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The Performance of a Continuous Extrusion-Drying-Cooling Feed Plant for Production of Livestock Extrudates

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ABSTRACT

The needs to feed the ever increasing world population sustainably and reduce the cost of livestock production are pushing the world to adopt circular agriculture (CA) that demands for the paradigm shift from conventional feed ingredients to co-products as feed ingredients for feed manufacture. However, owing to the high cost of feed pelleting machines the co-products are not being used optimally in the developing countries like Nigeria as they are being fed to animals as mash meal instead of feed extrudates as demanded by CA. It, therefore, follows that this sustainable move needs to be balanced against the ability of farmers to procure relevant equipment to manufacture quality feed extrudates from 100 % co-products. A number of small size extruder models were developed but were found to have low capacities, low efficiencies and require high power input. The extruder models also did not address the drying unit operation, and this pushed for the development of a continuous extrusion-Drying-Cooling (CEDC) Feed plant. The CEDC feed plant, which was developed using locally available materials, consists of the following components: an electric motor, an extruder with changeable die, and drying-cooling unit, which are integrated. The performance of the CEDC feed plant was evaluated and found to produce performance data that compare favourably with existing commercial models. The plant has a performance capacity of 510 kg/hr and produced physical quality feed whose average quality characteristics are durability index (0.986), hardness (0.6915 MPa), diameter (8.96 mm) and length (58.805 mm).

KEYWORDS: Co-Products, Durability index, Expansion ratio, Extrusion, Feed Extrudates, and Sustainability.

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I. INTRODUCTION

Today, as the world is fighting to feed the ever-increasing global population (United Nations. 2019), the livestock industry is being plagued by two major challenges, minimizing the environment foot print (FAO, 2018) and skyrocketing prices of conventional feed ingredients. The world is, therefore, considering this present method of production as unsustainable and hence is calling for the adoption of a new and sustainable production approach called circular agriculture (CA) (Bianchi *et al.*, 2020). The tenet of CA is to utilize agricultural wastes as often and as effectively as possible. CA requires that farmers use by-products to feed their livestock. Consequently, these by-products which hitherto were discarded as wastes are now being valourised and hence are called co-products (Parfitt *et al.*, 2010; Krymowski, 2021). The use of co-products is being adopted in the European countries because of CA, but its adoption in the developing countries like Nigeria is as a least cost formulation strategy (Krymowski, 2021).

Many researchers observed that the world should embrace the technology of extrusion cooking of feed components in order to make feed production more sustainable (Kavelak & Vladimir, 2019; Koeleman, 2013). Feed manufacture by extrusion requires that the ground feed diet be conditioned, extruded or pelleted, dried and cooled immediately after production to avoid them getting burnt. This implies that a typical conventional feed

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manufacturing plant should consist of such stand-alone equipment as a preconditioner, an extruder, a dryer and a cooler. Consequently, these feed plants are expensive to procure and operate. It was, however, observed by Hofe (2020) and Kwakman (2020) that these feed plants were not standard mills as they work well in processing some ingredients and fail to process others. Unfortunately, rather than research to standardize these plants or make them affordable, researchers reported that most recent advances of research and development in the extrusion technology have been in terms of the automation of control, increased capacity, and optimization of energy efficiency and thereby pushing their costs beyond the economic and technical abilities of average farmers in the developing countries (Koelman, 2013). The scenario is also reported in the United States (US). According to Penrod (2020), extrusion is not widely available even in the United States (US) and blamed the limited availability of extruders on the special nature of extrusion that will not make it economical at low capacity. The limited availability of extruder is more precarious in the developing countries. This explains why the co-products are not being used optimally in the developing countries like Nigeria as they are being fed to animals as mash meal instead of feed extrudates as demanded by CA. This sustainable move of using co-products needs to be balanced against the ability of farmers to procure relevant equipment to manufacture quality feed extrudates from 100 % co-products. Today, the economic realities have necessitated that there be a movement back toward smaller custom-designed feed mills in developing countries so that the local farmers can take good advantages of the locally available co-products (Leukam, 2017; Thorsten & Amandus, 2010).

Fortunately, Gonzalez-Valadez *et al*. (2008) had earlier worked on the design and evaluation of an extruder to convert crop residues to animal feed. The result of the research was an extruder that is shorter and has a lower specific energy in comparison with commercial extruders but requires a prime mover of 36kW. The findings also indicated that the extruder size is not a problem as the various functions of screw extruders can be performed in the same process depending on the size of the extruder and the screw design. These findings led to the development of a good number of small and cheaper locally made extruder prototypes.
Nwaokocha and Akinyemi (2008) worked on the development of a dual type cork-screw laboratory size pellet mill, while Fayose *et al*, (2017) designed, fabricated, and tested an indigenous single screw extruder whose capacity was 27.12 kg/s and extruder efficiency, 64%. This design was later modified by Koyenikan *et al.*, (2019) to improve the floatability of fish feed by incorporating some systems and increasing the barrel temperature from 90 °C to 130 °C. The throughput capacity of the extruder was considered to be rather too low at 12 kg/h. Orisaleye and Ojolo (2019) designed and developed a straight screw extruder whose capacity is less than the smallest model manufactured by KEMPC (2006), but its efficiency was higher by 5.27 % compared to that of the dual type cork-screw laboratory size pellet mill that was developed by Nwaokocha and Akinyemi (2008).

Oduntan and Bamgboye (2021), on the other hand, worked on the development of single Screw extruder for the production of pineapple pomace fish feed and came up with extruder design with a new level of versatility. Aries and Jaime (2018) studied the design and technical evaluation of a roll-type extrusion mill developed in the Philippines, and found the mill to have 97.87 % pelleting efficiency and about 76.32 kg/h capacity. Each of the above discussed extruders that were developed for local farmers have one or two of the following deficiencies: low pelleting efficiency, low capacity, and high-power consumption. Most importantly, all of them neglected drying which is an important unit operation required to reduce the moisture level in extrusion cooked product (Rokey *et al.*, 2010). This need led to the development of a CEDC feed plant for improved sustainability of

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livestock production. The objectives of this research is to evaluate the performance of a Continuous Extrusion-drying-Cooling Feed Plant for production of Livestock Extrudates

2. MATERIALS AND METHODS

2.1 Materials

The materials used for this study are blends of co-products consisting of cassava peels, yam peels, multigrain wastes (*azaraza*), poultry wastes, and palm kernel cake.

2.2 Methods

2.2.1 Description of the Test Feed Plant

The test feed plant is a CEDC feed plant whose picture is shown in Figure1. It consists of an extruder, dryer-cooler unit, and temperature controllers. The extruder which consists of hopper, screw shaft, barrel, die, and heaters attached to the barrel surface are driven by a 5 - Hp, three-phase electric motor. The dryer-cooler unit is made up of drying-cooling chamber, an air blower, electric heater, air suction, and exhaust discharge system. The temperature controllers ensure intelligent control of the temperatures of the feed in the extruding barrel, and the hot air mixing with the feed pellets in the drying chamber.

Figure 1: Picture of the Feed Plant Prototype

The working principle of the CEDC feed plant is depicted in Figure 2. Compounded and conditioned feed meal is introduced into the plant through the feeding hopper, while the extruder screw steadily picks the feed from the hopper; conveys it through the extruding chamber; and forces it out through the dies as hot damp feed extrudates. These extrudates are automatically fed by gravity into the dryer where they mix with high velocity hot air flowing from bottom upwards and stay for sometime for drying before being discharged through the cooling chamber.

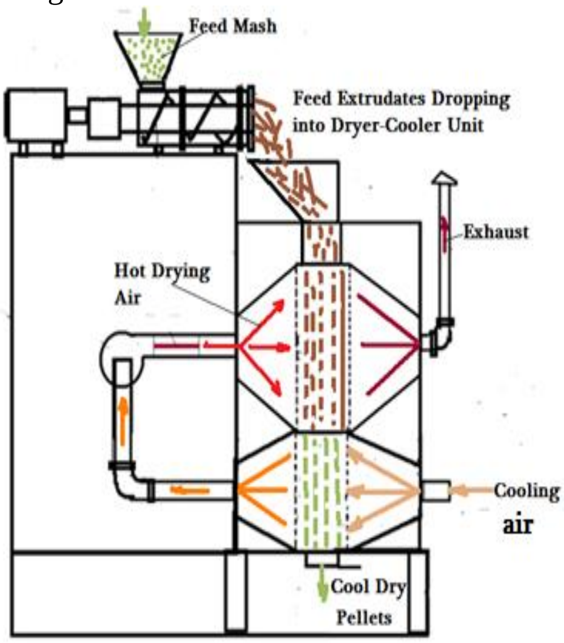

Figure 2: CEDC Feed Plant Working Principle

2.2.2 Preparation for Performance Evaluation

The proximate analysis of the co-products were carried out, and based on the results an alternative diet formula of a typical swine diet consisting of 10 % yam peels, 20 % cassava peels, 20 % multigrain waste, 10 % poultry waste, and 40 % palm kernel cake was formulated for the performance evaluation. The diet was ground to less than 1.0 mm particle size using a hammer mill and then analysed for its composition.

The resulting ground diet was adjusted to 20% moisture content, in order to ensure proper extrusion cooking, by adding appropriate amounts of water and thoroughly mixing the two using a laboratory rotary mixer. The water was

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added slowly using a spray bottle to prevent agglomeration. The conditioned diet blend was stored overnight to allow for the distribution and equilibration of moisture at room temperature (25 °C).

2.3 Manufacturing of Test Samples

30kg feed diet mash was processed in three batches, each having a mass of 10kg with the operating parameters set as follows: the plant barrel temperature was set at 120 ^{o}C and the drying air temperature at 80 ^{o}C, After each sample processing, the area was cleaned and then prepared for the next sample processing. This procedure was repeated for the succeeding operation.

The mass of the manufactured feed extrudates samples 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 samples were stored for approximately 48 hours at room temperature to allow for further drying, after which they were subjected to such physical quality tests as size, durability and hardness.

2.4 Physical Quality Tests

The feed exudates samples were subjected to some physical and mechanical properties tests and the properties were measured in 5 replications.

2.4.1 Extrudate Size

The dimensions (diameter and length) of each of 10 extrudate samples were measured with a veneer caliper. The feed extrudate length to diameter ratio was calculated.

The expansion ratio (ER) which is defined as the ratio of the cross-sectional area of extrudates to the cross-sectional area of the die-hole was also calculated using the expression (1).

$$E_R = \frac{{D_{FE}}^2}{D_D} \quad (1)$$

Where:

E_R = Expansion ratio

D_{FE} = Diameter of feed extrudate

D_D = Diameter of die-hole

The coefficients of variation of the extrudates sizes were calculated in order to check their uniformity and appearance. The coefficient of variation was calculated using the equation (2)

$$C_v = \frac{\sqrt{\frac{\sum^N (x_i - \mu)^2}{N}}}{\mu} \quad (2)$$

Where:

Cv = coefficient of variation,

xi = the ith random variable,

μ = mean of the data series, and

N = the number of variables

2.4.2 Pellet Durability Index (PDI)

Durability measurement was carried out using the Tumbler Can. 500 grams of the feed pellet samples were respectively placed in the box and then rotated at 50rpm for 10 minutes, after which the pellets were removed and screened. Then the feed pellets were sieved in a mechanical sieve shaker. The PDI which is expressed as a percentage (%) was calculated by using equation (3).

$$P = \frac{M_{at}}{M_{bt}} x\ 100\% \quad (3)$$

Where:

PDI = Pellet durability index (%)

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

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

Each sample was tested five times to get concurrent results.

2.4.3 Pellet Hardness (Breaking Strength) Test

The breaking strength was tested 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 equation (4).

$$Б = \frac{3PL}{2BD^2} \quad (4)$$

Where:

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Б = breaking strength,
P = the load (force) at the fracture point,
L = the length of the supported span of the sample,
D = the diameter of the sample,
The resulting breaking strength (mpa) was the average value of five samples.

2.5 Performance Data

1.5 kg sample of the feed mix were subjected to extruding process while the discharged extrudates were collected at the die before entering the drying-cooling unit and then weighing them on an electronic balance. This experiment was replicated three timed. The results obtained were used to calculate the pelleting capacity and pelleting recovery.

2.5.1 Pelleting Capacity

The pelleting capacity was calculated by equation (5).

$$C_p = \frac{3600 w_o}{T_o} \quad (5)$$

Where:
C_p = the pelleting capacity (kg/h)
w_o = the total weight of extruded feeds collected at the die before drying-cooling (kg)
T_o = the total operating time (s).

2.5.2 Pelleting Recovery

The pelleting recovery was calculated using equation

$$P_r = \frac{Wo}{Win} x\ 100\ \% \quad (6)$$

Where:
P_r = pellet recovery rate
Wo = the total weight of extruded feeds collected at die before drying-cooling (kg)
Win = the total weight of feed mix input (kg).

2.5.3 Production/Pelleting Efficiency

Another batch of 1.5kg of the test diet mix were processed through the extrusion, drying and cooling operations before collecting the extruded feed at the dryer-cooler discharge. The weight of the extrudates was measured using an electronic balance while a moisture meter was used to measure the moisture. This experiment was replicated three times. The extrudates weight measurements were used in calculating the production/efficiency using the equation:

$$\eta_p = \frac{Wod}{Win} x\ 100\ \% \quad (7)$$

η_p = production efficiency
Wod = the total weight of extruded feeds collected after drying-cooling (kg)
Win = the total weight of feed diet mix input (kg).

3. RESULTS AND DISCUSSION

3.1 Proximate Analysis of the Experimental Diet

The results of the proximate analysis of the experimental feed diet and a typical conventional feed diet are shown in Table 1.

The comparison of the nutritional components of the experimental diets and that of a conventional feed made of 75% maize, 15 % soybeans, and 10 % peanut shows that both diets have comparable contents of crude starch and crude protein. The experimental diet, however, contains two times the crude fat content and over four times the crude fibre content of the given conventional diet. Thus, the experimental diet can produce quality feed..

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Table 1: Proximate Analysis of the Experimental Diet and Conventional Diet

Ingredients	% Weight Composition	
	Exp.Diet	Conv. Diet
Moisture	20.00	24.34
Starch	62.256	64.00
Crude Protein	1.225	0.85
Fat	3.063	1.51
Crude Fibre	8.456	2.10
Ash	5.000	7.00

Exp. = experimental, Conv.= conventional

3.2 Physical Quality of the Feed Extrudates

The picture of the manufactured feed extrudates is shown in Fig. 3.

Fig.3: Produced Feed Extrudates

The results of the measurements and calculations of the physical quality of the extruded feed pellets such as length, diameter, durability and hardness are given in Table 2.

The results in Table 2 show that the length to diameter ratio of the feed extrudates varied from 6.38 to 6.72 indicating that the feed extrudates have stable lengths. This conclusion is in line with the conclusion of Stark (2016) who reported that feed extrudates whose lengths averaged between 2 – 4 times their diameters have stable length. Furthermore, the coefficients of variation of the length and diameter are 2.36 % and 0.56 %, respectively which are insignificant. The feed extrudates can, therefore, be said to have uniform sizes and hence good appearance that promotes high feed consumption by livestock as postulated by Gomez-Nicholau and Montero (2021).

The high PDI values (0.98 – 0.99) of the feed extrudates demonstrate that the feed extrudates are of high quality. This durability range is more than the average durability measurement of 0.923 for crop residues reported by Gonzalez-Valadez *et al.* (2008). Sopade *et al.* (2016) concluded that pellet is considered unsatisfactory or low in quality if durability is less than 90 %, therefore, it can be concluded that these experimental feed extrudates are very durable and satisfactory. The high PDI can be traced to high fibre content of the co-products.

The radial E_R can be said to be low at values ranging from 0.98 – 1.00. This low E_R may be as a result of increased feed moisture content as expounded by Ekielski *et al.* (2007) and use of co-product as the feed ingredients (Sobata *et al.*, 2020). It is important to note that low E_R implies denser feed and may be desirable depending on the livestock being considered.

Table 2: Results of the Physical Quality Tests

Replicat	1	2	3	4	C_v (%)
L (mm)	58.5	56.8	60.5	59.5	2.36
D (mm)	9.0	8.9	9.0	8.9	0.56
L/D	6.5	6.38	6.72	6.69	2.12
E_R	1.0	0.98	1.00	0.98	1.01
PDI`	0.99	0.99	0.99	0.98	0.44
H (MPa)	0.69	0.69	0.694	0.692	2.40

Replicat = Replications, L = Length
D = Diameter, H = Hardness

3.3 Feed Production Specifications

The measured and calculated operating data of the feed plant are presented in Table 3.

This average pelleting capacity of 524 kg/h was considered satisfactory in accordance with the conclusion of Gonzalez-Valadez *et al.* (2021) which stated that most of the requirements of small farmers could be fulfilled by an extruder with capacity between 440 and 970 kg/hr. This pelleting recovery is equivalent to the pelleting efficiency and with a value of 98.5% the CEDC feed plant studied here has 0.7% pelleting efficiency higher than the roll-type extrusion mill developed in the Philippines. The feed plant, therefore, can be considered to be efficient.

Table 3: Feed Extrudate Production Data

Test	Feed Extrudates Mass (kg) before	Feed Extrudates Mass (kg) after Drying	Time (Sec)	Pellet cap	Pellet recov.	Moist Cont. (%)
1	1.46	1.36	10.8	486.7	97.3	13.0
2	1.49	1.34	9.8	547.3	99.3	11.5
3	1.485	1.35	9.9	540.0	99.0	12.2
Av	**1.48**	**1.35**	**10.17**	**524.7**	**98.5**	**12.2**

Av = average, Cap = Capacity, recov. = Recovery, Moist Cont. = Moisture content

4. CONCLUSION

The performance of a CEDC feed plant was evaluated and the results discussed. The results show that the plant was able to produce stable and quality feed with good appearance using 100% co-products. The average physical quality characteristics are PDI (0.988), hardness (0.6915MPa), E_R (0.996mm) and length/diameter ratio (6.53). The coefficients of variations in the feed extrudate properties are insignificant as the values lie between 0.44% and 2.40%. The plant which produces and dries feed extrudates has a field capacity of over 520kg/hr. with pelleting efficiency of 98.5% and an average feed extrudate moisture content of 12.47%.

Finally, the CEDC feed plant is recommended for local farmers as it can handle co-products with high efficiency. However, for future improvement of the performance of the feed plant, there is need to analyse and optimise the thermal efficiency of the drying-cooling unit.

NOMENCLATURE AND UNITS

% = percentage
η_p = production efficiency
C_p = the pelleting capacity
M_{at} = Mass of the pellets after tumbling
M_{bt} = Mass of the pellets before tumbling
T_o = the total operating time
w_o = the total weight of extruded feeds
Б = breaking strength,
CA = circular agriculture
CEDC = continuous extrusion-Drying-Cooling
D = Diameter of the sample,
D_D = Diameter of die-hole
D_D = Diameter of die-hole
D_{FE} = Diameter of feed extrudate
D_{FE} = Diameter of feed extrudate
E_R = Expansion ratio
E_R = Expansion ratio
L = length of the supported span of the
P = the load (force) at the fracture point,
PDI = Pellet Durability Index
P_r = pellet recovery rate

US = United States
Win = total weight of feed mix input
Wo = total weight of extruded feeds collected at the die before drying-cooling
Wod = total weight of extruded feeds collected after drying-cooling

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