into several categories such as low fat, baked but not fried, high fiber products made from millets. 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. Snacks contribute an important part of many consumers' daily nutrient and calorie intake (Bhattacharya *et al.*, 1997).

Millets are important ecological food security crops known for their nutritional quality. Although recognized as nutritious cereals, they are generally absent in commercial channels; rather they are little explored for the possibility of developing novel food products using new processing technologies. India is a top producer of millets with an annual production of 334500 tons (43.85%) (FAO, 2012) and Kodo (*Paspalum scrobiculatum*) is one among the six other minor millets. Nutrient composition of Kodo per 100 g edible portion with 12 % moisture content is: protein 9.8 g, fat 3.6 g, ash 3.3 g, fiber 5.2 g, carbohydrate 66.6 g, energy 353 kcal, Ca 35 mg, Fe 1.7 mg, thiamine 0.15 mg, riboflavin 0.09 mg and niacin 2.0 mg (Hulse *et al.*, 1980).

Soy protein is widely used in food applications due to its functionality and health benefits (Liu, 1997; Riaz, 2006). Effective October 1999, the US Food and Drug Administration has approved the use of soy protein health claims on food labels based on human intervention studies and clinical trials that show a high association between consumption of soy protein and the reduced risk of coronary heart disease (e-CFR 101.82, 1999). American Soybean Association (ASA) recommended standard for defatted soy flour is protein 50%, moisture 9%, fat 1.5%, crude fiber 3.5% and ash 7% (Gandhi, 2009).

Water chestnut (Trapa bisinosa Roxburg) locally known as Singhara, is an annual aquatic warm season crop. In general, the cultivation of water chestnut is distributed throughout the country especially in Punjab, Bihar, Uttar Pradesh, Madhya Pradesh, Tamil Nadu, Maharashtra and in some parts of Uttarakhand. The nutrient composition of the raw fruit per 100 g edible portion is: energy 117 kcal, moisture 66.4 g, protein 4.1 g, fat 0.4 g, total carbohydrate 27.8 g, fibre 0.8 g, ash 1.3 g, Ca 54 mg, P 114 mg, Fe 1.2 mg Na 21 mg, K 452 mg, β-carotene traces, thiamine 0.13 mg, riboflavin 0.06 mg, niacin 2.0 mg and ascorbic acid 7 mg (Leung *et al.*, 1972)

In order to incorporate healthy and tasty nutrients available in kodo, soybean and water chestnut and to prepare an extrudate snacks as well as to ensure high value to the millet growing farmers. In this experiment, the effect of operational parameters on the physical properties of extrudates were studied.

Materials and Methods

Raw materials

The kodo millet flour, defatted soy flour and water chest nut flour were taken as raw materials for the present study. The kodo millet was procured from Tamia (block), Chhindwara (MP). Defatted soy flour was procured from Ruchi Soya Industries Ltd., Indore (MP). Water chest nut flour was procured from the local market of Jabalpur, manufactured by Dhanhar Exim Pvt. Ltd. Dhanhar House, Bhajiwali Pole, Bhagal, Surat (Gujarat).

Extrusion

In the present study, a laboratory extruder model single screw (Brabender D47055 DUISBURG, Germany) was used for extrusion of different blends of kodo millet flour, defatted soy flour and water chest nut flour. The extruder consists of grooved barrel with heating elements and cooling jackets. The constructional features of the extruder incorporate motor and gear unit, coupling, loading unit, extruder barrel with screw and control cabinet. A temperature controller controls the temperatures of all the zones; the maximum temperature which can be achieved by each zone is 450^{o}C. The feeding zone of the extruder is water-cooled and compression and metering zones are air-cooled. A round die head assembly is fixed at the end of the barrel. In the present study a round die of 3 mm diameter was used. The feed screw with feeding device is mounted above the feed opening. Transducers and sensors are available for measuring melt pressure and melt temperature within the extruder and on the die head assembly. A 1.5 kW, 50 Hz and 1395 rpm electric motor is used to drive the extruder (make: Lenze Extertal, Germany). The L/D ratio of the screw used in Brabender food extruder is 20:1 and the compression ratio of the screw was 2:1.

Experimental design

Central Composite Rotatable Design of Response Surface Methodology (RSM) was used to reduce the number of experimental runs without affecting the accuracy of results and determines interactive effect of variables on the response (Cocharan and Cox, 1957). In this study Central Composite Rotatable Design (CCRD) with half replicate of five independent variables with five levels of each has been chosen in table 1.

The Central Composite Rotatable Design can be fitted into a sequential programme starting with an exploratory 2k factorial to which a linear response surface is fitted (Cocharan and Cox, 1957). Based on the information available in the literature and preliminary trial five independent variables namely; Die Head Temperature (^{o}C), Barrel Temperature (^{o}C), moisture content, Blend ratio (Kodo flour : Defatted soy flour : Water chestnut flour) and screw speed (rpm) were selected for production of ready to eat snack food. The experimental plan consisted of 32 treatment combinations of each independent variable chosen. The data obtained from the experiment outlined were processed using the Design Expert 9. The adequacy of model was tested using F ratio and coefficient of determination R^2.

The model was considered when the calculated F ratio was more than that of table value (Henika, 1982). The effect of variables at linear, quadratic and interactive level on the response was described using significance at 1, 5 and 10% level of confidence.

In this present study, the effect of operational parameters i.e. moisture content of blend, die head temperature (DHT), barrel temperature (BT), blend ratio (BR) and screw speed (SS) on the physical properties viz. moisture content of extrudates (MCE), sectional expansion index(SEI), bulk density (BD), and water absorption index (WAI) of extrudates were studied.

Blend preparation

Water chestnut and defatted soy flour was procured from market and flour of kodo millet was prepared by grinding in the hammer mill. The moisture content of the flour at different blend ratios was measured by standard air oven method. The moisture content of the samples was regulated in five different levels i.e. 8, 10, 12, 14 and 16% (wb). After getting the moisture content of kodo millet flour-defatted soy flour-water chestnut flour blends, additional water required to raise the moisture content to desired levels of blends i.e. 8, 10, 12, 14 and 16% (wb) was calculated. Then the calculated amount of water plus an additional amount of 10% of calculated water was added to supplement the evaporation losses during mixing and conditioning. The mixtures were then stored in plastic bags for 24 h in order to equilibrate (tempering of the samples) and then their moisture content was determined. If the determined moisture content was not desired, certain amounts of either distilled water or materials were added for correction.

Preparation of extrudates

The conditioned samples were then feed to the Brabender single screw extruder under set operational conditions. The product after coming out of the extruder discharge end through round die, expanded due to sudden release of pressure. The extrudates were collected and packed in laminated polythene bags and properly labeled for further analysis.

Determination of physical properties

Moisture Content of the Extrudate (MCE)

Moisture content of extrudates was measure using standard air oven method according to AOAC, 2002.

Sectional expansion index (SEI)

It is measure of degree of puffing extrudate, it is an important property from the point of view of quality of extrudate to yield a soft, porous and crispy extrudate. In present study a rounf die of 5mm was used. Samples of extrudates are collected randomly from the extruded mass of each batch and their diameter is measure along thee mutually orthogonal axes using digital screw gauge (least count 0.01mm) from the average value of ten data observed was determined to give the diameter at the section, and then from the diameter of extrudate and the given diameter of die the sectional expansion index was calculated below (Harper, 1981a; Alvarez-Martinez *et al.*, 1988; Fan *et al.,* 1996; Singh *et al.,* 2000):

$$\text{Sectional Expansion Index (SEI)} = \frac{\text{Diameter of Extrudate/mm}}{\text{Diameter of Die/mm}} \qquad (1)$$

Bulk Density (BD)

Bulk density is the mass per unit bulk volume is calculated including the volume of void spaces, it is calculated by tapping method. The extruded are filled in cylinder of capacity 100ml and tapped the extrudates are allowed to settle thoroughly inside the cylinder and when there is no more settling observed further the taping of cyinder is stopped and is weighed and the mass of 100 ml sample is recorded. Now the bulk density is calculated as (Chinnaswamy and Bhattacharya, 1983; Ushakumari *et al.*, 2007):

$$BD\ (Kg/m^3) = \frac{(\text{mass of 100 ml sample})(Kg)}{\text{volume of sample } (100\text{ ml} \times 10^{-6})m^3} \quad (2)$$

Water Absorption Index (WAI)

It is calculated by grinding the extrudate and applying the following equation (Anderson *et al.*, 1969; Yagci and Gogus, 2008):

$$WAI = \frac{(W_2 - W_1)}{W1} \times 100 \quad (3)$$

Where,

W_1 = weight of grind extrudate sample (10 g)

W_2 = weight of grind extrudate sample after keeping in water (about 10 times of weight sample) for half an hour.

Results and Discussion

Moisture content of extrudates (MCE)

The predicted polynomial model developed for MCE is:

$$MCE = +5.75 + 0.12 \times A - 0.025 \times B + 0.17 \times C + 0.14 \times D - 0.11 \times E - 0.14 \times AB + 0.34 \times AC - 0.19 \times AD - 0.19 \times AE + 0.31 \times BC - 0.11 \times BD + 0.087 \times BE - 0.037 \times CD + 0.062 \times CE + 0.038 \times DE - 0.048 \times A^2 + 0.052 \times B^2 + 0.077 \times C^2 - 0.098 \times D^2 + 0.027 \times E^2 \ldots\ldots\ldots\ldots\ldots (4)$$

Where A = moisture content of blend, B = blend ratio, C = barrel temperature, D = die head temperature and E = screw speed.

The moisture content of extrudates ranged from 4.61 to 7.02 with a mean value of 5.76 %(wb). It can be observed in figure 1 that the moisture content of extrudates increases and the rate of increase is almost uniform with increase in moisture content of feed. Also the moisture content of extrudates decreases with increase in the proportion of defatted soy flour in blend. The increase in moisture content of extrudates at higher moisture values is because of retention of more moisture in extrudates obtained from high moisture feed. Whereas the decrease in moisture content of extrudates with increase in proportion of defatted soy flour may be because defatted soy flour has more amount of gluten while water chestnut and kodo millet are gluten free grains. Gluten has the more capacity to retain water even at higher temperature (Harper, 1981b).

Also it was observed that moisture content of extrudates decrease with increase in barrel temperature of Zone III which is because at higher barrel temperature the temperature of feed melt is more and shear in completed more uniformly therefore after evaporation the moisture of central part is retained in the extrudates. The moisture content of extrudates decreased with increase in die head temperature (Fig. 1) which is because the die head temperature increases the amount of moisture evaporated by flash off increases and ultimately the moisture content retained in extrudates decreases. The coefficient of determination R^2 had a value of 0.6353for the model with F-value of 0.96. This implies that the model terms had a significance level of probability less than 0.552 (Fig. 2).

Sectional Expansion Index (SEI) of extrudates

The predicted polynomial model developed for SEI is:

$$SEI = +3.91 - 4.583 - 003 \times A + 0.047 \times B - 0.032 \times C + 0.060 \times D - 0.029 \times E - 0.16 \times AB - 0.051 \times AC - 0.018 \times AD + 0.069 \times AE - 0.041 \times BC + 0.25 \times BD - 0.041 \times BE + 0.30 \times CD - 0.026 \times CE + 0.047 \times DE + 0.063 \times A^2 - 0.11 \times B^2 - 0.091 \times C^2 - 0.060 \times D^2 - 0.011 \times E^2 \ldots\ldots\ldots\ldots\ldots (5)$$

Where A = moisture content of blend, B = blend ratio, C = barrel temperature, D = die head temperature and E = screw speed.

The sectional expansion index ranged from 2.80 to 4.91 with a mean of 3.75. According to Baladran-Quintana *et al.,* (1998), expansion is an important characteristic of extruded products being developed as snack and ready-to-eat products by food industries. The response graph shows that sectional expansion index decreased sharply with increasing feed moisture. Increasing feed moisture results in lower degree of starch gelatinization for different products (Falcone & Phillips, 1988; Kokini *et al.,* 1992; Saalia, 1995). The increase would decrease the dough temperature, because moisture would reduce friction between the dough and the screw/barrel and have a negative impact on the starch gelatinization, thereby reducing the product's expansion. Also as it is seen from figure 3 the decrease in amount of defatted soy flour increases the sectional expansion index because defatted soy flour has high value protein content which reduces the sectional expansion of extrudates. Similar finding were reported by Nelson (2003) and Berrios (2010) that increasing the proteins levels will lead to decrease in diameter and expansion ratio of the extrudates.

It can be observed from figure 4 that sectional expansion index increase with increase in the barrel temperature of Zone III because at higher barrel temperature, the temperature of feed melt is more and shear in completed more uniformly therefore after evaporation the moisture of central part is retained in the extrudates. Figure 4 which shows increase in sectional expansion index with increase in die head temperature which is because the increase in die head temperature increase the amount of moisture evaporated by flash off and as the more and more capillaries are formed and more porous structure is created which ultimately results in increased diameter of extrudates. The coefficient of determination R^2 had a value of 0.945 for the model with F-value of 0.54. This implies that the model terms had a significance level of probability less than 0.89.

Bulk Density (BD) of extrudates

The predicted polynomial model developed for BD is:

$$BD = + 132.26 + 1.46 \times A + 0.46 \times B + 3.96 \times C - 4.79 \times D + 4.79 \times E + 4.19 \times AB + 5.81 \times AC - 9.94 \times AD - 3.06 \times AE + 10.19 \times BC - 7.06 \times BD - 5.19 \times BE - 6.69 \times CD + 0.69 \times CE + 3.19 \times DE - 2.64 \times A^2 + 5.74 \times B^2 - 0.89 \times C^2 + 0.24 \times D^2 + 2.24 \times E^2 \ \ldots\ldots\ldots (6)$$

Where A = moisture content of blend, B = blend ratio, C = barrel temperature, D = die head temperature and E = screw speed

Table.1 Details of levels of process and operational parameters

Independent Variables	Levels				
	-2	**-1**	**0**	**+1**	**+2**
Moisture Content (% wb)	8	10	12	14	16
Blend Ratio (M:SF:WCF)* (Millet Flour : Defatted soy flour : water chestnut flour)	70:**5**:25	70:**10**:20	70:**15**:15	70:**20**:10	70:**25**:5
Die Head Temperature(^{o}C)	160	180	200	220	240
Barrel Temperature (^{o}C)	120	140	160	180	200
Screw Speed (rpm)	80	100	120	140	160

Table.2 Analysis of variance for physical properties (MCE, BD, SEI and WAI) of extrudate

ANOVA	Source	DF	SS	MSS	F	P
MCE	Regression	20	7.81	0.39	0.96	0.552
	Residual	11	4.48	0.41		
	Total	31	12.30			
BD	Regression	20	9279.85	463.99	0.53	0.896
	Residual	11	9665.62	878.69		
	Total	31	18945.47			
SEI	Regression	20	4.09	0.20	0.54	0.890
	Residual	11	4.18	0.38		
	Total	31	8.27			
WAI	Regression	20	50309.55	2515.48	1.58	0.220
	Residual	11	17543.23	1594.84		
	Total	31	67852.78			

Fig.1 Effect of moisture content and die head temperature on MCE

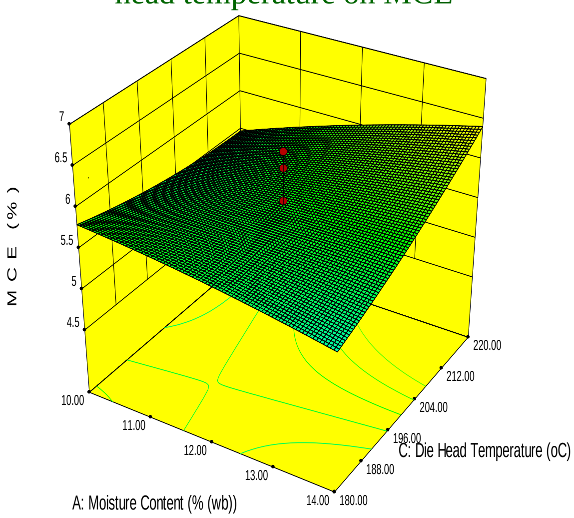


Fig.2 Effect of moisture content and blend ratio on MCE

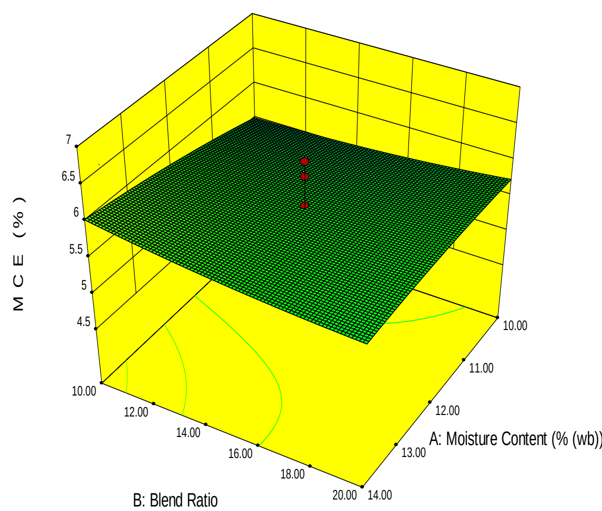


Fig.3 Effect of blend ratio and barrel temperature on SEI of extrudates

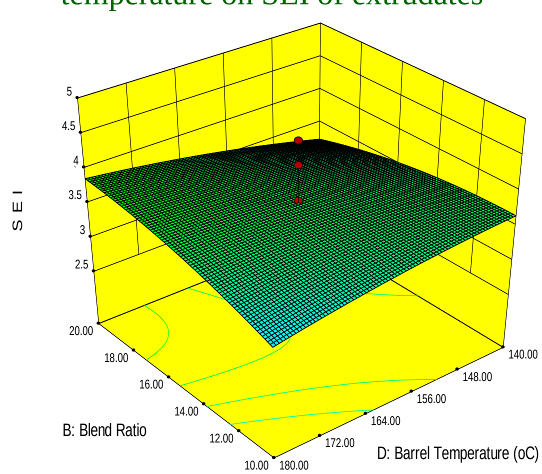


Fig.4 Effect of die head temperature and barrel temperature on SEI of extrudates

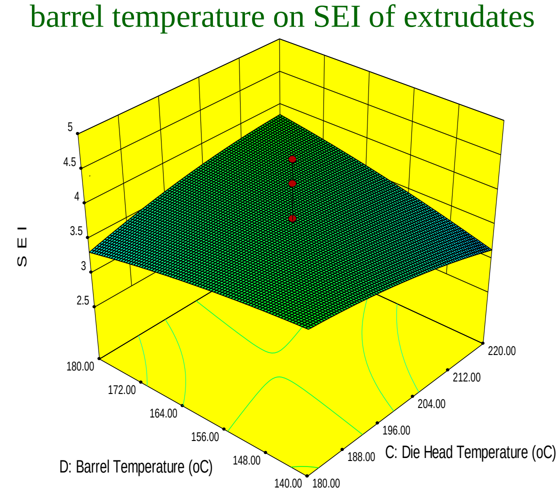


Fig.5 Effect of blend ratio and moisture content on BD of extrudates

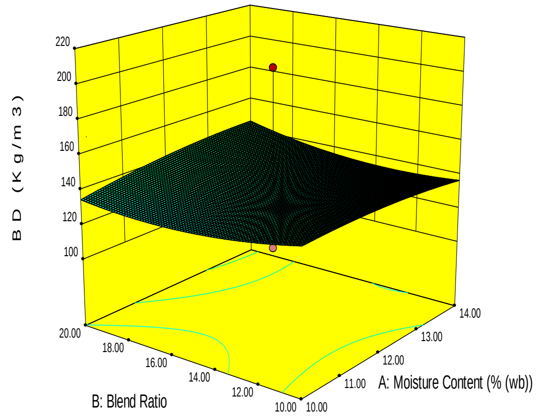


Fig.6 Effect of die head temperature and blend ratio on BD of extrudates

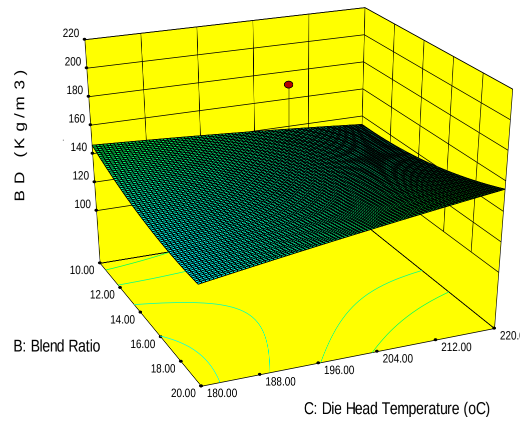


Fig.7 Effect of die head temperature and blend ratio on WAI of extrudates

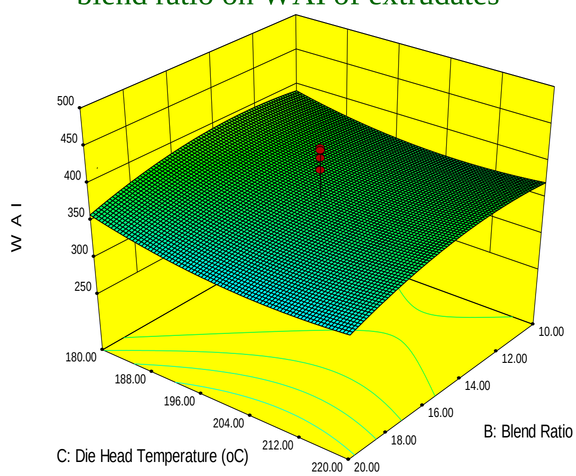
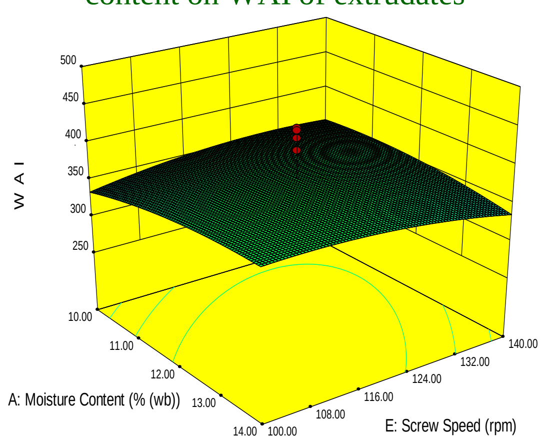


Fig.8 Effect of screw speed and moisture content on WAI of extrudates



The BD achieved a maximum value of 208 Kg/m^3 and a minimum value of 101 Kg/m^3 and its mean value was 135.78 Kg/m^3. Bulk density is a very important parameter in the production of expanded and formed food products. It is a measure of how much expansion has occurred as a result of extrusion. It can be seen from figure 6 when die head temperature increases the bulk density decreases, because when heat developed during extrusion is increased the temperature of the moisture above the boiling point so that when the extrudate exits from the die, a part of the moisture would quickly flash-off as steam and result in an expanded structure with large alveoli and low density. On the other hand, if not enough heat is generated to flash-off enough of the moisture (either through low process temperature or high feed moisture), less expansion occurs resulting in a high bulk density product with collapsed cells which usually disintegrates on cooling.

It can be seen from figure 5 that at high moisture levels, the bulk density is also high. This is because the extrusion cooking is not enough to cause vaporization of moisture, leading to retention of moisture and hence the reduced puffing of the product. As a result denser product is obtained. Extrudates density is inversely related to overall expansion. It can be seen (Fig. 5) that bulk density increases with increase in proportion of defatted soy flour. The higher bulk density may be due to the presence of defatted soy flour in the composite mixes sample which reduces the puffing quality of extrudates. High density product is an indication of more uniform and continuous protein matrix and therefore, the extrudate is dense with parallel layers, no air pockets and is not spongy upon hydration (Filli, 2009). Similar types of results were observed by Deshpande *et al.,* (2011). The coefficient of determination R^2 had a value of 0.898 for the model with F-value of 0.53. This implies that the model terms had a significance level of probability less than 0.896.

Water Absorption Index (WAI) of extrudates

The predicted polynomial model developed for WAI is:

$$WAI = + 394.18 + 3.64 \times A - 17.04 \times B - 10.93 \times C - 10.56 \times D - 2.75 \times E - 4.63 \times AB - 6.19 \times AC + 1.26 \times AD - 12.71 \times AE - 0.91 \times BC + 14.37 \times BD - 19.94 \times BE - 0.52 \times CD - 8.38 \times CE - 1.43 \times DE - 9.66 \times A^2 - 17.63 \times B^2 + 15.12 \times C^2 - 2.91 \times D^2 - 10.77 \times E^2 \quad \text{……….} (7)$$

Where A = moisture content of blend, B = blend ratio, C = barrel temperature, D = die head temperature and E = screw speed.

The water absorption index achieved a maximum value of 480.8 and a minimum value of 284.2 and its mean value was 374.79. Water absorption index is referred to as measurement of the degree of starch gelatinization (Owusu-Ansah *et al.,* 1983a; Pinnavaia and Pizzirani, 1998). Water absorption has been generally attributed to the dispersion of starch in excess water and the dispersion is increased by degree of starch damage due to gelatinization and extrusion-induced fragmentation, that is, molecular weight reduction of amylose and amylopectin molecules (Rayas-Duarte *et al.,* 1998) (Table 2).

At higher die head temperature the WAI was higher because it decreases the moisture content if extrudates and therefore ability of extrudates to absorb moisture. It was found (Fig. 8) that increase in screw speed increases the WAI of extrudates as at higher screw speed more shear is generated resulting in more porous structure, which is responsible, increased absorption of moisture when soaked in water. It can be seen (Fig. 7) that when the WCF content is high, low value of WAI is probably due to the sucrose content of chestnuts. Sucrose, in fact, as well known, has a restrictive effect on gelatinization process (Wootton and Bamunuarachchi, 1980). The coefficient of determination R^2 had a value of 0.7415 for the model with F-value of 1.58. This implies that the model terms had a significance level of probability less than 0.220.

After complete evaluation of all the attributes for physical parameters like moisture content, bulk density, sectional expansion index and water absorption index, it was found that there were strong correlations between the moisture content of feed and blend ratio, while barrel temperature, and die head temperature had significant influence and screw speed had not significant influence on the physical of extrudates. The moisture content of extrudates ranged from 4.61 to 7.02 with a mean value of 5.76 % (wb). The maximum and minimum values shown for BD of extrudates were 208 kg/m^3 and 101 kg/m^3 with a mean of 135.78 kg/m^3. The SEI ranged from 2.80 to 4.91 with a mean of 3.75. The WAI achieved a maximum value of 480.8 and a minimum value of 284.2 and its mean value was 374.79.

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