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Optimisation of the Technical Quality of a Co-Product Mix Basedfeed for Improved Sustainable Swine Production

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ABSTRACT

The desire for sustainable feeding of world population and the skyrocketing prices of cereals in the world market are demanding that co-products be used optimally by turning them into quality extrudates. Unfortunately, most local co-products have not been used to manufacture swine feed extrudates. At best these local co-products have been fed to pigs as ground mash or meal. In this study co-products mix based swine feed extrudateswere developed using yam peels (10%), poultry waste (10%),multigrain waste (20%), cassava peels (20%),and palm kernel cake (40%). Then using a continuous extrusion-drying-cooling feed plant, the swine diet of co-products mix was processed into feed extrudates which were tested for their durability index and breaking strength. The tests were carried out on the basis of Taguchi's L8 orthogonal array taking five design factors, diet formulation (I, II), feed mash moisture content (20,40%), barrel temperature (80, 120^{o}C), die length/ diameter ratio (1, 1.5), and drying air temperature (50, 8 ^{o}C). The results were analysed using Analysis of Variance to study the effects of main factors, their interaction effects and to establish the optimum values of pellet technical quality characteristics. The most significant factor and interactions are barrel temperature, and interaction between L/D ratio and drying air temperature, and between co-products and mash moisture content. The feed extruded using a factor combination of diet1, 40% moisture content, 120^{o}Cbarrel temperature, 1.5 L/D ratio, and 80^{o}C air drying temperature gave the optimum durability index of 0.991 and breaking strength of 0.774 MPa.

Keywords: Breaking strength, Co-products, Durability index, Feed Extrudates, Swine

INTRODUCTION

Conventional poultry and swine diets are based mainly on maize and soybeans to the extent that about 70-80 percent of maize production is used as feed ingredient in the world [1]. Today, the cereals are not easily available for feed production because a reasonable quantity of the cereals is now being used for bio-fuel production [2] and to feed a large part of the world population especially in developing countries. The cereals supply-demand gap is exacerbated by the associated and inevitable generation of enormous by-products [3] during the processing of the cereals for food and bio-fuels. Thus, owing to insufficient production, and prohibitive cost of the conventional feed sources aggravated by stiff competition between men and livestock for these conventional ingredients [1], feed costs climbed and hovered at 65- 80% [4] of the total costs of livestock production. As a surviving strategy in the face of the skyrocketing prices of conventional grains [5, 6] pig farmers in the world have embraced the by-products of agriculture and food processing industries as supplements or alternatives for the conventional grains for feeding their pigs. In the past, these by-products used to be discarded as wastes but following the realization of their usefulness, the European Federation of Feed Manufacturers (FEFAC) advocated for a shift from a by-product to a co-product mentality [7]. Thus, the by-products are now called co-products as their utilization in livestock feeding supports the sustainability and profitability of the entire food production system.

Apart from being considered unfit for direct human consumption [8], some of these co-products have low quality, or high fibre content, while some others contain anti-nutritional factors which influence feed palatability, digestibility, and impair animal production performance [9]. Nonetheless, pigs do well with these co-products because, as ruminants, they are naturally endowed to convert them to food products for man. Therefore, with the rising prices of feed grain, Zijlstra [10] postulated that for the foreseeable future co-products should be used by the pork industry to a much greater extent as feedstuff in swine feed. Moreover, the current use of co-products for livestock is being supported and promoted by the new and sustainable production approach of the future, known as circular agriculture (CA). CA is being considered to replace the present conventional model of food production that is characterized by a "take-produce - consume-discard" pattern [11]. The CA demands that the co-products be utilized optimally and this requires that the co-products be converted to the appropriate feed forms and quality.

One way to achieve optimal utilization of co-products is to convert them to feed extrudates or pellets by extrusion. Extrusion involves grinding to reduce particle size and increase digestibility [9]; and heating to reduce concentrations of anti-nutritional factors. Extrusion is considered as being popular and sustainable [12] and aims at producing granule-shaped compound feed with appropriate nutritional and technical qualities [13]. Another way to ensure optimality in the use of co-products is to avoid feed waste that is lost under the influence of post-processing effects [10]. Because feed extrudates are not usually consumed where and when they are manufactured, they have to undergo such post-processing operations as handling, transportation, storage, and feeding. Thus, these feed extrudates are inevitably subjected to friction, vibration, and pressures, which cause poor quality feed extrudates [14] to disintegrate by abrasion and fragmentation. Abrasion is the wearing away of fine particles from the sides of the feed extrudates caused by friction while fragmentation is said to occur when feed pellet breaks into big particles as a result of tension, compression, or collision during storage and transportation [15]. From the nutritional and environmental points of view, abrasion is considered more damaging than fragmentation because of the problem of segregation. The feed waste associated with abrasion and fragmentation can be minimized by ensuring that feed extrudates have high technical quality. According to Haubjerg*et al.*, [16], technical quality of feed is a term used to describe the several characteristics of feed extrudates that enable them to:

- endure mechanical stresses during handling and transportation; and

- have density, geometry and size

The technical quality of feed extrudates is evaluated in terms of the mechanical durability and hardness (breaking strength) of the feed extrudates. Mechanical durability refers to the capacity of the feed extrudate to maintain its shape and size during handling, transportation, and pneumatic feeding [17]. It is expressed by means of pellet durability index (PDI). Hardness is used to gauge whether or not the pellets are too hard for the particular target animal.

The hardness and durability of pellets depend upon the raw materials used to formulate the diet and processing parameters (18 - 20). However, Fahrenholz [21] warned against high inclusion of co-products in feed rations as this deteriorates the extrudates quality and weakens the strength. This poses a big challenge as the feed grain markets are demanding that higher and higher inclusion levels of co-products in swine feed be achieved. Zijlstra [10] suggested a possible solution. According to them, the risk of high inclusion level of co-products in swine feed might be managed better by including multiple co-products each at a lower inclusion level than a large quantity of a single co-product. Unfortunately, rather than researching into the possibility of resolving the challenge of including an increasing amount of co-products in feed, most research efforts [22] were directed towards studying the impact of individual co-products.

In view of the importance of co-products to improving the sustainability of livestock production, this study was conceived with the aim of optimization of the technical quality of a co-products mix based feed for improved sustainable swine production.The specific objectives include:

1. Formulating an alternative swine feed using a mix of co-products;
2. Manufacturing of feed extrudates using the formulated swine diet of co-products mix;
3. Determining the durability and breaking strength of the various feed sample;
4. Investigating the effects of processing factors and factors interactions on the durability and hardness of the feed extrudates; and
5. Optimizing the technical quality of the feed extrudates.

MATERIALS AND METHOD

Materials

Two different swine diet formulas were used; the first was made of conventional materials such as maize, soya beans and peanut, while the second (an alternative) was composed mainly of co-products materials which included palm kernel cake ((PKC), poultry waste (PW), cassava peels (CP), yam peels (YP) and multi-grain winnowing waste (*Azaraza*).

Design of Experiment - Taguchi Method

Using the Taguchi method to design the experiment involved undertaking the following actions:

Identifying the Objective Function

The object of this study consists in maximizing the technical quality of the fees pellets in terms of their mechanical durability and breaking strength. Hence, the objectives function, Larger – the – better, was chosen. The calculation of the signal – to – Noise (S/N) was carried out using equation (1).

$$S/N = 10Log_{10}\frac{1}{n}\sum_{i=1}^{n} Y_i^{\ 2}$$

Where:

n = Sample size; and

Y = measured value of the particular quality test.

Identifying the Control Factors and their Levels

Five factors were considered as control factors for constructing the matrix for the experimentation while the other factors were considered as Noise factors as shown in Table 1.

Table 1: Factors that Affect Feed Extrudates Quality

Control Factors	Noise Factors
Diet Formulation	Raw Material Variation
Feed moisture	Test Apparatus Conditions
Barrel Temperature	Operator's Skill
Die L/D ratio	Weather condition
Drying Air Temperature	

In the study, two levels were chosen for all the control factors as shown in Table 2.

Table 2: Process Parameters and their Levels

Process Parameters	Designation	Level 1	Level 2
Diet Formulation	A	I	II
Feed Mash Moisture (%)	C	20	40
Barrel Temperature (°C)	B	80	120
Die L/D Ratio	D	1	1.5
Drying Air Temperature (°C)	E	50	80

Selection Orthogonal Array (OA)

The appropriate OA for conducting the experiment was determined by first calculating the degree of freedom (DoF) using the equation (2)

$$DoF = P^{L-1} \quad (2)$$

Where:
L = number of levels; and
P = number of factors.
Given that in this study that P = 5; and L = 2;
Then $DoF = 5^{2-1} = 5$

Since the total OA must be greater than or equal to the calculated DoF, the L8 OA was chosen as the most suitable standard OA. The control factors with their levels were filled into the OA table to produce the experimental layout with the selected values of the factors as shown in Table 3.

Table 3: L – 8 OA Experimental Layout

Experiment	Control Factors				
No	Diet Formula	Barrel Temp	Feed Moisture	Die L/D Ratio	Drying Air Temp
1	I	80°C	20%	1	50°C
2	I	80°C	20%	1.5	80°C
3	I	120°C	40%	1	50°C
4	I	120°C	40%	1.5	80°C
5	II	80°C	40%	1	80°C
6	II	80°C	40%	1.5	50°C
7	II	120°C	20%	1	80°C
8	II	120°C	20%	1.5	50°C

As shown by the experiment layout above, the eight experiments required were A1B1C1D1E1, A1B1C1D2E2, A1B2C2D1E1, A1B2C2D2E2, A2B1C2D1E2, A2B1C2D2E1, A2B2C1D1E2, and A2B2C1D2E1.

Formulation of Experimental Diets

Prior to the formulation of the test feed diets, all the co-products feed materials were sent for analysis for their individual proximate compositions. Then, using the results of the proximate analysis of the ingredients, the formulations were done such that the two diets had comparable compositions as shown in Table 5.

Table 5: Ingredient Proportions of Diet Formulations

Ingredients	%Mass Composition	
	I	II
Maize	75	-
Peanut	10	-
Soyabeen	15	-
Multigrain Waste (*Azaraza*)	-	20
PKC	-	40
Poultry Waste	-	10
Cassava Peels	-	20
Yam Peels	-	10

The required weight measurements of the various feed ingredients were taken and mixed to get 50 kg each of the formulations for the study. The two feed diets were each ground to less than 1.0 mm particle size using a hammer mill. Samples of the diets were equally subjected to proximate analysis. The resulting mash diets were each divided into two batches and then adjusted to two moisture levels, 20 and 40%, respectively, by adding appropriate amounts of water. Each of the four diet batches with the required quantity of water was mixed for approximately 20 minutes using a laboratory rotary mixer. The water was added slowly using a spray bottle to prevent agglomeration. The conditioned diet blends were stored overnight to allow for the distribution and equilibration of moisture at room temperature (25 °C).

Manufacture of the Experimental Feed Extrudates Samples

Experimental feed extrudates were manufactured with the continuous extrusion-drying-cooling (CEDC) feed plant at the Chemical and Materials Laboratory of the Scientific Equipment Development Institute (SEDI), Enugu. The feed plant which integrates the various unit processes involved in feed manufacturing in an automated way such that the feed manufacturing consists of the processes of extrusion, drying and cooling taking place in one stream. The picture of the CEDC feed plant is shown in the Figure 1.

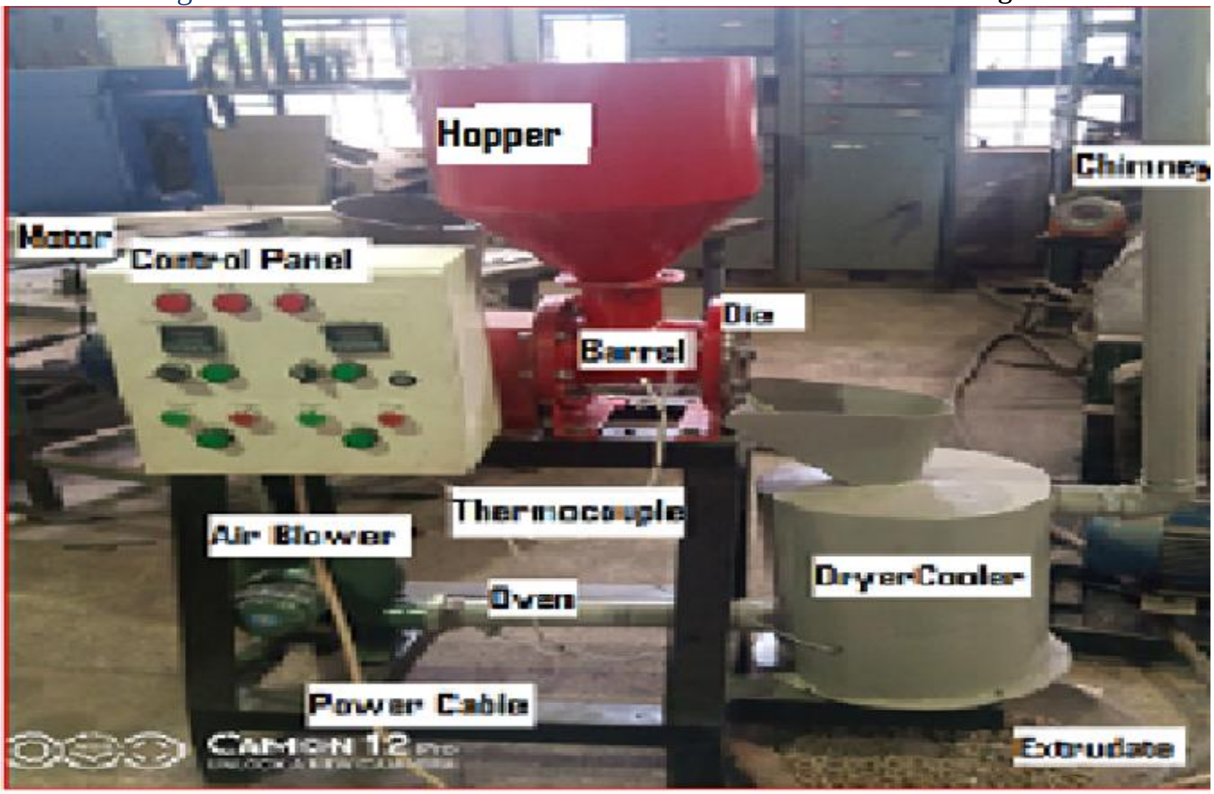

Figure 1: The CEDC Feed Plant

Operating the CEDC feed plant the four feed diet samples were used and the operating parameters varied according to the experimental protocol as stipulated by the OA to produce the required test extrudates samples. 10 kg of each sample was produced and labeled. The picture of some samples of the produced feed extrudates is given in Figure 2.

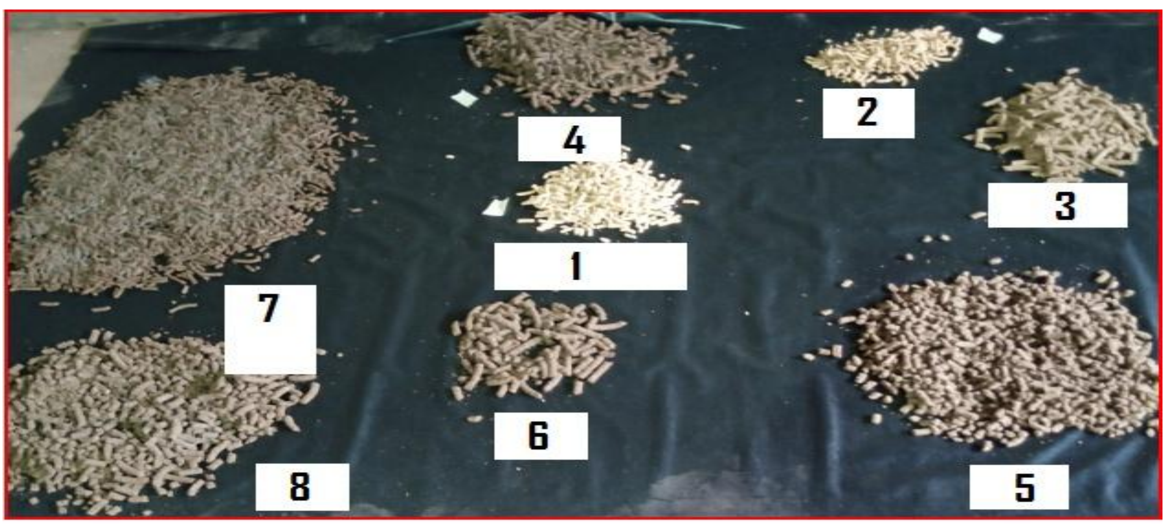

Figure 2: The Test Feed Extrudate Samples

After each sample manufacture, the area was cleaned and then prepared for the next sample test trial. This procedure was repeated for the succeeding test trials. The mass of the extrudates of each sample and the time taken to produce them were taken and recorded. The operating time was counted to start at the feeding of the feed mix into the hopper and end after the last discharge of the main products exited from the outlet. The manufactured feed extrudates of the eight samples were stored for approximately 48 hours at room temperature (25 °C) to allow for further drying of the feed extrudates.

Measurement of Extrudates Mechanical Quality

The technical qualities of the feed samples were measured in terms of mechanical durability and breaking strength. The properties were measured in 5 replications.

Pellet Hardness (Breaking Strength) Test

The breaking strength was measured using a handmade 3-point load testing apparatus consisting of two end supports for the test sample and a load applicator centrally located. The breaking strength test consisted in balancing the feed extrudate test sample on the end supports and applying a load until failure. Then the breaking strength was calculated using the formula (3).

$$\text{Б} = \frac{3PL}{2\text{Б}D^2}$$

)

Where:

P = the load (force) at the fracture point

L = the length of the supported span of the sample

R = the radius of the sample

The resulting breaking strength (MPa) was the average value of five samples.

Pellet Durability

Durability measurement was carried out using the Tumbler Can apparatus. 500 grams of the feed extrudates samples were placed in the box and then rotated at 50 revolutions per minute (rpm) for 10 minutes, after which the pellets were removed and screened. Then the feed pellets were sieved in a mechanical sieve shaker. The PDI was calculated by using equation (4).

$$PDI = \frac{M_{at}}{M_{bt}} x\ 100\%$$

Where,

PDI = Pellet durability index (%)

M_{at} = Mass of the pellets after tumbling (g)

M_{bt} = Mass of the pellets before tumbling (g)

RESULTS AND DISCUSSION

Nutritional Compositionns of the Feed Ingredients

The results of the proximate analysis of the various co-products used in the stis study are shown in Table 4.

Table 4: Nutritional Compositions of the Co-products

Ingredients	MgW	Pk	PW	CP	YP
Moisture	9.70 2	51.60	49.00	3	
Carbohydrate	51.60	59.167	23.20	16.16	60.145
Crude Protein	23.20	20.85	0.26	0.73	22.10
Crude Fat	0.94	3.789	0.94	0.11	3.591
Crude Fibre	0.26	8.944	9.70	10.50	8.244
Ash	14.30	5	14.30	23.50	4

Table 6: Proximate Analysis of the Experimental Diets

Ingredients	Formula I	Formula II
Moisture	24.34	18.225
Starch	64.00	62.256
Crude Protein	0.85	3
Fat	1.51	3.063
Crude Fibre	2.10	8.456
Ash	7.20	5

The comparison of the nutritional components of Diet I made of conventional cereals and Diet II made of co-products shows that both diets have comparable crude starch content, while the concentration of crude protein in Diet II was approximately three times its content in Diet I. Similarly, Diet II contains two times the crude fat content and over four times the crude fibre content of Diet I. Thus, Diet II can produce quality feed with residual fat without extra fat addition. Since the most expensive ingredients are those supplying energy and protein and considering the relatively low cost of co-products, Diet II could be considered attractive alternative feed ingredient as far as least-cost formulation is concerned. Because the high fat content of Diet II is traceable to PKC content, it has become important to note that PKC used resulted from mechanical expression and not from solvent extraction. that may produce PKC with very little residual oil.

Technical Quality of Feed Extrudates Measurements

The results of the measurements and calculations of the technical quality properties of the extruded feed are presented in this section.

PDI

The results of the five replicated measurements of the PDI of the experimental feed extrudates are presented in Table 7.

Table 7: PDI of the Feed Extrudate Samples

Samples	PDI				
	1	2	3	4	5
1	0.982	0.973	0.986	0.968	0.966
2	0.958	0.967	0.955	0.963	0.954
3	0.992	0.979	0.983	0.980	0.979
4	0.990	0.987	0.983	0.992	0.985
5	0.938	0.943	0.955	0.932	0.951
6	0.966	.974	0.965	0.969	0.972
7	0.956	0.917	0.894	0.948	0.954
8	0.953	0.961	0.954	0.947	0.962

These results are presented in a bar chart (Figure 3) in order to provide clearer viewing.

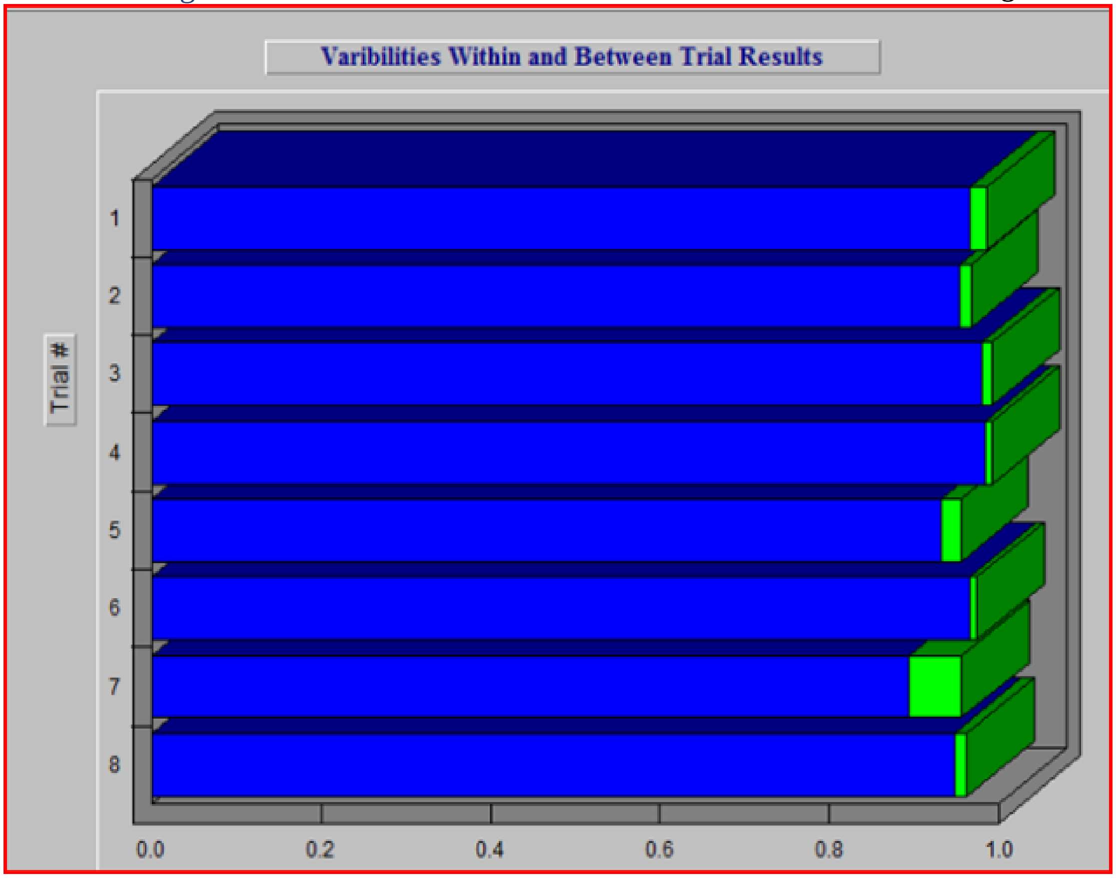

Figure 3: Bar Chart Showing the PDI Measurements Results

A cursory examination of Figure 3 indicates that the PDI measurement results recorded low variations both within and across the factors.

Breaking Strength

The results of the strength tests measurements and calculations are given in Table 8

Table 8: Breaking Strength of the Feed Extrudate Samples

Samples	Pellet Breaking Strength (MPa)				
	1	2	3	4	5
1	0.213	0.223	0.231	0.254	0.209
2	0.251	0.239	0.256	0.268	0.259
3	0.685	0.675	0.684	0.690	0.690
4	0.690	0.690	0.689	0.694	0.692
5	0.414	0.424	0.418	0.410	0.419
6	0.643	0.651	0.638	0.645	0.629
7	0.197	0.196	0.200	0.203	0.197
8	0.207	0.207	0.211	0.207	0.206

The bar graph representation of the breaking strength measurements and calculation results is as shown in Figure 4. In this graph, the relative proportions of the breaking strength for each level of the factor are displayed in stacked columns.

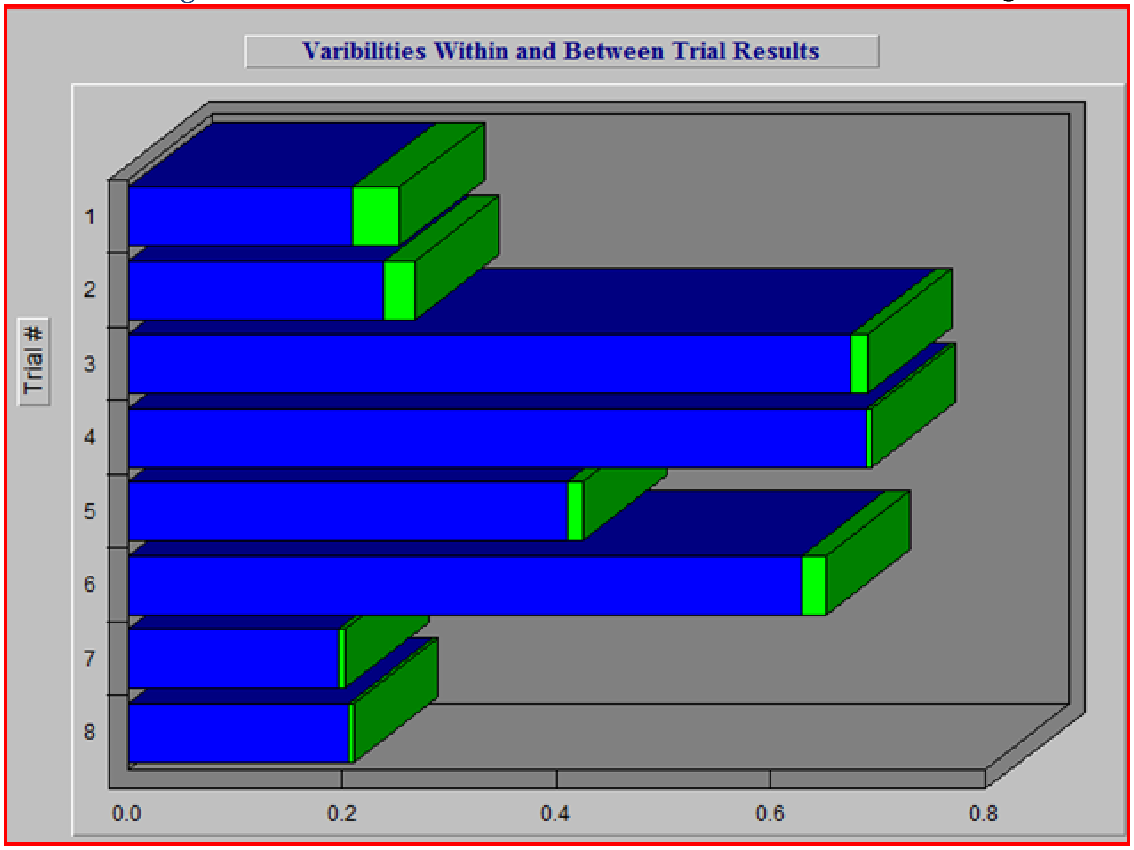

Figure 4: Bar Charts Showing the Results of Breaking Strength Measurements

Figure 4 shows that the breaking strength varied wide across the feed samples. These indicate that the feed extrudate breaking strength has some positive correlation with the extrudate diameter.

Main Factors and Interactions Effects

The effects of changing the diet, feed moisture content, barrel temperature, die L/D ratio, and drying air temperature on the mechanical durability and breaking strength of the feed extrudates are graphically represented as main effects plots.

Main Effects on PDI Plot

The main factors effects on the PDI are plotted as shown in figure 5.

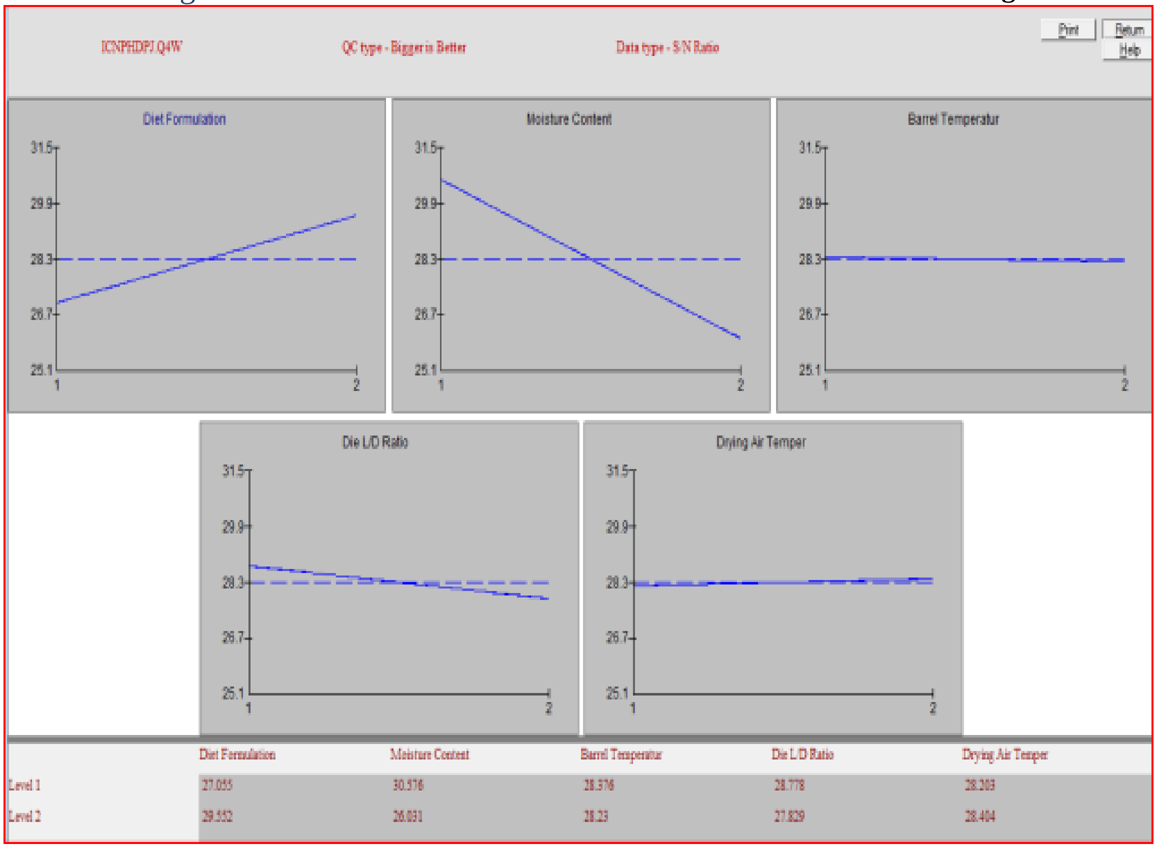

Figure 5: Multigraph Plot of Main Factor Effects on PDI

The graphs show that PDI has the highest value with Diet II which is made of co-products and reduces as more conventional ingredients are incorporated into the diet and attaining the lowest value at a point where the diet is made of 100% conventional ingredients. Similar findings were reported by [23]. This result was, however, unexpected considering the fact that the two diets, I and II, have comparable starch contents, 64% and 62.256%, respectively. The better durability of Diet II when compared to Diet I can be explained by the fact that diet II contained more fibre. However, in the overall, the average PDI of all the test samples ranged from 94.3% to 98.7 % implying that the feed extrudates were mechanically stable enough to withstand the stresses involved in the post-processing operations.

Main Effects on Hardness

Figure 6 is a graphical representation of the main factors effects on the breaking strength of the feed extrudates.

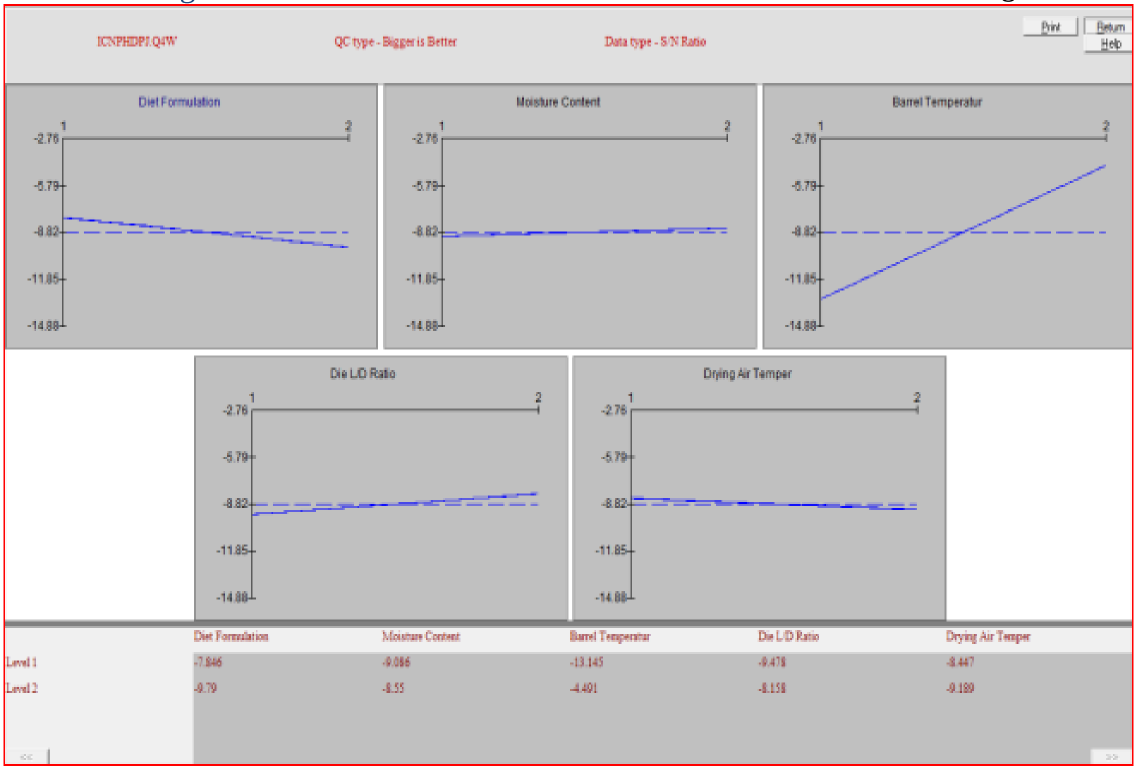

Figure 6: Multigraph Plot of Main Factor Effects on Breaking Strength

From the graph it can be deduced that only barrel temperature has significant positive effect on the breaking strength of the feed extrudates. While Diet Formulation and Die L/D Ratio had insignificant effects, Mash Moisture Content appeared to have very little or no effect on the breaing strength of the feed extrudates.

Interactions between the Influencing Parameters

In the design of the experiment, it was assumed that there were no interactions between the control factors. To confirm this assumption, the ten possible interactions between the factors were subjected to severity index tests. The results show that of all the ten possible interactions only five of them actually occurred within the control factor levels considered in this study.

Interaction Effects on PDI

The five factor interactions that affected the PDI in this study and their severity indices are shown in figure 7. From the chart, it can be seen that

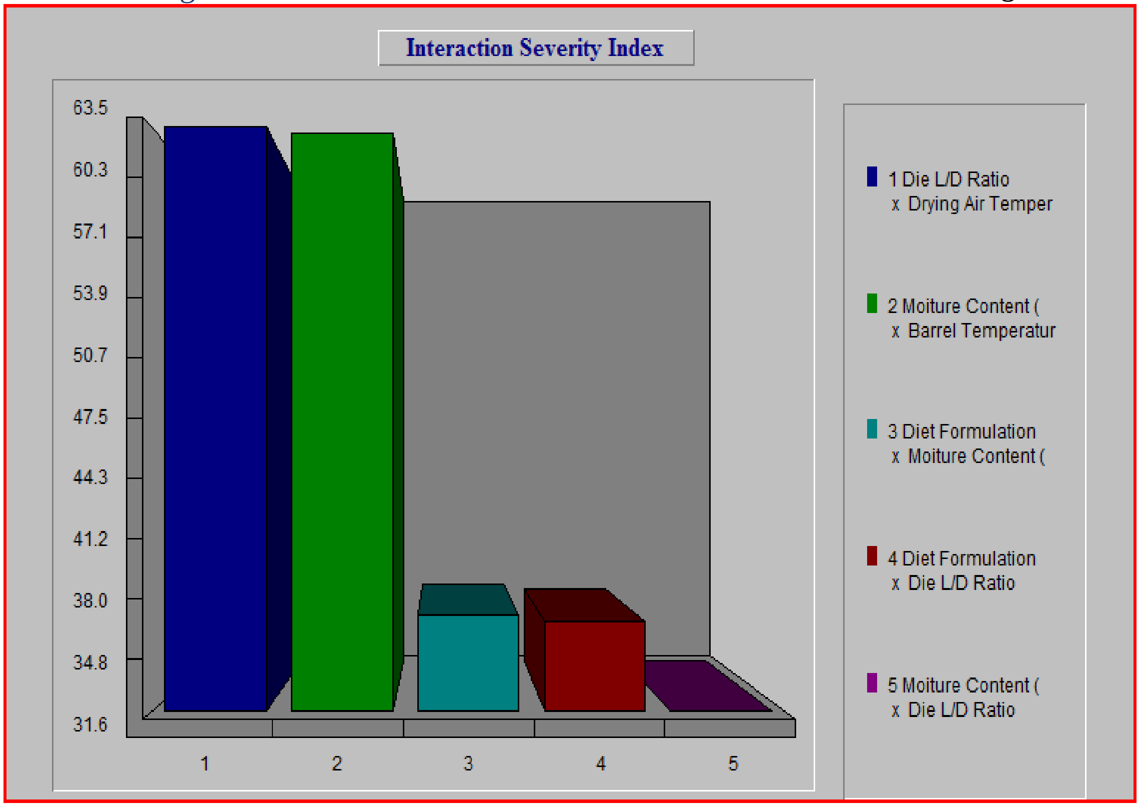

Figure 7: Bar Chart of Factor Interactions on PDI

The two highest interactions were the interactions between Die L/D ratio and Drying Air Temperature and between Moisture Content and Barrel Temperature with severity index values of 63.48 and 63.16, respectively. The severity index was 36.83 for the interaction between Diet Formulation and Moisture Content and 35.1 for the interaction between Diet Formulation and Die L/D Ratio.

Interaction Effects on Pellet Breaking Strength

From Figure 8 which charts the factor interactions effecting the breaking strength of the feed extrudates, the possible interactions affecting the feed extrudates hardness were the Diet Formulation and Mash Moisture content with severity index of 81.7 and the interaction between Die L/D Ratio and Drying Air Temperature with severity index of 59.65.

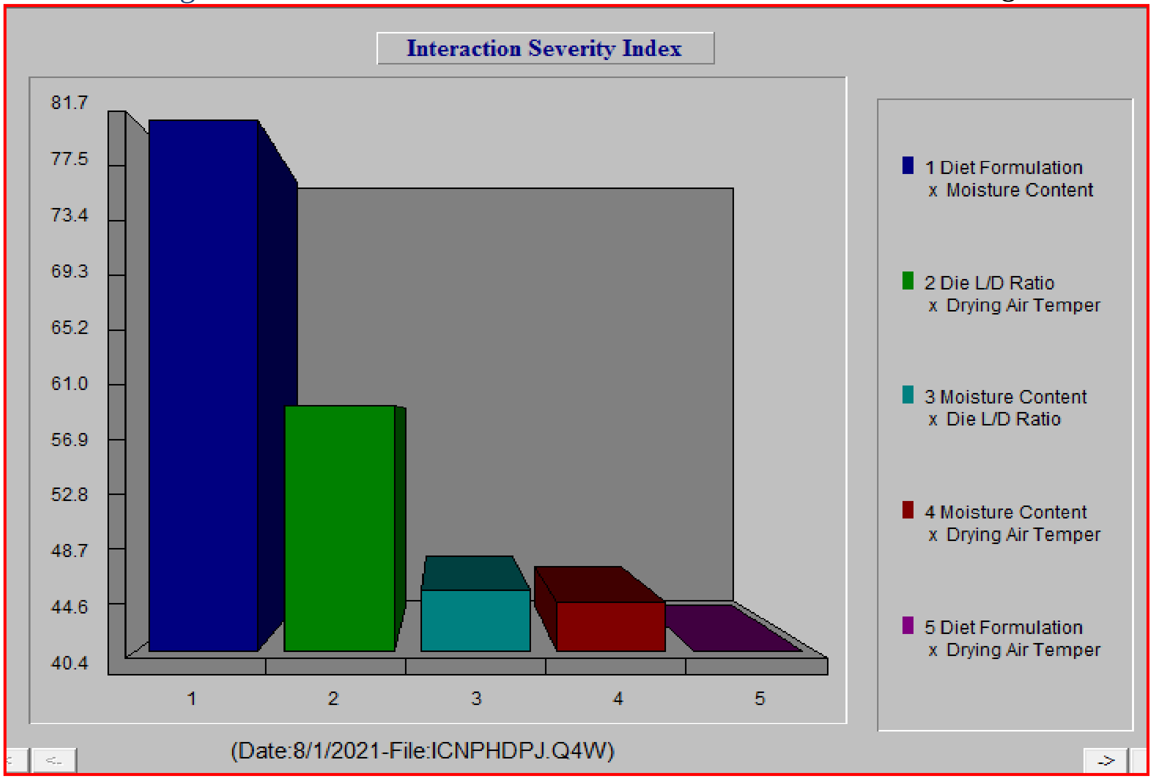

Figure 8: Bar Chart of Factor Interactions on Breaking Strength

From the foregoing therefore, the assumption of no interaction between the control factors at the two levels considered cannot be considered justified. These interaction effects were, therefore subjected to analysis of variance (ANOVA) test to confirm their significance.

Optimisation of the Parameters

The relative influences of the control factors and their interactions to the variability of the experimental results were modified by POOLing on the basis of a 5% significance level and a 95% confidence level in order to obtain the optimal process parameters and their interaction levels for the extruded feed pellets technical quality as presented in Table 9.

Table 9: Optimum Quality Values

Quality Characteristics	Significant Factors/Interactions		Optimum Values
Durability	A1, C2	D1E1	0.991
Breaking Strength	C2	A1B2	0.774MPa

CONCLUSION

The experimental results showed that a co-product mix based swine feed made from 10:10:20:20:40 blend of yam peels, poultry waste, cassava peels, multigrain waste and palm kernel cake could produce swine feed extrudates with high technical quality. The technical quality compares favourably with those of the conventional feed made of maize (75%), peanut (15%), and soyabeans (10%). All the factors considered affected the technical quality characteristics with the barrel temperature having the most influential factor with positive influence on the durability of the feed extrudates. The significant factors interaction affecting the technical quality are the interactions between the Die L/D ratio and Drying Air Temperature; and Diet Formulation and Mash Moisture and all their effects are positive. The findings of the study show that on the basis of 95 % confidence interval, subjecting co-products mix feed diet to the processes of extrusion, drying and cooling in one stream can boost the optimum technical quality of the resultant swine feed extrudates to PDI of 0.991 and hardness of 0.774 MPa by setting the parameters at C2, B1, D1, and E1.The data obtained from this study could be used to design economic extruders for the processing of the several locally available co-products into quality and mechanically stable and durable feed.

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