# Optimization of Some Physical and Functional Properties of Extruded Soybean Crud Residue-base Floating Fish Feed

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**Abstract:** Effect of some extrusion factors on soybean crud residue-based floating fish feed was investigated. Extrusion was conducted at 20%, 25% and 30% moisture content level, die size of 2 mm, 4 mm and 6 mm and screw speed of 150 rpm, 200 rpm and 250 rpm. Pearson square method of fish feed formulation was used to attain a 35% protein content of catfish feed protein requirement. Optimized value of extrusion factors moisture content, die size and screw speed were 30%, 6 mm and 150 rpm respectively and optimized result of responses, expansion rate (ER) floatation rate (FR) sinking velocity (SV) specific mechanical energy (SME) swelling capacity (SC) water absorption index (WAI) water solubility index (WSI) hydration capacity (HC) and hydration index (HI) are 32.73%, 95.87%, 0.024 ms$^{-1}$, 16.97 KJ/kg, 1.73, 1.61, 2.76, 0.51, and 0.67 respectively. Feed moisture content and die size have the most significant effect on the physical and functional properties of extrudate. Coefficient of determination $R^2$ ranges from 0.65 to 0.96, lack of fit not-significant, desirability in optimization of 0.806, suggesting adequacy of research. Soybean crud residue base floating fish feed has been formed and evaluated with an outcome of high efficacy. This extruded produce can be used for both domestic and industrial scale of catfish feed production.

**Keywords:** Extrudate, Soybean, Expansion, Floatation, Residue

## 1. Introduction

Legume and grain foods are well known for supply of food classes to human and livestock [19]. Soybean (*Glycine max* (L.) Merrill), popular among legume food and grains, with the high content of protein, fibers, fat, and starch [11]. It originated from East Asia and one of the most cultivated legume in the temperate region (3000 BC) in China and long recognized in surrounding countries like Japan, Korea, and Malaysia, where it is a long-established cultivated plant [8]. Soybean of 40% protein content necessitate additional value chain in its usage in domestic and industrial scale, being processed to soymilk, tofu and other soy foods [33]. Soybean Crud Residue (SCR) is the extract for every soybean being processed to soymilk or tofu, after the separation of the molten state [18]. SCR contains 20% protein and fibers 9% inclusive of high moisture content (70% – 80%), which makes its handling strenuous and it drying exuberant through conventional means. SCR of 1.2 kg was produced as a waste for every 1 kg of soybean processed to soymilk [5]. Several tones of SCR were being produced annually in Nigeria with it high nutritional value but being used as land fill on refuse dump.

Extrusion cooking as gained recognition in the food processing industry with a number of operation affecting the physiochemical and functional properties of the food produced for consumer safety [16]. High Temperature Low Retention Time (HTLT) of extrusion process as made it suitable for processing ready to eat foods mostly made from cereal and leguminous grains like soybean, cowpea, maize and cassava flour etc. and production of animal feeds like floating fish feed [1]. Extrusion process operations convert starchy and protein-rich food into viscoelastic resin after gelatinization of starch

components, forced out of high temperature and high pressure in the barrel aided by the share forces generated from the rolling screw. The abrupt reduction in pressure at the die surface allows the quick evaporation of moisture content in the food and expansion of the food, uniform sizing of food was attained at the cutting point on the die orifice [2, 23]. Large quantity of soybean crud residue (SCR) being produced from processing of soybean as being a serious concern in the food manufacturing industry due to management of this waste and the nuisance it constitute to the environment [31]. In other to reduce this degradation in our surrounding food engineers and technologist are seeking management model of the agro-by-product [18]. Production of floating fish feed from this by-product will reduce the cost of fish production since feeding of fish constitutes 60% - 80% of total management costs [26].

The aim of this research is to investigate the effect of extrusion condition on the physical and function properties of soybean crud residue (SCR) base floating fish feed. Response surface methodology (RSM) a collection of a Statistical techniques use for experimental design, model development, evaluating impact and effect of factors on responses, optimization of factors condition and level desirability [22] was used to assess the aim and objectives of this research work.

# 2. Materials and Method

## 2.1. Procurement of Materials

Soybean (*Glycine max* (L.) Merrill) was purchased at Oja-Oba market in Akure. Cassava starch fishmeal were purchased in Farm support feed mill Akure.

### 2.1.1. Preparation of Soybean Crud Residue
First operation was to clean about 22 kg of soybean grains using laboratory aspirator (Vegvari Ferenc Type OB 125, Hungary) to remove dirty and unwanted materials like stalks, leaves and other foreign matter. It was then soaked in distilled water for 12 hours in an aluminum can of about 35 litters at room temperature to improve it handling. Dehulling was the next stage of preparation this was done manually in a bowl of 50 litters' capacity with a treated water, it chaff and some dirty materials were been removed leaving behind well soaked soybean grains. It was milled using attrition milling machine (Imex GX 160, Japan) the grain was processed to molten state soybean. The molten state was further mixed with water and sieved by using mesh number 25 (BS, 1985) to separate the liquid and solid soybean. Soybean crud residue is the wet solid pulverized soybean, it was then poured into a sack bag for dewatering by placing it under a screw jack (3031.14 series, England) pressure increase was consistent for quick and adequate moisture reduction for about three hours. Pulverization of soybean crud residue was achieved using pulverizing machine (FPP-300, India) and later sun dried on a mat for a day (at 33°C and 28.21% relative humidity) before packing to polythene bag for further use.

### 2.1.2. Formulation of Soybean Crud Residue Base Floating Fish Feed
Pearson square method for determine protein content in fish feed formula was used, The predicted protein content of the feed was 35% after identifying the amount of protein in each of the constituent through proximate analysis, maize contain 10% protein, soybean crud residue 30%, cassava starch 3.6%, wheat bran 17%, soybean meal 40%, fish meal 65%. The constituent was grinded properly and mixed thoroughly using mechanical mixer (335 LP china). Calculation of arithmetic procedures in Pearson square method is as summaries [28, 10].

*Table 1. Arithmetic result of pearson square method of fish feed formulation.*

| | First Group | | Second Group |
|---|---|---|---|
| Average | 17.3% | | 37.3% |
| Percentage of group in 35% protein. | 11.85% | | 88.30% |
| First group constituent percentage. | 3.95% | | 29.43% |
| Percentage of | Components of | | |
| Maize | 0.39% | Soybean crud residue | 8.82% |
| Soybeans meal | 1.58% | Wheat bran | 4.98% |
| Cassava starch | 0.14% | Fish meal | 19.11% |
| Summation of group | 2.11% | | 32.91 |
| Total | | 35.02% | |

First group average= $10 + 40 + 3.6 = \frac{53.6}{3} = 17.9\%$

Second group average = $17 + 30 + 65 = \frac{112}{3} = 37.3\%$

Component of this feeds were readily locally available food materials, proportion of each component in the feed are maize 14%, soybean crud residue 35%, wheat bran 25%, soybeans meal 10%, cassava starch 10%, fish meal 5%, vitamin C 0.3%, Methionine 0.4%, antioxidant 0.3% make 100% proportion of every 1 kg of fish feed formulated.

## 2.2. Extrusion Cooking

Feed formulated was divided into 20 specimen, each was fed into the machine with the aid of a feeder attached to the upper end of the barrel at 2.0 kg/min, and a single screw extruder in Department of Agricultural and Environmental Engineering Federal University of Technology Akure was used. Moisture content, die size and screw speed were varied based on experimental design. The screw performs functions of mixing, transporting and compression of feed, heated by heat generated in the

barrel causing cooking effect, gelatinizing feed, improving it physiochemical and biochemical qualities. Experimental samples were collected after gelatinization was attained and were being left in open air for some minutes to cool, before packing into a polythene bag prior to further analysis.

### 2.3. Moisture Content

Moisture content (*wet basis)* of the feed was calculated and determined with the use of modified equation (1) used by [38]

$$\text{Moisture content } wet\ basis = \frac{W_i - W_f}{W_I} \ X \ 100 \qquad (1)$$

Where, $W_i$ is the initial weight (g), $W_f$ is the final weight of the sample (g). The amount of water to be added was determined with the use of a modified equation of [20] in equation 2

$$Q = \frac{W(A-B)}{100-A} \qquad (2)$$

Where, Q is the amount of water required ($m^3$), A is initial moisture content (%), B is final moisture (%) to be attained, W is initial weight of feed (g).

### 2.4. Determination of Physical and Functional Properties

#### 2.4.1. Expansion Rate

This is the rate at which the feed expanded immediately after extrusion at the die orifice. veriner caliper was used to measure the diameter of the die and diameter of extruded feed. Ratio of diameter of die and diameter of extruded feed was used to express expansion. Expansion rate was determined using equation 3 (Twum and Pare, 2018).

$$\text{Er} = \frac{D_1 - D_2}{D_2} \ X \ 100 \qquad (3)$$

Where, Er is expansion rate, $D_1$ is diameter of extruded feed, $D_2$ is diameter of die hole.

#### 2.4.2. Flotation Test

Floatation test was performed using a transparent conical flask for each treatment. A specific amount of extruded feed was immersed in water and at the end of every observation the number of extruded feed afloat both the initial number and the final number of feeds were recorded, the floatation rate was determined using equation 4 from Solomon *et al.* (2011) with slight modification.

$$\text{Floatation rate} = \frac{\text{final number of feed afloat}}{\text{intial number of feed afloat}} \ x \ 100 \qquad (4)$$

#### 2.4.3. Sinking Velocity Test

A sinking velocity test was conducted using a transparent conical flask and some amount of water. The water was filled into the flask to a height of 30 cm and a number of feeds were poured in it, this was kept constant while the time spent by each and every sample to reach the bottom of the flask was recorded. Sinking velocity was determined using equation 5 below.

$$\text{Sinking velocity (ms}^{-1}) = \frac{h}{t} \qquad (5)$$

Where
h is the height of the water column (m),
t is the time (s) taken by the extrude to reach the bottom of the container.

#### 2.4.4. Specific Mechanical Energy (SME)

The amount of energy generated from the machine and being converted to energy that transforms the extrude – the work done by the machine on the extrude is called the specific mechanical energy of the machine. This was determined with the use of mathematical equation from [24]

$$\text{SME} = \frac{2\pi \times \tau \times \frac{S_S}{60}}{F_r} \times 3.6 \text{ kJ/k} \qquad (6)$$

Where; $\tau$ is the torque (Nm), $S_s$ is screw speed (rpm), Fr is feed rate (kg/min).

The calculation of machine torque was done with the use of equation 7.

$$\tau = \frac{60p}{2\pi N} \qquad (7)$$

#### 2.4.5. Water Absorption Index (WAI)

It was determined by the method used by Filli *et al.,* (2010) and modified by Sharmila and Athmaselvi (2017) with slight modification. A 2 g sample of each of the feed was mixed with 20 ml distilled water in a centrifuge tube, allowed to stand at ambient temperature of 25°C for 30 min, and then centrifuged for 30 min at 2,000xg. Decantation of supernatant was done into a stainless steel pan of known mass and dried to a constant weight at 105°C. The weight of gel in the centrifuge tube was recorded and equation 8 was used to determine WAI

$$\%\text{WAI} = \frac{W_1}{W_2} \times 100 \qquad (8)$$

Where, $W_1$ is weight of gel in grams (g) $W_2$ is weight of extrudate (g)

#### 2.4.6. Water Solubility Index (WSI)

Water solubility index determines the amount of polysaccharides or polysaccharide release from the granule on the addition of excess of water. WSI was the weight of dry solids in the supernatant from the water absorption index test expressed as percentage of the original weight of the sample it was determined with the use of modified method used by Beuchat (1977) and Gbenyi *et al.* (2016)

$$(\%) \text{ WSI} = \frac{W_S}{W_d} \ x \ 100 \qquad (9)$$

Where, $W_S$ is Weight (g) of dissolved solid in supernatant, $W_d$ Weight of dry solids (g)

#### 2.4.7. Hydration Capacity and Hydration Index

These were determined by the method used of [6] with some modification. One hundred feeds were counted and

weighed. The feeds were then transferred into a measuring cylinder. About 100 ml of distilled water was added. The cylinder was then covered with an aluminum foil and allowed to stay for 12-18 h at room temperature. The water was decanted; superfluous water was removed with the aid of filter paper. The feeds were then weighed and the hydration capacity calculated using the following expressions.

$$HC = \frac{W_2 - W_1}{n} \text{ (g/feed)} \qquad (10)$$

Where, $W_1$ is weight of feeds before soaking, $W_2$ is weight of feeds after soaking n is number of feeds. Hydration index (HI) was calculated using the formula below:

$$HI = \frac{HC}{W} \text{ (feed}^{-1}) \qquad (11)$$

Where, HC is Hydration Capacity per feed and W is Weight of one feed (g)

### 2.4.8. Experimental Design

The statistical analysis of this research was designed using central composite face-centered design (CCFC) in Design Expert 11 Stat-Ease Microsoft Window (Minnapolise MN USA 2018) statistical software. Table 2 shows the design procedure and levels of variables used in this experiment. Matrix of this experiment was shown in Table 3 being developed from central composite face-centered design. Fourteen star point and six central point made up the experimental space, added up to 20 runs of experiment. Model obtained from the experiment was fitted to a second order polynomial regression model [3].

$$Y = P_O + P_1 X_1 + P_2 X_2 + P_3 X_3 + P_{11}(X_1)^2 + P_{22}(X_2)^2 + P_{33}(X_3)^2 + P_{12}X_1 X_2 + P_{13}X_1 X_3 + P_{23}X_2 X_3 + \varepsilon$$

Where, $X_1, X_2$ and $X_3$ are operating parameters, moisture content, die size and screw speed respectively $P_O$ is the regression constant; $P_1, P_2$ and $P_3$ are linear regression terms, $P_{11}P_{22}$ are $P_{33}$ quadratic regression terms; $P_{12}P_{13}$ are $P_{23}$ the cross-product regression terms; $\varepsilon$ is the error term.

***Table 2.** Independent variables and their levels of replicate.*

| Factors | Replicate | | |
| --- | --- | --- | --- |
| | -1 | 0 | +1 |
| Moisture Content (%), | $X_1$ | 20 | 25 | 30 |
| Die Size (mm), | $X_2$ | 2 | 4 | 6 |
| Screw Speed (rpm), | $X_3$ | 150 | 200 | 250 |

***Table 3.** Central composite face centered (CCFC) design matrix and the independent factors in their coded and actual values.*

| Runs | $X_1$ | $X_2$ | $X_3$ | Moisture Content (%) | Die Size (mm) | Screw Speed (rpm) |
| --- | --- | --- | --- | --- | --- | --- |
| 1 | 0 | 0 | 0 | 25 | 4 | 200 |
| 2 | 0 | 0 | 1 | 25 | 4 | 250 |
| 3 | 0 | 1 | 0 | 25 | 6 | 200 |
| 4 | 0 | 0 | 0 | 25 | 4 | 200 |
| 5 | 0 | 0 | 0 | 0 | 4 | 200 |
| 6 | 0 | 0 | 0 | 25 | 4 | 200 |
| 7 | 0 | 0 | 0 | 25 | 4 | 200 |
| 8 | -1 | -1 | +1 | 20 | 2 | 250 |
| 9 | +1 | +1 | -1 | 30 | 6 | 200 |
| 10 | +1 | -1 | +1 | 30 | 2 | 250 |
| 11 | 0 | 0 | 0 | 25 | 4 | 200 |
| 12 | +1 | +1 | +1 | 30 | 2 | 150 |
| 13 | 0 | 0 | -1 | 25 | 2 | 150 |
| 14 | +1 | +1 | +1 | 30 | 6 | 250 |
| 15 | -1 | +1 | +1 | 20 | 6 | 250 |
| 16 | +1 | 0 | 0 | 30 | 4 | 200 |
| 17 | -1 | 0 | 0 | 20 | 4 | 200 |
| 18 | 0 | +1 | 0 | 25 | 6 | 200 |
| 19 | -1 | -1 | -1 | 20 | 2 | 150 |
| 20 | -1 | +1 | -1 | 20 | 6 | 150 |

Key: $X_1$= Moisture content, $X_2$ = Die size, $X_3$ = Screw speed.

### 2.4.9. Statistical Analysis

Design expert 11 Stat-Ease Microsoft Window (Minnapolise MN USA, 2018) statistical analysis software was used in the statistical analysis of data. Analysis of variance (ANOVA) was used to validate the significance of the experimental result, interaction of predicted and observed value was established using correlation analysis of response surface methodology (RSM). Numerical optimization and interactive graphs were used to optimize the various input variables and responses.

# 3. Result and Discussion

## 3.1. Experimental Result Obtained for Statistical Analysis

The central composite face-centered design (CCFC) of design expert 11 developed the experimental design used in inputting and analyzing experimental result data statistically, Table 4 shows varying levels of dependent variables, moisture content, die size, and screw speed, inclusion of result gotten for responses. Analysis of this data developed models of quadratic and linear regression, ANOVA result indicate good fit of models with lack of fit not significant and close range between the predicted and observed coefficient of determination $R^2$.

**Table 4.** *Experimental result obtained for statistical analysis.*

| Run | Moisture Content | Die Size | Screw Speed | ER | FR | SV | SMER | SC | WAI | WSI | HC | HI |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | % | mm | rpm | % | % | ms$^{-1}$ | KJ/kg | | g/g | % | g/feed | feed$^{-1}$ |
| 1 | 25 | 4 | 200 | 28 | 86 | 0.0245 | 22 | 2.2 | 1.4 | 2.9 | 0.3 | 0.42 |
| 2 | 25 | 4 | 250 | 28 | 86 | 0.0245 | 22 | 2.2 | 1.4 | 2.9 | 0.3 | 0.42 |
| 3 | 25 | 6 | 200 | 31 | 85 | 0.0232 | 18 | 1.7 | 1.5 | 2.7 | 0.4 | 0.66 |
| 4 | 25 | 4 | 200 | 28 | 86 | 0.0245 | 22 | 2.2 | 1.4 | 2.9 | 0.3 | 0.42 |
| 5 | 25 | 4 | 200 | 28 | 86 | 0.0245 | 22 | 2.2 | 1.4 | 2.9 | 0.3 | 0.42 |
| 6 | 25 | 4 | 200 | 28 | 86 | 0.0245 | 22 | 2.2 | 1.4 | 2.9 | 0.3 | 0.42 |
| 7 | 25 | 4 | 200 | 28 | 86 | 0.0245 | 22 | 2.2 | 1.4 | 2.9 | 0.3 | 0.42 |
| 8 | 20 | 2 | 250 | 22 | 84 | 0.0262 | 24 | 2.1 | 1.7 | 2.4 | 0.4 | 0.60 |
| 9 | 30 | 6 | 150 | 32 | 97 | 0.0233 | 17 | 1.8 | 1.6 | 2.8 | 0.5 | 0.68 |
| 10 | 30 | 2 | 250 | 22 | 85 | 0.0264 | 24 | 2.1 | 1.9 | 2.4 | 0.4 | 0.57 |
| 11 | 25 | 4 | 200 | 28 | 86 | 0.0245 | 22 | 2.2 | 1.4 | 2.9 | 0.3 | 0.42 |
| 12 | 30 | 2 | 150 | 22 | 85 | 0.0264 | 24 | 2.1 | 1.9 | 2.4 | 0.4 | 0.57 |
| 13 | 25 | 4 | 150 | 28 | 86 | 0.0245 | 22 | 2.2 | 1.4 | 2.9 | 0.3 | 0.42 |
| 14 | 30 | 6 | 250 | 32 | 97 | 0.0233 | 17 | 1.8 | 1.6 | 2.8 | 0.5 | 0.68 |
| 15 | 20 | 6 | 250 | 22 | 90 | 0.0231 | 17 | 1.8 | 1.5 | 2.9 | 0.5 | 0.67 |
| 16 | 30 | 4 | 200 | 29 | 88 | 0.0244 | 19 | 1.6 | 1.5 | 2.8 | 0.3 | 0.39 |
| 17 | 20 | 4 | 200 | 22 | 87 | 0.0245 | 21 | 2.0 | 1.4 | 2.7 | 0.2 | 0.43 |
| 18 | 25 | 6 | 200 | 23 | 83 | 0.0261 | 21 | 2.1 | 1.8 | 2.5 | 0.4 | 0.56 |
| 19 | 20 | 2 | 150 | 22 | 84 | 0.0262 | 23 | 2.1 | 1.7 | 2.4 | 0.3 | 0.6 |
| 20 | 20 | 6 | 150 | 30 | 90 | 0.0231 | 17 | 1.8 | 1.5 | 2.8 | 0.5 | 0.67 |

## 3.2. Model Description and Development

Physical and functional properties of resin data, generated a regression equation model after statistical analysis was conducted on it and were being presented in Table 5. The independent Factors in the equation model $X_1$ $X_2$ and $X_3$ moisture content, die size, and screw speed respectively, significantly affect the responses, expansion rate, floatation rate, sinking velocity, specific mechanical energy, swelling capacity, water absorption index, water solubility index, hydration capacity and hydration index. Coefficient of determination ($R^2$) of all these dependent variables are 0.77, 0.88, 0.65, 0.94, 0.75, 0.90, 0.88, 0.91 and 0.96 respectively. Lack of fit were not significant for all responses except of floatation rate and water solubility index which is till acceptable. $R^2$ of 0.60 was used for a good fit, though; [17] postulate 0.80 value of $R^2$ for a good fit, [3] narrated that 0.80 (80%) value of $R^2$ is enormous in preliminary study, therefore recommended a $R^2$ value of 0.60 (60%) as an adequate value. The predicted and observed value were very close in all the responses indicating a good fit of the models. These are the fitted model of responses below:

$$ER = 27.38 + 1.9X_1 + 3.2X_2 - 0.800X_3 - 0.9483X_1{}^2 - 2.72X_2{}^2 + 1.55X_3{}^2 + 1.5X_1X_2 + 1.00X_1X_3 - 1.000X_2X_3 \ (R^2 = 0.7750)$$

$$FR = 84.90 + 1.7X_1 + 4.9X_2 + 0.000X_3 + 4.26X_1{}^2 - 3.33X_2{}^2 + 2.76X_3{}^2 + 1.50X_1X_2$$

$$+0.0000X_1X_3 + 0.0000X_2X_3 \ (R^2 = 0.8823)$$

$$SC = 2.16 - 0.00380X_1 - 0.1722X_2 - 0.0000X_3 - 0.3017X_1{}^2 - 0.0145X_2{}^2 + 0.0983X_3{}^2$$

$$-0.0250X_1X_2 + 0.000X_1X_3 + 0.0000X_2X_3 \ (R^2 = 0.7530)$$

$$HC = 0.2793 + 0.0200X_1 + 0.0547X_2 + 0.0100X_3 + 0.0017X_1{}^2 + 0.0970X_2{}^2 + 0.0517X_3{}^2$$

$$-0.0125X_1X_2 - 0.0125X_1X_3 - 0.01125X_2X_3 \ (R^2 = 0.9118)$$

$$HI = 0.4097 - 0.0080X_1 + 0.0411X_2 + 0.000X_3 + 0.0159X_1{}^2 + 0.1747X_2{}^2 + 0.0259X_3{}^2$$

$$+0.0100X_1X_2 + 0.0000X_1X_3 + 0.0000X_2X_3 \ (R^2 = 0.9680)$$

Quadratic model was formed for all the responses except sinking velocity which has a linear model.

$$SV = 0.0247 - 0.0001X_1 - 0.0013X_2 + 0.000X_3 \ (R^2 = 0.6523)$$

$$SME = 22.07 - 0.1000X_1 - 3.35X_2 + 0.1000X_3 - 2.17X_1{}^2 + 0.676X_2{}^2 - 0.1772X_3{}^2$$

$$-0.125X_1X_2 - 0.1250X_1X_3 - 0.1250X_2X_3 \ (R^2 = 0.9415)$$

$$WAI = 1.42 + 0.0700X_1 - 0.1172X_2 + 0.000X_3 - 0.0017X_1{}^2 + 0.3155X_2{}^2 - 0.0517X_3{}^2$$

$$-0.0250X_1X_2 + 0.000X_1X_3 + 0.00X_2X_3 \ (R^2 = 0.9026)$$

$$WSI = 2.85 + 0.000X_1 + 0.1931X_2 + 0.0100X_3 - 0.0207X_1{}^2 - 0.3638X_2{}^2 - 0.293X_3{}^2$$

$$-0.0125X_1X_2 - 0.01250X_1X_3 + 0.025X_2X_3 \ (R^2 = 0.8881)$$

***Table 5.*** *Regression coefficient for physical and function properties of extrudates.*

| Coefficients | ER | FR | SV | SME | SC | WAI | WSI | HC | HI |
|---|---|---|---|---|---|---|---|---|---|
| $P_o$ | 27.38 | 84.90 | 0.0247 | 22.07 | 2.16 | 1.42 | 2.85 | 0.2793 | 0.4097 |
| $P_1$ | 1.9 | 1.70 | 0.0001 | -0.1000 | -0.0380 | 0.0700 | 0.0000 | 0.0200 | -0.0080 |
| $P_2$ | 3.27 | 4.90 | -0.0013 | -3.35 | -0.1722 | -0.1172 | 0.19311 | 0.0547 | 0.0411 |
| $P_3$ | -0.8000 | 0.000 | 0.0000 | 0.1000 | 0.0000 | 0.0000 | 0.0100 | 0.0100 | 0.0000 |
| Quadratic | | | | | | | | | |
| $P_{11}$ | -0.9483 | 4.26 | -------- | -2.17 | -0.3017 | -0.0017 | -0.0207 | 0.0017 | 0.0159 |
| $P_{22}$ | -2.72 | -3.33 | -------- | 0.6767 | -0.0145 | 0.3155 | -0.3638 | 0.0970 | 0.1747 |
| $P_{33}$ | 1.55 | 2.76 | -------- | -0.1724 | 0.0983 | -0.0517 | 0.1293 | 0.0517 | 0.0259 |
| Interaction | | | | | | | | | |
| $P_{12}$ | 1.50 | 1.50 | -------- | -0.1250 | -0.0025 | -0.0250 | -0.0125 | -0.0125 | 0.0100 |
| $P_{13}$ | 1.00 | 0.0000 | -------- | -0.1250 | 0.0000 | 0.0000 | -0.0125 | -0.0125 | 0.0000 |
| $P_{23}$ | -1.0000 | 0.0000 | -------- | -0.1250 | 0.0000 | 0.0000 | 0.0125 | -0.0125 | 0.0000 |
| Lack of Fit | NS | Sig. | NS | NS | NS | NS | Sig. | NS | NS |
| $R^2$ | 0.7750 | 0.8823 | 0.6523 | 0.9415 | 0.7530 | 0.9026 | 0.8881 | 0.9118 | 0.9680 |
| Adjusted $R^2$ | 0.5725 | 0.7763 | 0.5871 | 0.8888 | 0.5308 | 0.8150 | 0.7874 | 0.8323 | 0.9392 |
| S. D | 2.37 | 1.79 | 0.0007 | 0.7001 | 0.1384 | 0.0744 | 0.0927 | 0.0361 | 0.0277 |

$Y = P_O + P_1X_1 + P_2X_2 + P_3X_3 + P_{11}(X_1)^2 + P_{22}(X_2)^2 + P_{33}(X_3)^2 + P_{12}X_1X_2 + P_{13}X_1X_3 + P_{23}X_2X_3 + \varepsilon$;
ER = expansion rate, FR = floatation ratio, SV = sinking velocity, SME = specific mechanical energy, SC = swollen capacity, WAI = water absorption index,
WSI = water solubility index, HC = hydration capacity, HI = hydration index, NS = not significant, sig. = significant,

### 3.3. Expansion Rate

Change in pressure from high rate to low rate atmospheric pressure in the barrel to the exit lead to flash – off of internal moisture content and vapour pressure being replaced with air caused a puff called expansion [9]. Sectional expansion of extrudate is mostly high in the extrusion of starchy constituent than protein foods, soybean has low expansion rate [39]. Expansion rate of extruded soybean crud residue based floating fish feed was affected positively by moisture content and die size, there was increase in the expansion rate from 22% to 32% as the die size varied from 2 mm to 6 mm, likewise; moisture content was directly proportional to expansion rate, though; there is tendency of decrease in expansion rate if moisture content increases further, as it being shown on the graph between expansion range of 22% to 28% at moisture content of 30%. Most extruded product expansion rate increases with increase in variation of moisture content level coupled with variation in screw speed level, with presence of adequate water for expansion of the resin. [23, 14]. The die hole on the die head fixed to the barrel of the extruder has more significant effect on expansion of the resin than moisture content, this was in line with [4] in their research on extrusion of kodo based extrudate. The highest expansion rate was 32% recorded at 6 mm die size and 30% moisture contect, ANOVA result shows that effect of die size and moisture content on expansion rate was significant at both $p < 0.05$ and $p < 0.01$ level of significant, lack of fit of the model generated was not significant which validate good fit of the model.
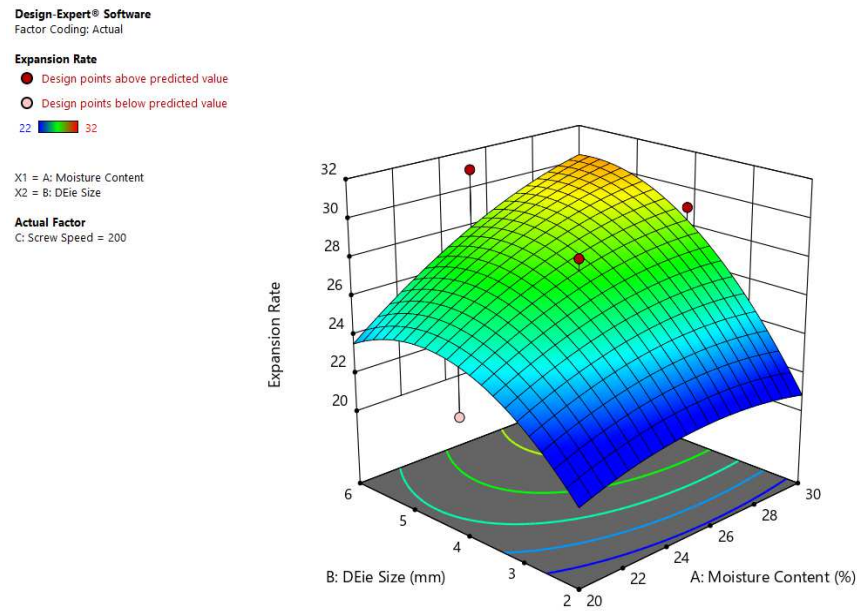
*Figure 1. Effect of some extrusion factors on expansion rate of soybean crud residue based floating fish feed extrudate.*

## 3.4. Floatation Rate

Floatation is the ability of the feed to obey law of buoyance, using the void created during expansion and reduced bulk density. Airspace formed in the feed during extrusion process being dependent of extrusion factors aided the rate of floatation of extrudate and duration of floating, this was in line with [29] in the test of buoyance for fish feed. It serve as a device to know how healthy and hardy the fish (s) [27]. Floatation of soybean crud residue based floating fish feed has the highest value of floatation of 97% being observed at 6 mm die size and 30% moisture content. This was in line with [25] research on comparative analysis of sinking time index and water stability of the different levels of cassava flour and brewer yeast. Floatation was significantly affected by moisture content, figure 1 showed decrease in floatation rate between 24% to 28% moisture content. The highest level of floatation was 97% at 30% moisture content and 6 mm die size. [37] recorded 97% floatation in feed with cassava starch has binder. [28] also observed similar reaction in their quest for farm made floating fish feed. ANOVA result reviled that floatation rate was significant at p value of $p < 0.01$ level of significant, coefficient of determination $R^2$ was 0.88. 88% of coefficient of determination $R^2$ was considered enormous, however; 60% $R^2$ was used for good fit in this research work, in other words; 88% coefficient of determination $R^2$ indicates a very good fit. Close rang of our predicted value to our observed authenticate a good fit of model generated.
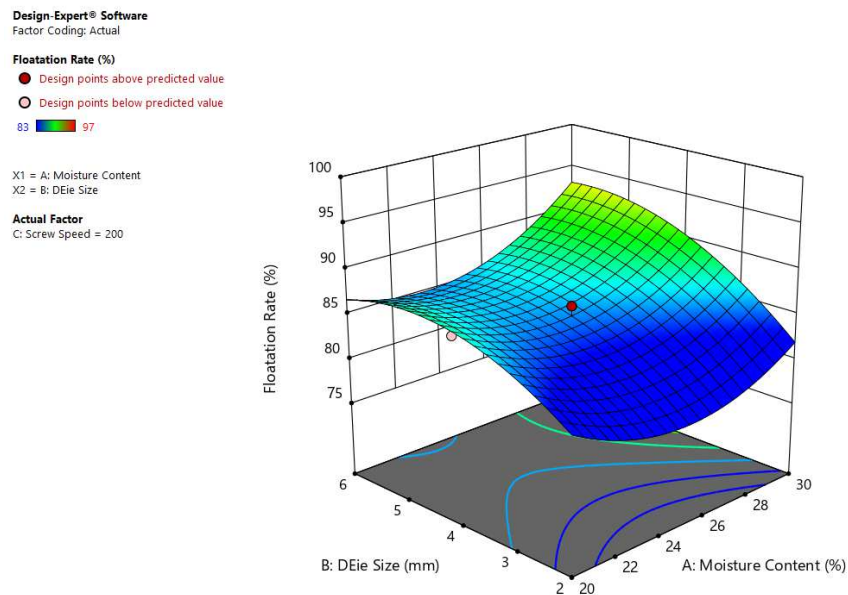


*Figure 2. Effect of some extrusion factors on floatation rate of soybean crud residue based floating fish feed extrudate.*

## 3.5. Sinking Velocity

Sinking feed is a challenge that bedeviling aquaculture production over the years, feeds of high bulk density were majorly found to have fast sinking rate due to low level of expansion for void creation during extrusion to aid it floatation [7]. Its high rate of dissociation in water contaminate the water, giving rise to bad odor, increase in microbial activities and deteriorating biochemical 20, 30 standards of water content, high protein content feeds are in this category soybeans fish feeds are not excluded [39]. Moisture content and die size has significant effect on sinking velocity at p-value of 95%. It was observed that die size and sinking velocity were inversely proportional, 2 mm die size has the highest sinking velocity of 0.0264 ms$^{-1}$, while 6 mm die size has the lowest sinking velocity of 0.023 ms$^{-1}$. [37] Also made similar observation in cassava starch binding agent of formulated floating fish feed. [25] Made similar inference that sinking velocity could be affected by the type of binding agent and rate of expansion couple with quantity of void created during expansion to aid buoyancy and reduce sinking velocity. Die size has more effect on sinking velocity than moisture content, this may be as a result of vapour evaporation at the exit of the die during extrusion. Coefficient of determination $R^2$ of 0.65 was recoded from ANOVA result, and lack of fit of not significant was postulated, validating the good fit of the linear regression model formed. However; of all the responses only sinking velocity generated linear model while other were quadratic model.
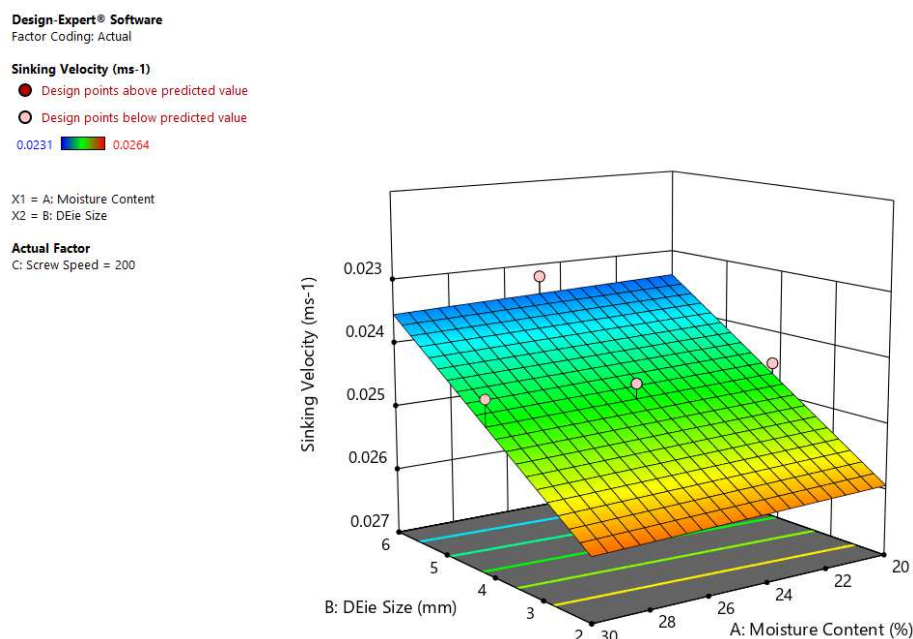


*Figure 3.* *Effect of some extrusion factors on sinking velocity of soybean crud residue based floating fish feed extrudate.*
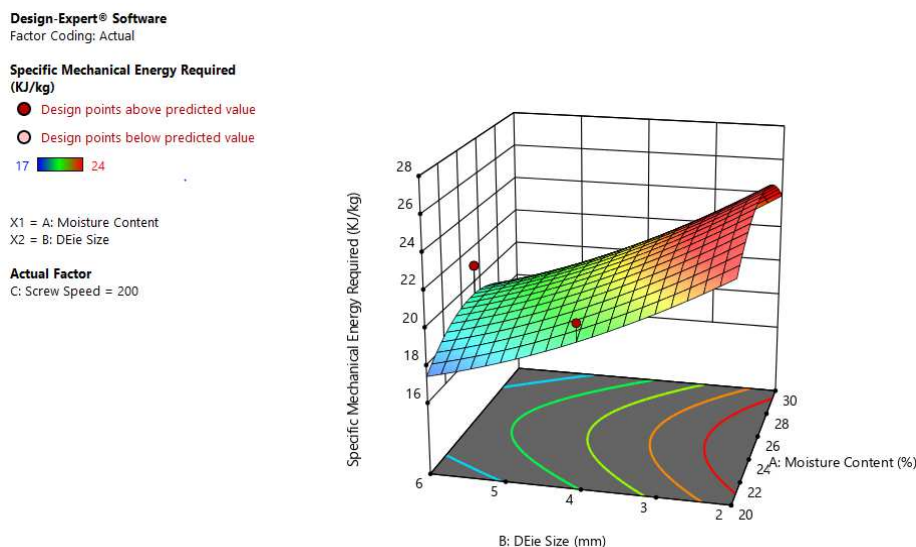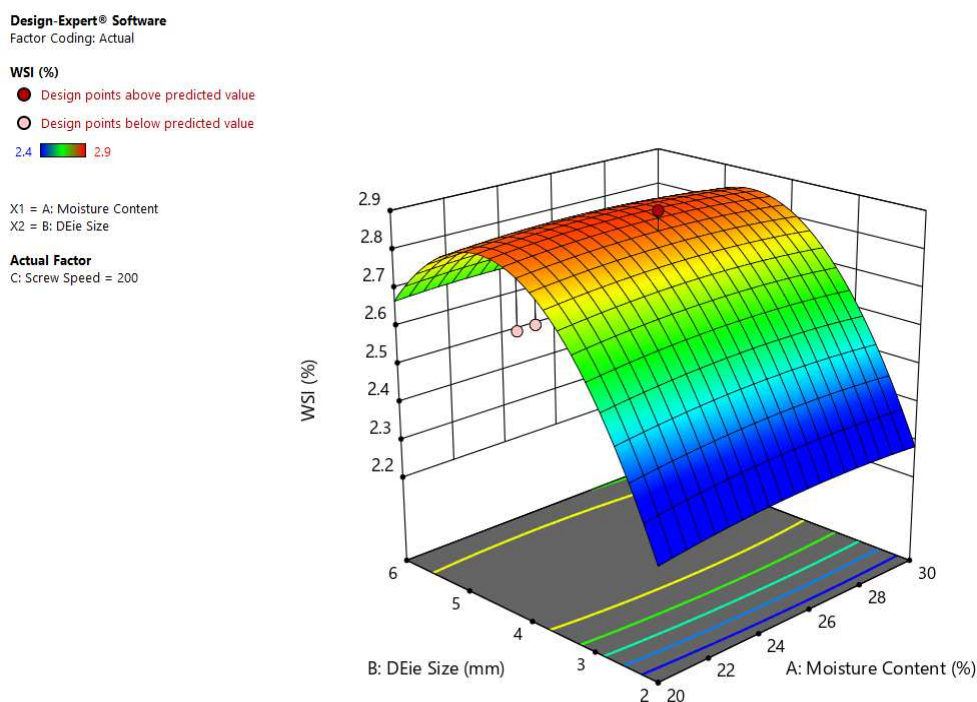


*Figure 4.* *Effect of some extrusion factors on Specific mechanical energy of soybean crud residue based floating fish feed extrudate.*

### 3.6. Specific Mechanical Energy

The energy required to process soybean crud residue based floating fish feed in extruder is dependent of moisture content of the resin, die size and screw speed of the machine. Low moisture content of resin in the barrel caused clogging at die opening, over stressing the screw auger leading to breakage of power transmission unit, the chain. Hole of the die played a significant role in flow rate of extrudate we observed that at low orifice there was accumulation of stress while at bigger die sizes flow rate was high due to allowance of die size. This was corroborated by [35] in his research on effect of extrusion temperature and moisture on physical, functional and nutritional properties of kabuli chickpea, sorghum, maize and their blends. The highest specific mechanical energy was 24 kJ/kg at 26% moisture content and 2 mm die size, while the least was 17 KJ/kg 6 mm die size and 20% moisture content. Coefficient of determination $R^2$ of 0.94 coupled with lack of fit not significant validates the good fit of quadratic equation model generated and authenticate the reliability of this work.
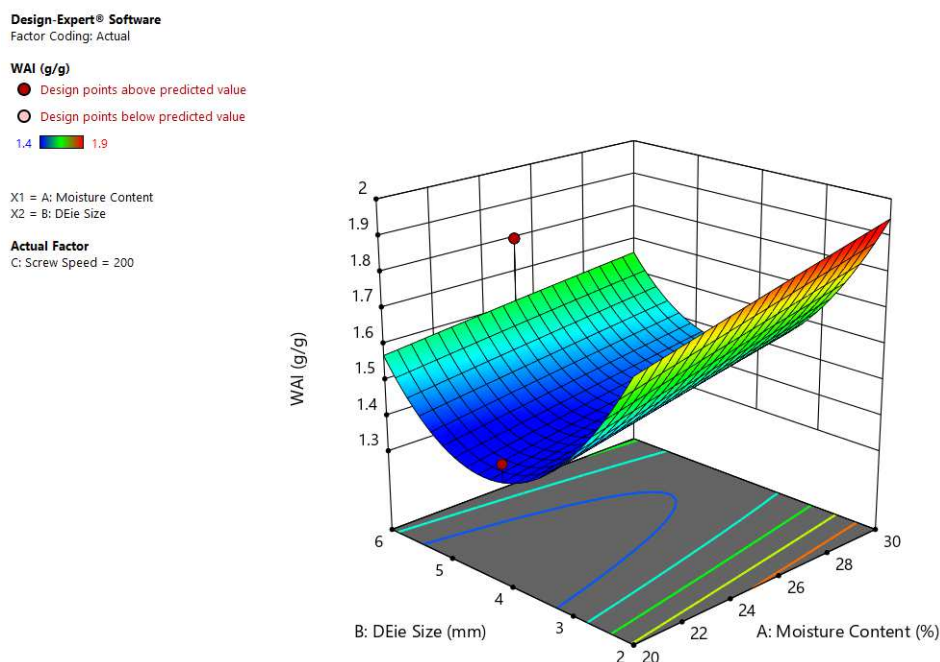


**Figure 5.** *Effect of some extrusion factors on WAI of soybean crud residue based floating fish feed extrudate.*

### 3.7. WAI and WSI

Water absorption index is one dependent features used to evaluate quality of extruded products. WAI may influence hydration capacity of such extruded product [33], water absorption of this extrudate varied from 1.4 to 1.9 g $H_2O$/g, this low WAI was also observed by [36] in the extrusion of soybeans flour. Soybeans being an oil seed will have low WAI, reason being that its oil layer will prevent absorption of water into its layer decreasing WAI of soybeans based extruded feed [12][13]. Starch based feeds tends to have high WAI, enhance during gelatinization properly formed by barrel temperature and feed moisture content during extrusion process [23][13]. The highest value of WAI 1.9 g/g was obtained at 30% moisture content and 2 mm die size, this may be as a result of increase in variation of moisture content of feed. This is in concord [13] report, Increase in moisture content of feed have significant effect on WAI, moisture acting as a catalytic agent of plasticizer in extrusion cooking affects starch granule and improve water absorption capacity. Coefficient of determination $R^2$ of 0.902 was obtained from ANOVA result, indicating a good fit of this research work. Moisture content, die size and screw speed have significant effect on WAI at p value of both $p < 0.05$ and $p < 0.01$. A quadratic model was generated to navigate through the work and lack of fit was insignificant validating the model. Water absorption index serve as measuring device in determining volume occupied by resin starch after swelling in water, justifying integrity of starch behavior in aqueous dispersion [23]. Swelling capacity, hydration capacity and their indices were being affected by water absorption index WAI.

WSI: The water solubility index (WSI) of extrudate in this work ranged from 2.4% to 2.9%. WSI of the resin increase with decrease in die size and later decrease as it reduces in figure 6. This was interned with [21] in the extrusion cooking of red and white beans, soybeans as a protein seed was significantly affected with screw speed, die size and moisture content. [15] Recorded decrease in WSI which is a function of degree of gelatinization and dissolution of starch content. Water solubility index WSI is a function of barrel temperature influenced by screw speed causing more shear force and tear aided by die size. Extrusion process is high torque low speed

and high temperature low retention time process [2, 23]. Variation in die size influence clogging during extrusion cooking, low die sizes tends to have clogging than high sizes leading to accumulation of forces consequential of high temperature, which has effect on the quantity water solubility index (WSI). [31] identify that starchy food content is not only responsible for WSI but other soluble content like protein. This affect the water solubility index (WSI) of soybeans crud residue based floating fish feed, moisture content during extrusion has significant effect on WSI at p-value of $p < 0.01$, coefficient of determination of $R^2$ 0.888 and closeness to predicted value of $R^2$ intensify the god fit of the result gotten. WSI was an indicator on degree of gelatinization of starch component and degradation of molecular components as well as measurement of quantity of soluble polysaccharides from starch of extruded product. The quadratic equation generated has a lack of fit of not significant validating the good fit of the model.
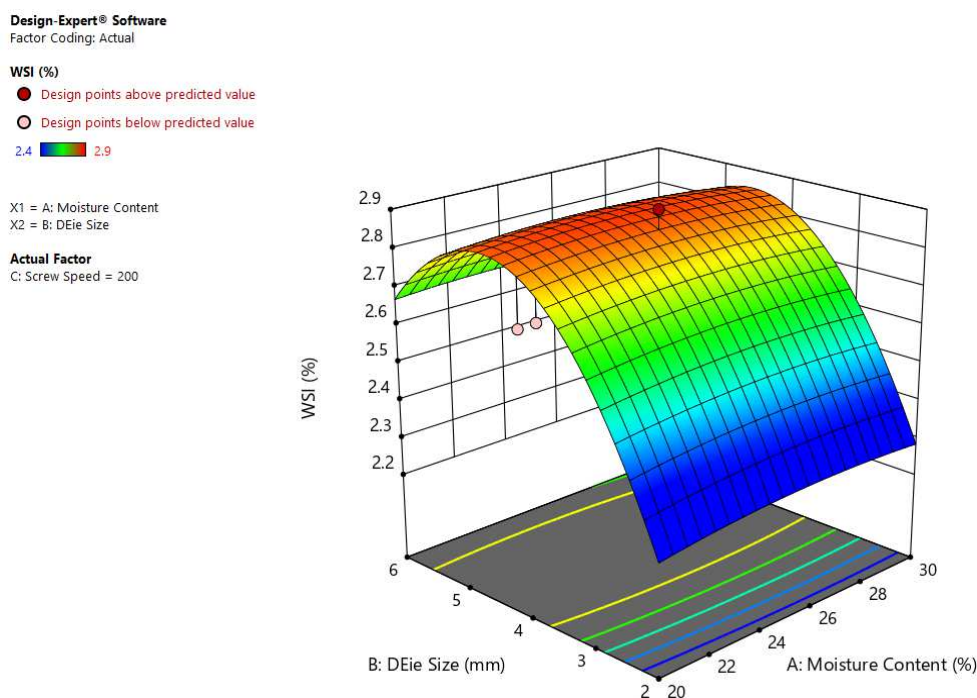


***Figure 6.*** *Effect of some extrusion factors on WSI of soybean crud residue based floating fish feed extrudate.*
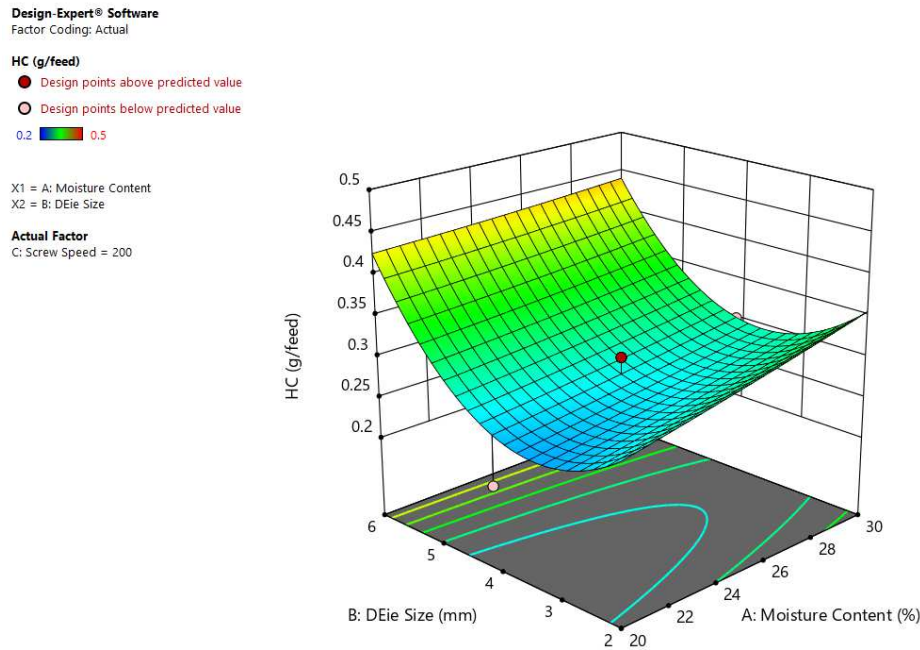
*Figure 7. Effect of some extrusion factors on HC of soybean crud residue based floating fish feed extrudate.*

## 3.8. Hydration Capacity and Hydration Index

Water affinity of plant based foods enhance evaluation of hydration capacity, water absorption and water solubility indices of their functional properties. Polymeric component basically starch material determines the increase or decrease range of hydration capacity, hydration index, water absorption capacity, water solubility index and swelling all these are known as water activities of extruded feed [1]. Hydration capacity and hydration index of soybeans crud residue base floating fish feed is shown of figures 8 and 9 hydration capacity of extruded food or feed indicate potency

of feed layers to bind and retain water molecules within their matrix. Highest value of HC is 0.5 g/feed at 30% moisture content, 6 mm die size and 150 rpm, while HI highest value is 0.68 feed$^{-1}$ obtained at moisture content of 30% screw speed of 150 rpm and die size of 6 mm. Extrusion factors have significant effect on HC and HI at p-value of $p < 0.05$, coefficient of determination $R^2$ of 0.9118, 0.9680 and a predicted $R^2$ of 0.8323, 0.9392 respectively. A quadratic model with a lack of fit not significant was obtained from the ANOVA result validating the essentiality of the model and ability to navigate through the model.
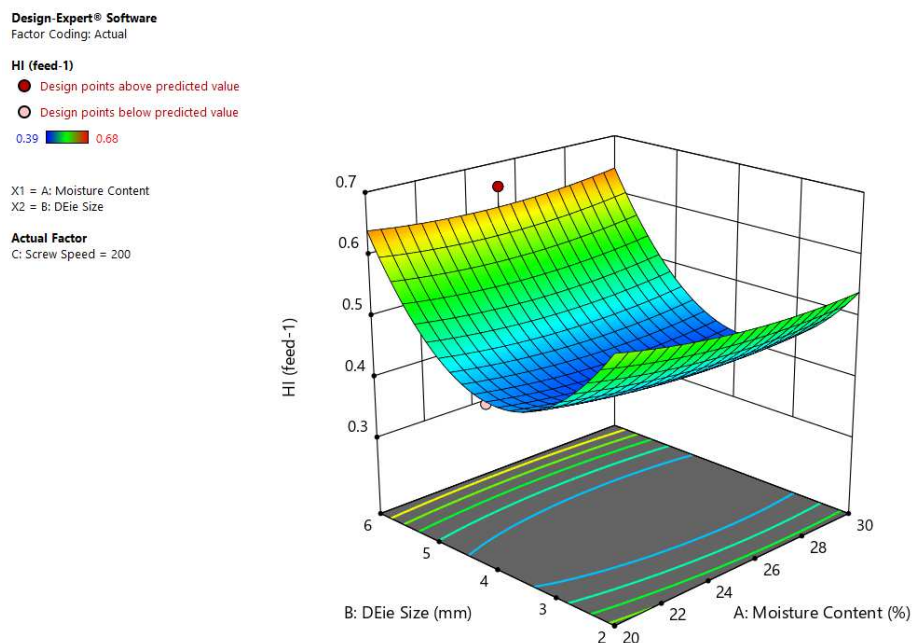


*Figure 8. Effect of some extrusion factors on HI of soybean crud residue based floating fish feed extrudate.*

### 3.9. Swelling Capacity

Swelling capacity of extrudate increases inversely to die size increase, but moisture content initially increase with increase in moisture content and has the highest value of swelling capacity 26% moisture content, 2 mm die size and screw speed of 250 rpm, it later decrease at higher moisture content values. Extrusion factors have significant effect on swelling capacity at $p<0.01$ coupled with coefficient of determination $R^2$ 0.7530. $R^2$ of 75% is very appreciable since

the bench, mark for this study is 60% and the showed a good fit of our experiment. A quadratic model embedded with interactions showed lack of fit not significant validating good fit of the model. Swelling capacity is dependent of water absorption index and both were function of starch component in the feed. Feeds with high protein content have low swelling capacity, soybeans crud residue is excluded of this class, however; this is shown from the result of this experiment.
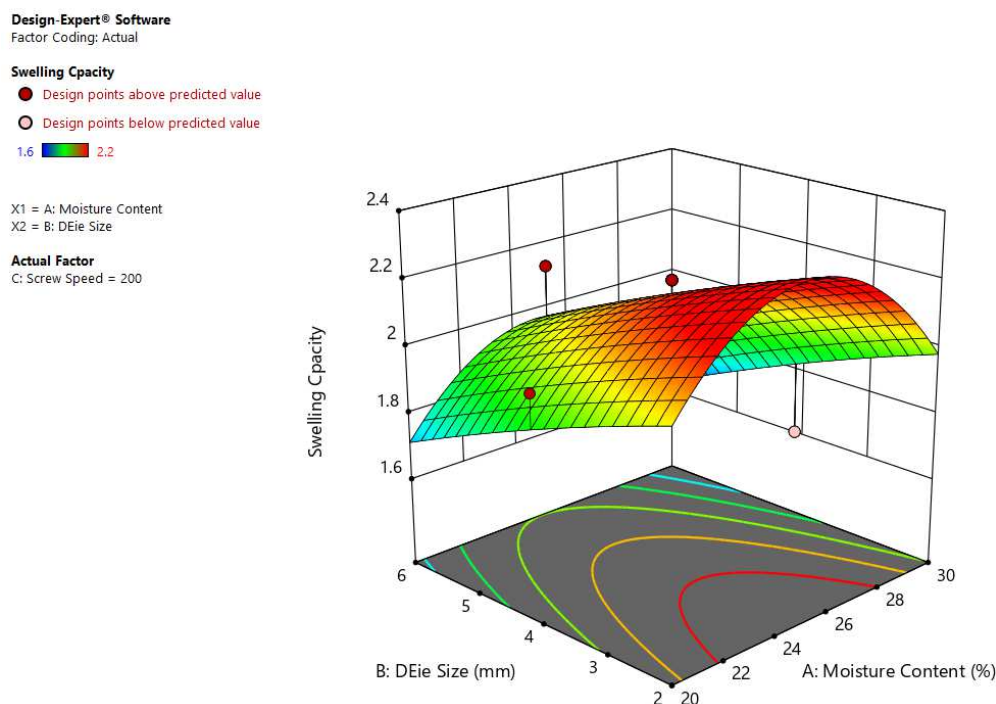


*Figure 9. Effect of some extrusion factors on swelling capacity of soybean crud residue based floating fish feed extrudate.*

### 3.10. Protein Solubility

The highest percentage of protein solubility was 16.3% at pH value of 10 while the lowest was 8.1% at pH value of 3. This graphical representation indicate that protein solubility was of high performance at alkaline medium, due to good digestibility that was obtained at pH of 11, which is of 15.7% value, pH 8 was 18.4%, pH 7 was 15%, pH 6 was 14.6% and pH 5 was 14.1. protein solubility decreases as the pH decreases, only pH 9 result contravenes this, having a result of 9.5% digestibility. This was in line with what [31] on their resarch on protein solubility of fish meal. The functionality of this feed in food system is largely dependent on its protein solubility, the more the solubility the better its performance in food system. Good protein solubility of this feed in alkaline medium is an indication that the protein isolates for the feed could be extracted by alkaline extraction followed by precipitation at their isoelectric pH. The feed is soluble both in acidic and alkaline medium, indicating that it can be given to fish in both acidic and non-acidic water.
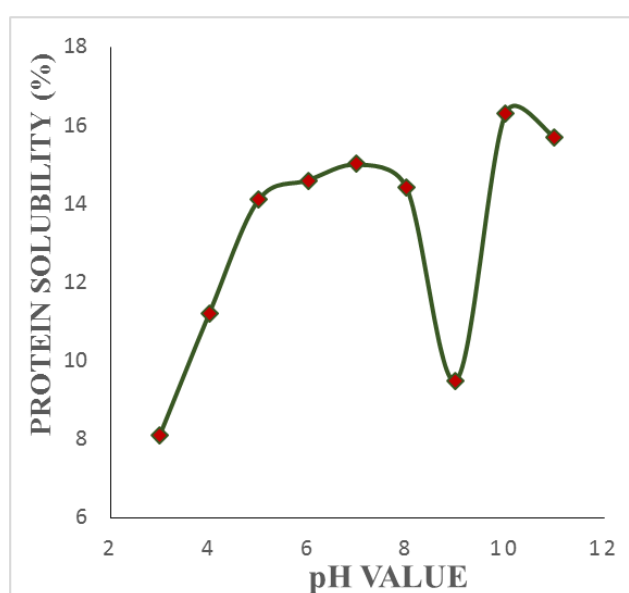


*Figure 10. Effect of moisture content and die size on HI of soybean crud residue based floating fish feed extrudate.*

***Table 6.*** *Laboratory result of protein solubility.*

| Ph Value | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 |
|---|---|---|---|---|---|---|---|---|---|
| Protein Solubility | 8.1 | 11.2 | 14.1 | 14.6 | 15.0 | 14.4 | 9.5 | 16.3 | 15.7 |

### *3.11. Optimization*

Optimization of input variables and responces were carried out numerically and interactive graphs were used in interpreting optimized variables and responces. Vraibles level was adjusted from interactive optimization plots unit, highest desirability value possible was obtained for each responces. Optimized value of input variables, moisture content, die size and screw speed, are 30%, 6 mm and 150 rpm respectively. Optimize value of responces Expansion Rate, Floatation Rate, Sinking Velocity, Specific Mechanical Energy, Swelling Capacity, Water Absorption Index, Water Solubility Index, Hydration Capacity and hydration index were 32.73%, 95.87%, 0.024 ms$^{-1}$, 16.97 KJ/kg, 1.73, 1.61, 2.76, 0.51, and 0.67 respectively. Desirability level of 0.806 out of 1.0 was obtained from the nuberical optimization. Desirability showed idealness of models generated in this resarch work. Figure 6. Is the desirability graph interpreting the relationship between maximized and the mininize responces during optimization and giving validity of desirability level.
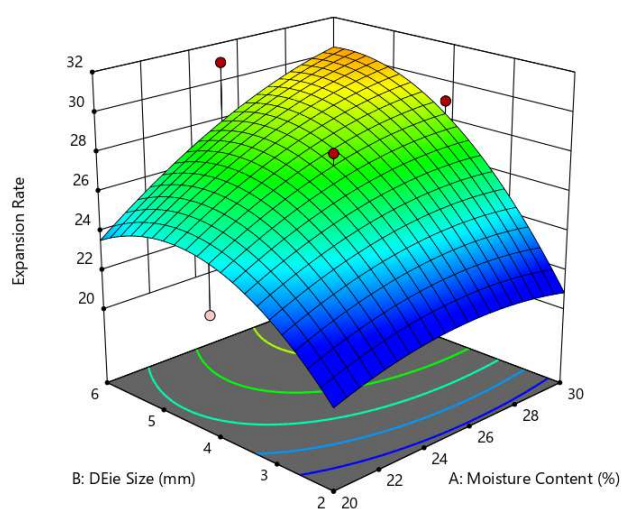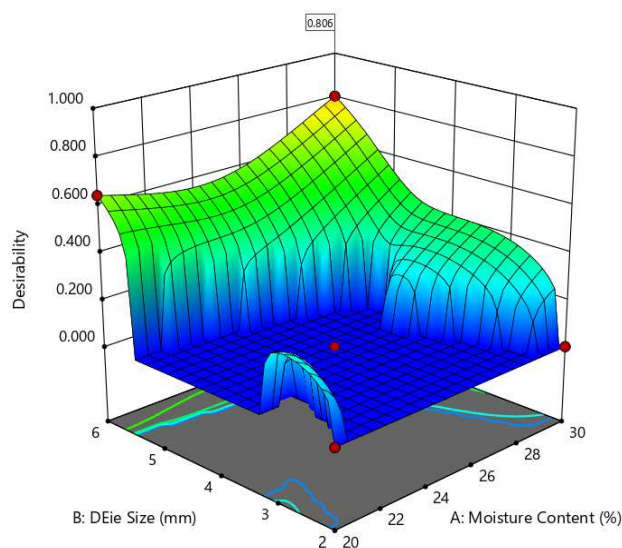




***Figure 11.*** *Desirability graph of soybean crud residue based floating fish feed.*

# 4. Conclusion

A well expanded, instantized soybean crud residue base floating fish feed with good water absorption index, protein digestibility and low sinking velocity was produced. Soybean crud residue is not a waste anymore, but; a useful material. Pearson square method was applied to get the feed formulation. Optimum level of all responses were established from numerical optimization. Feed moisture content and die size have distinct effect on functional and physical properties followed by screw speed during extrusion process. Application of central composite face-centered design in Response Surface Methodology (RSM) brought about the 3-D graphical representation which shows the relationship of all the three factors and each response at every instance. Postulation made from the result analysis indicate that soybean crud residue base floating fish feed is of good fit for fish feed production. A cheap source of fish feed has been obtained through this research work and an added value to the aqua-cultural sector for integral production of fish feed and fish.

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