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Research Article

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

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ABSTRACT

The 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 the 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 m s^{-1}, 16.97 kJ kg^{-1}, 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 the 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 producing model can be used for both domestic and industrial scales of catfish feed production.

RESEARCH ARTICLE

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INTRODUCTION

Legume and grain foods are well known for the supply of food classes to humans and livestock (Kocira, 2019). Soybean (*Glycine max* (L.) Merrill), popular among legume food and grains, with a high content of protein, fibers, fat, and starch (FAO, 2009). It originated from East Asia and is one of the most cultivated legumes in the temperate region (3000 BC) in China and is long recognized in surrounding countries like Japan, Korea, and Malaysia, where it is a long-established cultivated plant (Elvis *et al.*, 2015). Soybean of 40% protein content necessitates additional value chain in its usage on a domestic and industrial scale, being processed to soymilk, tofu, and other soy foods (Sharmila and Athmaselvi, 2017). Soybean Crud Residue (SCR) is the extract for every soybean being processed to soymilk or tofu, after the separation of the molten state (Kamble and Ran 2020). SCR contains 20% protein and fibers 9% inclusive of high moisture content (70%-80%), which makes its handling strenuous, and it is drying exuberant through conventional means. SCR of 1.2 kg was produced as a waste for every 1 kg of soybean processed to soymilk (Bo, 2008). Several tones of SCR were being produced annually in Nigeria with its high nutritional value but being used as a landfill on the refuse dump.

Extrusion cooking has gained recognition in the food processing industry with several operations affecting the physicochemical and functional properties of the food produced for consumer safety (Hongyuan and Alan, 2010). High-Temperature Low Retention Time (HTLT) of extrusion process as making 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 (Adeleye *et al.*, 2020). 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 (Alam *et al.*, 2016; Nagaraju *et al.*, 2021). Large quantity of soybean crud residue (SCR) being produced from the processing of soybean as being a serious concern in the food manufacturing industry due to the management of this waste and the nuisance it constitutes to the environment (Pelembe *et al.*, 2002). In other to reduce this degradation in our surrounding food engineers and technologist are seeking a management model of the agro-by product (Kamble and Ran, 2020). Production of floating fish feed from this by-product will reduce the cost of fish production since the feeding of fish constitutes 60%-80% of total management costs (Olomola, 1990).

The aim of this research is to investigate the effect of some extrusion condition on the physical and functional properties of soybean crud residue (SCR) base floating fish feed. Response surface methodology (RSM) was used to analysed the statistical result of this experiment. RSM is a collection of statistical techniques for experimentat design, model development, evaluating impact and effect of factors on responses, optimization of factors condition, and level of desirability was used to assess the aim and objectives of this research work.

MATERIALS and METHODS

Procurement of Materials

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

Preparation of Soybean Crud Residue

The first operation was to clean about 22 kg of soybean grains using a 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 litres at room temperature to improve its handling. Dehulling was the next stage of preparation this was done manually in a bowl of 50 litres capacity with treated water, it chaffs and some dirty materials have been removed leaving behind well-soaked soybean grains. It was milled using an 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 (BSI, 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 a 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.

Formulation of Soybean Crud Residue Base Floating Fish Feed

Pearson square method for determining 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 constituents through proximate analysis, maize contains 10% protein, soybean crud residue 30%, cassava starch 3.6%, wheat bran 17%, soybean meal 40%, fish meal 65%. The constituent was ground properly and mixed thoroughly using a mechanical mixer (335 LP china). Calculation of arithmetic procedures in the Pearson square method is as summaries (Orire and Sadiku, 2015; Enwemiwe 2018).

Table 1. Arithmetic result of Pearson square method of fish feed formulation.

	First Group		**Second Group**
Average	17.3%		37.3%
Percentage of the 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%
Soybean's 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 these feeds were readily locally available food materials, the 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.

Extrusion Cooking

Feed formulated was divided into 20 specimens, 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^{-1}, and a single screw extruder in the Department of Agricultural and Environmental Engineering Federal University of Technology Akure was used. Moisture content, die size, and screw speed was 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 its physicochemical and biochemical qualities. Experimental samples were collected after gelatinization was attained and were being left in the open air for some minutes to cool, before packing into a polythene bag before further analysis.

Moisture Content

Moisture content (*wet basis)* of the feed was calculated and determined with the use of modified Equation (1) used by Twum and Akash (2018)

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

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

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

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

Determination of Physical and Functional Properties

Expansion Rate

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

$$\text{Er} = \frac{D_{1-} D_2}{D_2} X\ 100 \tag{3}$$

Where; *Er* is the expansion rate, D_1 is the diameter of extruded feed, D_2 is the diameter of the die hole.

Flotation Test

A 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.

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

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 several feeds were poured in it, this was kept constant while the time spent by each sample to reach the bottom of the flask was recorded. Sinking velocity was determined using Equation 5 below.

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

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.

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 a mathematical Equation from (Ojo *et al.*, 2015)

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

Where; τ is the torque (N m), S_s is screw speed (rpm), F_r is feed rate (kg min^{-1}). The calculation of machine torque was done with the use of Equation 7.

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

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 the 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 the weight of gel in grams (g) W_2 is the weight of extrudate (g)

Water Solubility Index (WSI)

The water solubility index determines the amount of polysaccharides or polysaccharides released from the granule on the addition of an excess of water. WSI was the weight of dry solids in the supernatant from the water absorption index test expressed as a 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)

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

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

Hydration Capacity and Hydration Index

These were determined by the method used by Brachet *et al.* (2015) with some modifications. 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 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 was calculated using the following expressions.

$$HC = \frac{\mathrm{W}_2 - W_1}{n}\ (\text{g feed}^{-1}) \qquad (10)$$

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

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

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

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 (Minneapolis MN USA, 2018) statistical software. Table 2 shows the design procedure and levels of variables used in this experiment. The matrix of this experiment was shown in Table 3 is developed from a central composite face-centered design. Fourteen-star points and six central points made up the experimental space, adding up to 20 runs of the experiment. The model obtained from the experiment was fitted to a second-order polynomial regression model (Annor *et al.*, 2009).

$$Y = P_O + P_1X_1 + P_2X_2 + P_3X_3 + P_{11}(X_1)^2 + P_{22}(X_2)^2 + P_{33}(X_3)^2 + P_{12}X_1X_2 + P_{13}X_1X_3 + P_{23}X_2X_3 + \varepsilon$$

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; ε is the error term.

Table 2. Independent variables and their levels of replication.

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

Statistical Analysis

Design expert 11 Stat-Ease Microsoft Window (Minneapolis 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). RSM gives a three factorial graph combining two factors, showing the effect on each response. Numerical optimization and interactive graphs were used to optimize the various input variables and responses. It generated models for each of the responses with accurate validation to make a further prediction, evaluation, and postulation. The level of desirability shows the reliability of results, this level ranges from 0 to 1. The nearness to 1 the level of desirability the more reliable the result got from the research.

RESULTS AND DISCUSSION

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, the inclusion of result gotten for responses. Analysis of this data developed models of quadratic and linear regression, ANOVA result indicates 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. The experimental result was obtained for statistical analysis.

Run	Moisture Content	Die Size	Screw Speed	ER	FR	SV	SMER	SC	WAI	WSI	HC	HI
	%	mm	rpm	%	%	m s^{-1}	kJ kg^{-1}		g g^{-1}	%	g feed^{-1}	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

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 was not significant for all responses except for floatation rate and water solubility index which is still acceptable. R^2 of 0.60 was used for a good of fit, on the contrary: Joglekar and May (1987) agued that 0.80 value of R^2 for a good fit could be excesive for validation. Also, Annor (2009) narrated that 0.80 (80%) value of R^2 is outrageous in the preliminary study, therefore recommended an R^2 value of 0.60 (60%) as an adequate R^2 value for validation. 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:

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

$$FR = 84.90 + 1.7X_1 + 4.9X_2 + 0.000X_3 + 4.26{X_1}^2 - 3.33{X_2}^2 + 2.76{X_3}^2 + 1.50X_1X_2 + 0.0000X_1X_3 + 0.0000X_2X_3 \; (R^2 = 0.8823)$$

$$SC = 2.16 - 0.00380X_1 - 0.1722X_2 - 0.0000X_3 - 0.3017{X_1}^2 - 0.0145{X_2}^2 + 0.0983{X_3}^2 - 0.0250X_1X_2 + 0.000X_1X_3 + 0.0000X_2X_3 \; (R^2 = 0.7530)$$

$$HC = 0.2793 + 0.0200X_1 + 0.0547X_2 + 0.0100X_3 + 0.0017{X_1}^2 + 0.0970{X_2}^2 + 0.0517{X_3}^2 - 0.0125X_1X_2 - 0.0125X_1X_3 - 0.01125X_2X_3 \; (R^2 = 0.9118)$$

$$HI = 0.4097 - 0.0080X_1 + 0.0411X_2 + 0.000X_3 + 0.0159{X_1}^2 + 0.1747{X_2}^2 + 0.0259{X_3}^2 + 0.0100X_1X_2 + 0.0000X_1X_3 + 0.0000X_2X_3 \; (R^2 = 0.9680)$$

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

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

$$SME = 22.07 - 0.1000X_1 - 3.35X_2 + 0.1000X_3 - 2.17{X_1}^2 + 0.676{X_2}^2 - 0.1772{X_3}^2 - 0.125X_1X_2 - 0.1250X_1X_3 - 0.1250X_2X_3 \; (R^2 = 0.9415)$$

$$WAI = 1.42 + 0.0700X_1 - 0.1172X_2 + 0.000X_3 - 0.0017{X_1}^2 + 0.3155{X_2}^2 - 0.0517{X_3}^2 - 0.0250X_1X_2 + 0.000X_1X_3 + 0.00X_2X_3 \; (R^2 = 0.9026)$$

$$WSI = 2.85 + 0.000X_1 + 0.1931X_2 + 0.0100X_3 - 0.0207{X_1}^2 - 0.3638{X_2}^2 - 0.293{X_3}^2 - 0.0125X_1X_2 - 0.01250X_1X_3 + 0.025X_2X_3 \; (R^2 = 0.8881)$$

Table 5. The regression coefficient for physical and functional 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, S.D = standard deviation.

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 (Emmanuel *et al.,* 2004). Sectional expansion of extrudate is mostly high in the extrusion of starchy constituents than protein foods, soybean has a low expansion rate (Yatin et *al.,* 2015). The expansion rate of extruded soybean crud residue-based floating fish feed was affected positively by moisture content and die size, there was an 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 the tendency of decrease in expansion rate if moisture content increases further, as it is shown on the graph between expansion range of 22% to 28% at the moisture content of 30%. Most extruded product expansion rate increases with an increase in variation of moisture content level coupled with variation in screw speed level, with the presence of adequate water for expansion of the resin (Nagaraju *et al.,* 2021; Geetha *et al.,* 2016). The die hole on the die head fixed to the barrel of the extruder has a more significant effect on the expansion of the resin than moisture content, this was in line with (Azam and Singh, 2017) in their research on extrusion of Kodo based extrudate. The highest expansion rate was 32% recorded at 6 mm die size and 30% moisture content, ANOVA result shows that the effect of die size and moisture content on expansion rate was significant at both $p < 0.05$ and $p < 0.01$ level of significance, lack of fit of the model generated was not significant which validate good fit of the model.

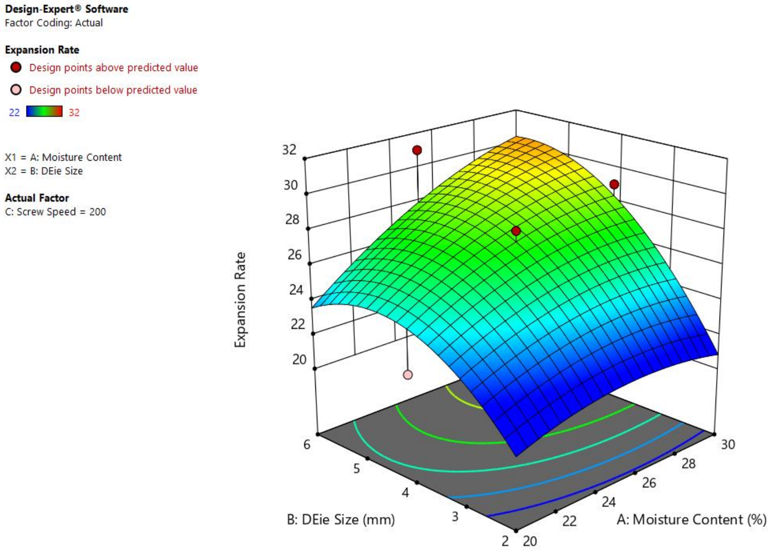

Figure 1. Effect of some extrusion factors on the expansion rate of soybean crud residue-based floating fish feed extrudate.

Floatation Rate

Floatation is the ability of the feed to obey the 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 Orire *et al.* (2015) in the test of buoyance for fish feed. It serves as a device to know how healthy and hardy the fish(s) (Orire and Emine, 2019). 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 Olaowale and Oluniyi (2019) 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 one showed a 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. Solomon *et al.* (2011) Recorded 97% floatation in feed with cassava starch has binder. Orire and Sadiku (2019) also observed a similar reaction in their quest for farm-made floating fish feed. ANOVA result reviled that floatation rate was significant at a p-value of $p<0.01$ level of significance, coefficient of determination R^2 was 0.88. 88% of the coefficient of determination R^2 was considered enormous, however; 60% R^2 was used for a good fit in this research work, in other words; 88% coefficient of determination R^2 indicates a very good fit. The close range of our predicted value to our observed authenticate a good fit of the model generated.

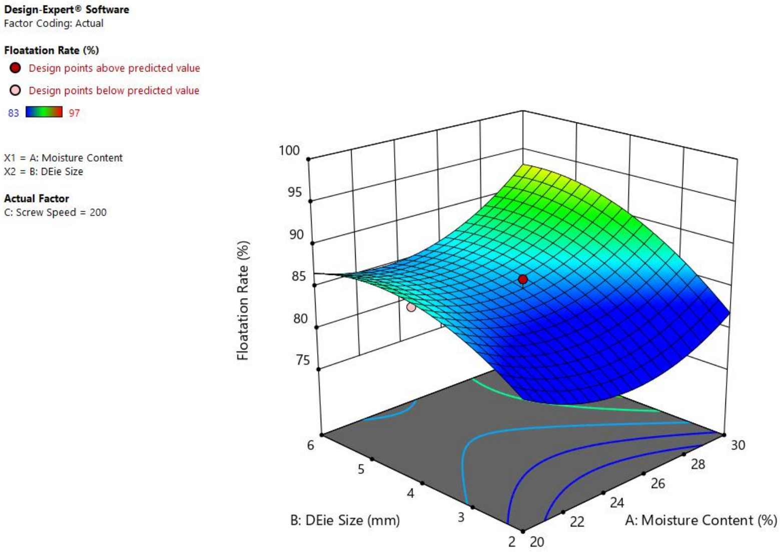

Figure 2. Effect of some extrusion factors on floatation rate of soybean crud residue-based floating fish feed extrudate.

Sinking Velocity

Sinking feed is a challenge that bedeviling aquaculture production over the years, feeds of high bulk density were majorly found to have a fast-sinking rate due to a low level of expansion for void creation during extrusion to aid its floatation (Efren and Damian, 2018). Its high rate of dissociation in water contaminates 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 (Yatin, 2015). Moisture content and die size have a significant effect on sinking velocity at a p-value of 95%. It was observed that die size and sinking velocity was inversely proportional, 2 mm die size has the highest sinking velocity of 0.0264 m s^{-1}, while 6 mm die size has the lowest sinking velocity of 0.023 m s^{-1}. Solomon (2011) Also made a similar observation in cassava starch binding agent of formulated floating fish feed. Olaowale and Oluniyi (2019) made a similar inference that sinking velocity could be affected by the type of binding agent and rate of expansion coupled with the 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 recorded 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 others were a quadratic model.

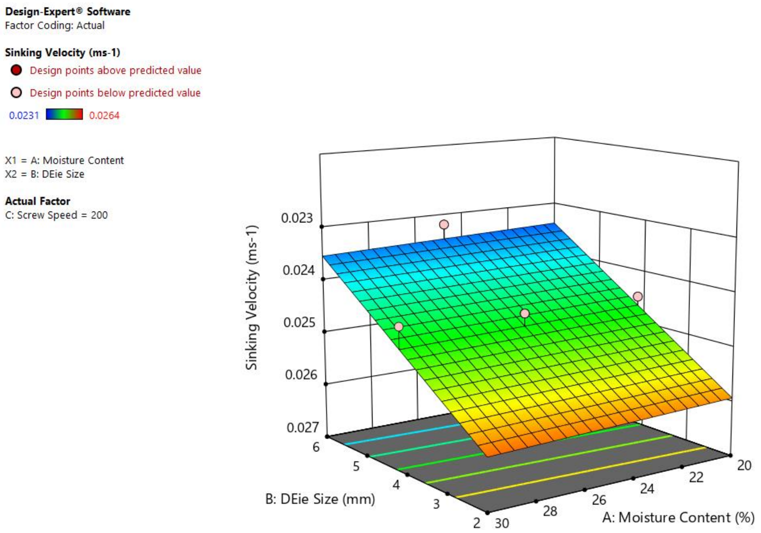

Figure 3. Effect of some extrusion factors on sinking velocity of soybean crud residue-based floating fish feed extrudate.

Specific Mechanical Energy

The energy required to process soybean crud residue-based floating fish feed in an extruder is dependent on the moisture content of the resin, die size, and screw speed of the machine. The low moisture content of the resin in the barrel caused clogging at the dying opening, overstressing the screw auger leading to breakage of the power transmission unit, the chain. The hole of the die played a significant role in the flow rate of extrudate we observed that at low orifices there was an accumulation of stress while at bigger die sizes flow rate was high due to allowance of die size. This was corroborated by Shuyang (2018) in his research on the 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^{-1} at 26% moisture content and 2 mm die size, while the least was 17 kJ kg^{-1}, 6 mm die size and 20% moisture content. The 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.

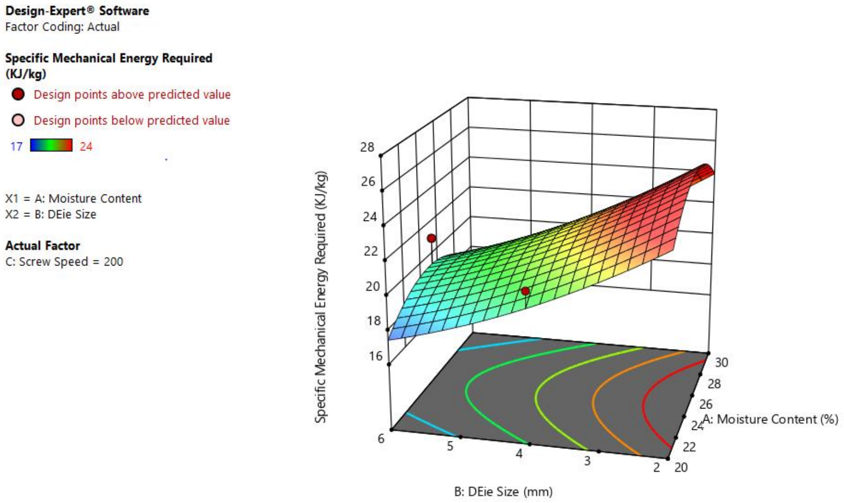

Figure 4. Effect of some extrusion factors on Specific mechanical energy of soybean crud residue-based floating fish feed extrude.

WAI and WSI

The water absorption index is one dependent feature used to evaluate the quality of extruded products. WAI may influence the hydration capacity of such extruded products. (Sharmila and Athmaselvi, 2017). Water absorption of this extrudate varied from 1.4 to 1.9 g H_2O g^{-1}, this low WAI was also observed by Singh *et al.* (2007) in the extrusion of soybeans flour. Soybeans being an oilseed will have low WAI, the reason being that its oil layer will prevent absorption of water into its layer decreasing WAI of soybeans-based extruded feed (Filli, 2010; Gbenyi, 2016). Starch-based feeds tend to have high WAI, enhanced during gelatinization properly formed by barrel temperature and feed moisture content during the extrusion process (Nagaraju *et al.*, 2021; Gbenyi, *et al.*, 2016). The highest value of WAI 1.9 g g^{-1} was obtained at 30% moisture content and 2 mm die size, this may be as a result of an increase in variation of moisture content of the feed. This is in concord with Gbenyi *et al.* (2016) report, increase in moisture content of feed have a significant effect on WAI, moisture acting as a catalytic agent of plasticizer in extrusion cooking affects starch granule and improve water absorption capacity. The coefficient of determination R^2 of 0.902 was obtained from the ANOVA result, indicating a good fit for this research work. Moisture content, die size and screw speed have a significant effect on WAI at the 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. The water absorption index serves as a measuring device in determining volume occupied by resin starch after swelling in water, justifying the integrity of starch behavior in aqueous dispersion (Nagaraju, 2021). 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 a decrease in die size and later decrease as it reduces in Figure 6. This was interned with Marcin *et al.* (2020) in the extrusion cooking of red and white beans, soybeans as a protein seed were significantly affected with screw speed, die size, and moisture content. Hamada *et al.* (2017) Recorded a decrease in WSI which is a function of the 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. The extrusion process is high torque low speed and high-temperature low retention time process (Alam *et al.*, 2016). Variation in die size influences clogging during extrusion cooking, low die sizes tend to have clogging than high sizes leading to accumulation of forces consequential of high temperature, which affects the quantity water solubility index (WSI). Pelembe (2002) identifies that starchy food content is not only responsible for WSI but other soluble content like protein. This affects the water solubility index (WSI) of soybeans crud residue-based floating fish feed, moisture content during extrusion has a significant effect on WSI at the p-value of $p<0.01$, coefficient of determination of $R^2=0.888$, and closeness to the predicted value of R^2 intensify the god fit of the result gotten. WSI was an indicator of the degree of gelatinization of starch components and degradation of molecular components as well as the measurement of the quantity of soluble polysaccharides from the starch of extruded product. The quadratic equation generated has a lack of fit of not significant validating the good fit of the model.

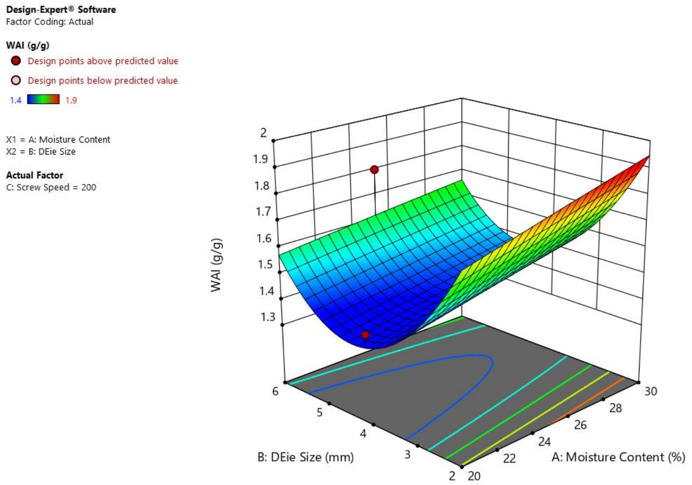

Figure 5. Effect of some extrusion factors on WAI of soybean crud residue-based floating fish feed extrudate.

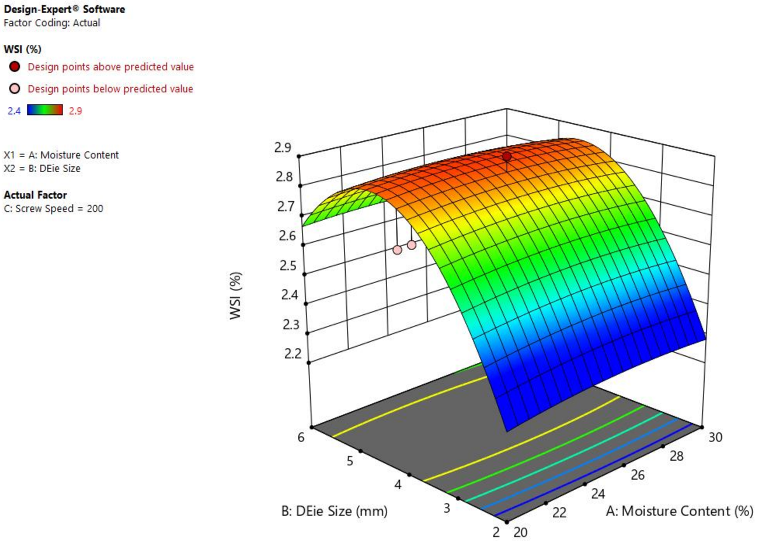

Figure 6. Effect of some extrusion factors on WSI of soybean crud residue-based floating fish feed extrudate.

Hydration Capacity and Hydration Index

Water affinity of plant-based foods enhances the evaluation of hydration capacity, water absorption, and water solubility indices of their functional properties. The polymeric component 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 (Adeleye *et al*., 2020). The hydration capacity and hydration index of soybeans crud residue base floating fish feed are shown in figures 8 and 9 hydration capacity of extruded food or feed indicates the potency of feed layers to bind and retain water molecules within their matrix. The highest value of HC is 0.5 g feed^{-1} 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 a significant effect on HC and HI at the 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.

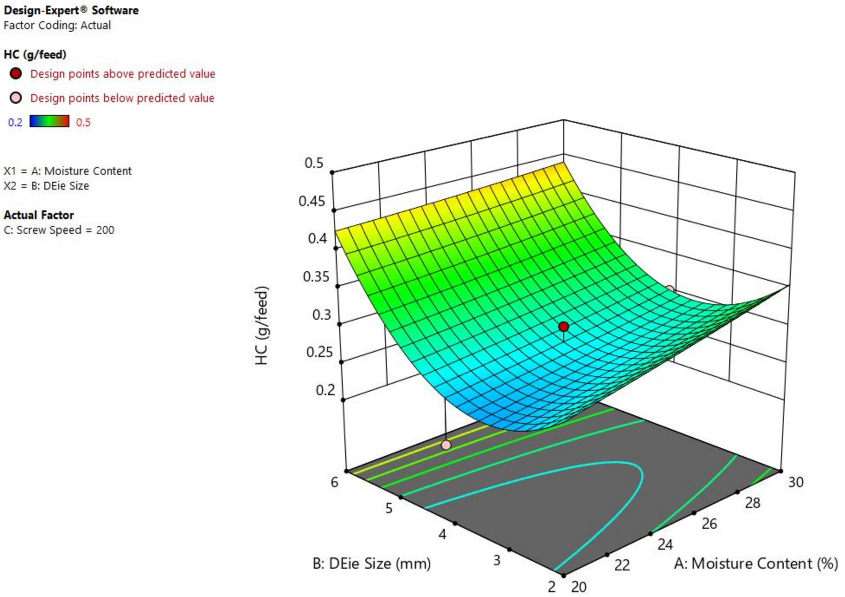

Figure 7. Effect of some extrusion factors on HC of soybean crud residue-based floating fish feed extrudate.

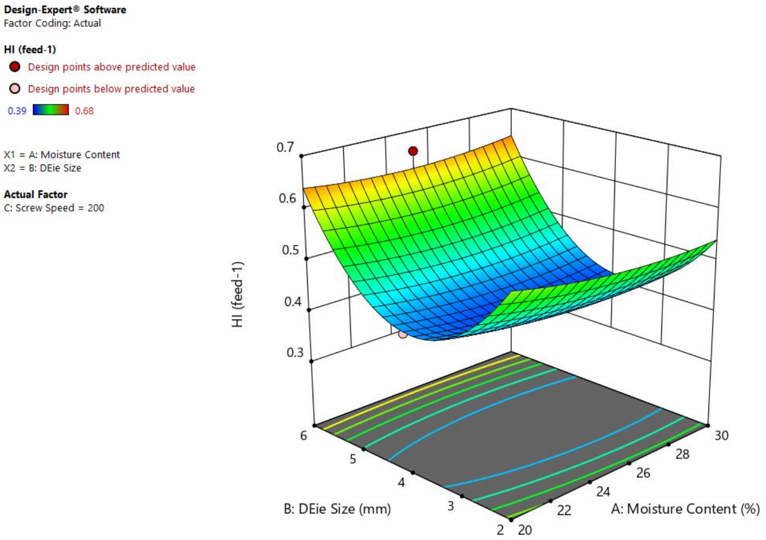

Figure 8. Effect of some extrusion factors on HI of soybean crud residue-based floating fish feed extrudate.

Swelling Capacity

The swelling capacity of extrudate increases inversely to die size increase, but moisture content initially increases 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 decreases at higher moisture content values. Extrusion factors have a significant effect on swelling capacity at $p<0.01$ coupled with the 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 for our experiment. A quadratic model embedded with interactions showed a lack of fit not significant validating the good fit of the model. Swelling capacity is dependent on the water absorption index and both were a function of the starch component in the feed. Feeds with high protein content have a low swelling capacity, soybeans crud residue is excluded from this class, however; this is shown from the result of this experiment.

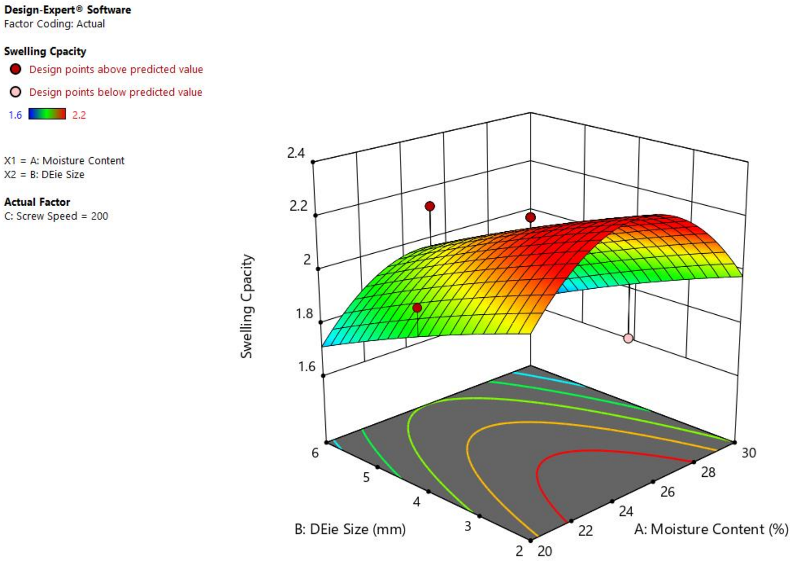

Figure 9. Effect of some extrusion factors on the swelling capacity of soybean crud residue-based floating fish feed extrudate.

Protein Solubility

The highest percentage of protein solubility was 16.3% at a pH value of 10 while the lowest was 8.1% at a pH value of 3. This graphical representation indicates 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 the pH 9 result contravenes this, having a result of 9.5% digestibility. This was in line with what Pelembe, (2002) in their research on protein solubility of fish meal. Solubility of protein in soybean crud residue in both acidic and alkaline medium could be a function of its aggregate. Shuhong *et. al.* (2013) coroborate this statement as factual due to the impact of aggregate, size, and fractions, on protein recovery from soybean. The functionality of this feed in the food system is largely dependent on its protein solubility, the more the solubility the better its performance in the food system. The good protein solubility of this feed in an 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 mediums, indicating that it can be given to fish in both acidic and non-acidic water.

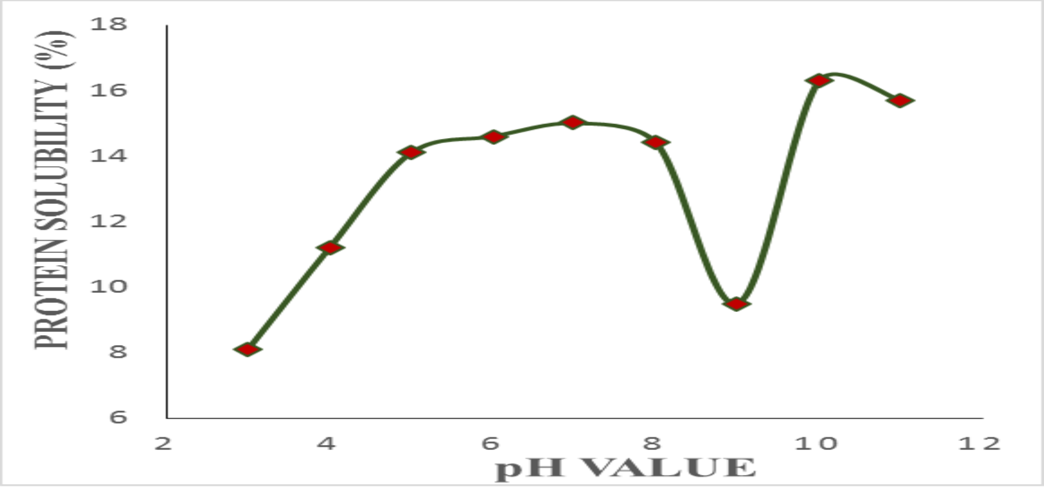

Figure 10. Effect of moisture content and die size on HI of soybean crud residue-based floating fish feed extrudate.

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

Optimization

Optimization of input variables and responses were carried out numerically and interactive graphs were used in interpreting optimized variables and responses. Variables level was adjusted from interactive optimization plots unit, highest desirability value possible was obtained for each responses. Optimized values of input variables, moisture content, die size and screw speed, are 30%, 6 mm, and 150 rpm respectively. Optimize the value of responses 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}, 1.73, 1.61, 2.76, 0.51, and 0.67 respectively. A desirability level of 0.806 out of 1.0 was obtained from the numerical optimization. Desirability showed the idealness of models generated in this research work. Figure 6. Is the desirability graph interpreting the relationship between maximized and the minimized responces during optimization and giving validity of desirability level.

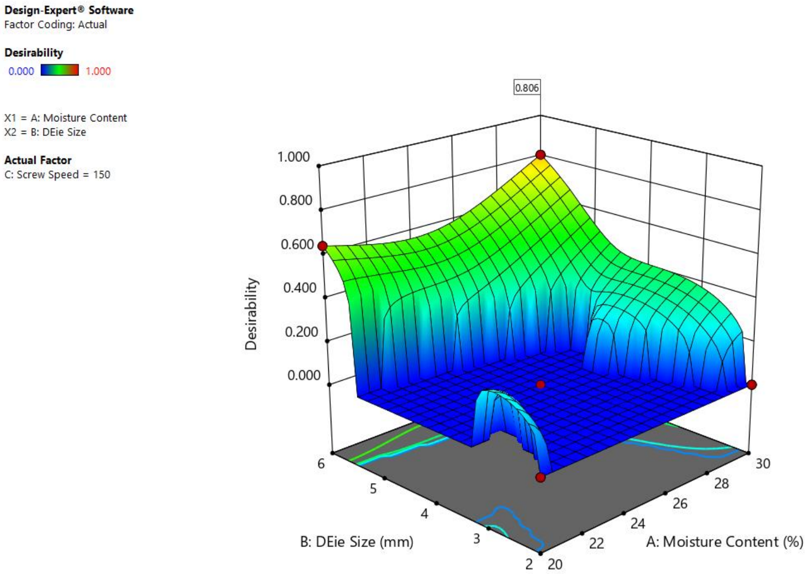

Figure 11. Desirability graph of soybean crud residue-based floating fish feed.

CONCLUSION

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

DECLARATION OF COMPETING INTEREST

The authors declare that they have no conflict of interest.

CREDIT AUTHORSHIP CONTRIBUTION STATEMENT

Saheed Abiola Olaoye: Investigation, methodology, conceptualization, formal analysis, data curation, validation and review, I made noble contributions.
Olanrewaju Temitope Owoseni: Investigation, methodology, conceptualization, formal analysis, data curation, validation and review, and I can be question for my contribution evaluation.
Ayoola Patrick Olalusi: I supervised each and every section of this research work and I can be communicated for and cloudy area.

ETHICS COMMITTEE DECISION

This article does not require any ethical committee decision.

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