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Effects of Selected Tuber Crops Starch on Some Extrusion Properties of Fish Feed

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Authors' contributions

This work was carried out in collaboration among all authors. Authors AMA and APO designed the study, performed the statistical analysis, wrote the protocol, wrote the first draft of the manuscript and managed the analyses of the study. Author CIAO managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

This research evaluates the effect of feed formulation on fish feed properties with the aim of providing information on its water absorption and physical properties of the feed. The main objective of the study is to analysis the effects of the 3 tuber crops (dried cassava, potato and cocoyam flour) on the floatability of fish feed. The fish feed ingredients with varying percentage (40, 70 and 100) of starch from cassava, potato and cocoyam were extruded using a single screw extruder with constant screw speed (285 rpm). The resulting extrudates were subjected to extensive analysis of physical properties, which included moisture content, mass, surface area, volume unit density, bulk density and porosity. The water absorption properties include, the relative absorption rate (%), the water stability (%), the expansion ratio (%) and the floating ability rate (%) were also determined. There was a linear increment between the increase in starch with floatability and water absorption properties of cassava and cocoyam starch; however, a nonlinear decrease relationship existed in percentages (%) of potato starch. The formulation with 40% cocoyam has the highest floatability while the least floatability was observed from 100% potato at first 10 mins of

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observation. At 40% starches, 76.66% of cassava, 66.66% of potato and 100% of cocoyam afloat for the period of observation (10-120 mins). In conclusion, the formulation with 40% cocoyam was adjudged as the preferable feed composition based on its floatability. From the result, it can be recommended that cocoyam starch support the floatability of fish feed.

Keywords: Extrudate; floatability; fish feed; relative absorption rate; water stability; expansion ratio; buoyancy.

1. INTRODUCTION

Starch is a biopolymer, with two types of macromolecules, namely amylose and amylopectin [1]. It is well known that a key modification during processing of starch is micro molecular degradation, which affects both amylose and amylopectin components [2,3]. Starch, an important carbohydrate constituent, is best characterized in terms of loss of crystallinity and gelatinization during extrusion [4,5]. Starch plays a vital role in the production of floating versus sinking feeds, because it acts as a binder and impacts product expansion. Most of the aqua-feeds have been developed via extrusion process, where the feed is expanded to achieve water stability or buoyancy in water with the use of extruder machines [6].

Extrusion is a powerful food processing operation, which utilizes high temperature and high shear force to produce a product with unique physical and chemical characteristics. Product characteristics of extrudates made from rice and other starchy ingredients depend on physicochemical changes that occur during extrusion due to the effects of extrusion variables [7]. Though the use of extruded floating feed is safer, because feed ingredients can be pasteurized or sterilized during feed extraction operation, thus aiding digestibility of feeds and reducing adverse effects of some feed material on the health of aquatic animals [8], yet extruder machines are quite expensive to purchase. Extruded feed is buoyant and almost hydrophobic as such leaching is low compared to sinking feeds [9]. The nutrients are retained within the periods of floating thereby enabling fish to consume whole extruded ration [6]. It is very suitable for pelagic or surface feeders in the sense that the fish quickly access the feed and do not expend much energy in going to the bottom to source for food. The production of feed using these machines is usually expensive as the machines are not cost-friendly. The purchase of expanded floating feeds from USA and other western countries has greatly increase the import expenditures of developing countries. [10] Reported that to meet the demand of fish farmers at both commercial and subsistence level affordable, the use of readily extruding machines in the developing of floating feeds becomes necessary, since feed floatation can be achieved via inclusion of floaters in feeds. Floating feed is a management tool in that farmers can see how much and how actively the fish eat, seeing the fish is almost a necessity when the ponds are harvested and restocked periodically without draining and the farmer has precise knowledge about the mass of fish in the pond [11]. The production of floating feeds using readily affordable floating agents to attain feed buoyancy becomes paramount. Therefore, it is imperative that emphasis should be geared towards the technology of developing buoyant (floating) fish feeds without adverse effect on the quality of compounded nutrients. Such feed must be very stable and afloat in water for a period of time before it sinks [6,12]. The objectives of this study were to analyze the feeds for catfish using cocoyam, potato and cassava starch as a binder and to investigate the effects of various levels of the starch on the resulting physical properties of the extrudates on the same processing parameters.

2. MATERIALS AND METHODS

2.1 Raw Materials

The cassava, potato and cocoyam (Wholesome and matured fresh tubers) used in the research were obtained from farmers within the main market situated at Akure, Ondo State, Nigeria. Also, the De- husked wheat and the edible corn were purchased locally within the town (Akure, Ondo State) while other ingredients for the formulations such as soybean meal, lysine, methionine etc. were gotten from K2 Flour Mills and Freedom Feed mills (Workshop, Akure). The tubers were peeled, washed, sliced and sun dried and thereafter grounded to powder in a Hammer mill and sieved through a mesh screen (500 μm) to obtain cassava, potato and cocoyam flour. Wheat and corn of moisture content 12.27% and 13.50% respectively were cleaned before milling in Hammer mill. Moisture content of the mixture was determined in three replicates using oven drying method following the ASAE Standard S358.2 [13].

2.2 Raw Material Formulation and Mixing

The formulation was calculated on dry weight basis (%). Three different formulations were made: formulation one consists of 100% of flours (potato, cassava and cocoyam); formulation two consists of 70% of the flours and 30% of others while the last formulation consists of 40% of the three flours and 70% of other ingredients (Table 1). In order to have uniform distribution throughout the formulation, all compositions were milled to almost equal particle sizes (500 μm) and equilibrated to room temperature after which it was weighed according to the formulation before mixing with hot water (±100°C) for at least 10 min.

2.3 Extrusion Processing

Extrusion cooking was performed using single-screw extruder locally manufactured at the Department of Agricultural Engineering, Federal University of Technology Akure, Ondo State, Nigeria. The machine has four different section: the hopper (a cone like design), which is the feeding zone made from a stainless steel that house a screw conveyor powered by 1hp electric motor that metered the feed into the extruder barrel; the transition zone (screw conveyor), covered by a four cylindrical steel barrel through which cooking and gelatinization takes place; An output zone through which the feed is been supplied to the die head (8 mm) and the cutting zone in which the extrudate was been cut into sizes by cutting blade power by 1 hp electric motor. The machine was powered by a 30KVA 3-phase electric motor in which the power transmission is accomplished through reducing gear 1: 10, chains and sprockets.

The mixed formulated feed at feed rate 7 kg/h and water feed rate 1.4 kg/h were introduced into the extruder, which was the best feeding rate experimentally derived for better flow rate. After extrusion, the collected extrudates were dried at 80°C for 10 min in conventional oven to remove surface moisture. After cooling to room temperature, they were stored at 20°C in polyethylene bags prior to analysis.

2.4 Measurement of Extrudate Properties

The resultant products were subjected to extensive physical and functional properties, namely: Moisture content (%), gravimetric characteristic which include unit density (kgm^{-3}), bulk density (kgm^{-3}), expansion ratio (-), water absorption rate (%), surface area (mm^2) and floatability rate (-).

2.4.1 Moisture content determination

Moisture content of the extrudates was determined by collecting certain mass of the samples from the exit of the die using plastic bags, sealed tightly and weighed into a Petri-dish of a known weight using equation 1 by [14]. It was allowed to cool for 3 h at room temperature and thereafter dried in the oven set at 105°C for 4 hours. The samples were removed and cooled in desiccators. After cooling, the samples were reweighed for any weight change. The result was calculated thus:

$$M_c = \frac{W_l}{W_o} \quad (1)$$

Where M_c is moisture content (%), W_l is the weight loss (kg) and W_o is the original weight of the sample (kg).

2.4.2 Gravimetrical characteristic

To obtain the unit mass, each sample was weighed by a precision electronic balance (LP 1002B, B. BRAN, ENGLAND) reading to an accuracy of 0.01 g. The true volume (V, cm^3) as a function of the percentage of tuber crop in the formulation was determined using the liquid displacement method. Toluene (C_7H_8) was used instead of water due to its absorption rate. According to [15], the porosity (Ɛ) can be expressed as follows:

$$\varepsilon = \frac{(\rho_t - \rho_b)}{\rho_t} \times 100 \quad (2)$$

Where ρ_t (kg/m^3) is the true density and ρ_b (kg/m^3) as bulk density.

This equation was used to calculate the porosity of the extrudate in this research as a function of the percentage of tuber crop in the formulation. Also, the surface area was calculated using the equation 3 as stated by [16].

$$S = \pi D^2 \quad (3)$$

Where *D* is the geometric mean diameter.

Table 1. Gross composition of the formulation for floatability

Ingredients	Formulation		
	1 (%)	2 (%)	3 (%)
Tuber crop	100.00	70.00	40.00
Wheat offal	-	5.76	11.52
Yeast	-	5.25	10.49
Fish meal	-	10.50	20.99
Soybean meal	-	5.25	10.49
Lysine	-	0.33	0.67
Methionine	-	0.33	0.67
Vit. Premix	-	0.33	0.67
Bone meal	-	0.83	0.67
Salt	-	0.08	1.67
V. Oil	-	1.33	2.67
Total	100.00	100.00	100.00

2.4.3 Unit density (UD)

The mass and the length of the sectioned extrudate were determined using a Kerro electronic balance (Model BLC3002) and a digital caliper (Mitutoyo Inc, Japan) respectively. The unit density of the extrudates according to [17] was determined as the ratio of mass to the volume of each piece, by assuming cylindrical shapes for each extrudate.

2.4.4 Bulk density (BD)

The bulk density of the sample was analyzed by filling up a measuring beaker of known volume with extrudates that has been cut into pieces of approximately 2 cm in length. A scraper was later used to remove the excess feed by pulling once gently over the edge of the beaker. The contents of the full were weighed on a balance. Each measurement was carried out in triplicate, and bulk density for each replicate was calculated as mass of the sample to the volume of the beaker (g/ml) [18].

2.4.5 Surface area

The surface area and volume were calculated by measuring the height and radius of 10 feed pellets. The mass was measured by electric digital balance (Kerro electronic balance, Model BLC3002) [15].

$$\textit{Surface area (SA)} = 2\pi r\,(h + r),\ mm^2 \qquad (4)$$

2.4.6 Expansion ratio (ER)

Expansion ratio of the extrudates was measured laterally with caliper (Mitutoyo Inc, Japan) and expressed as the ratio of cross sectional area of the extrudate to that of the die nozzle (8 mm) [19]. ER was obtained from a mean of 10 random samples. This was then calculated using equation 4.

$$Expansion\ ratio\ (\%) = \left[\left(\frac{D_p}{D_d}\right) - 1\right] \times 100 \qquad (5)$$

Where, D_p is the extrudate diameter and D_d is the die diameter.

2.4.7 Buoyancy test

The floatability of the extrudates at formulation 1, 2 and 3 were evaluated for 2 h. The buoyancy test was determined by placing samples containing 10 pellets into a 250 ml beaker filled to about 75% with distilled water, with the aid of a stop watch, and the degree of floatation was recorded within the time frame of 2 h. The sampling was replicated thrice, and the mean was statistically analyzed. The percentage floatation at instantaneous time was determined using the approach of [20] as shown in equation 5.

$$F = \left(\frac{F_f}{F_t}\right) \times 100\ \% \qquad (6)$$

Where: F is the percentage floatation, F_f is number of extrudate afloat and F_t is the number of pellets in sample.

2.4.8 Relative absorption rate (RAR)

The relative absorption rate is the measure of the volume of water absorbed in relation to the initial weight of the pellets. This was calculated according to expression in equation 6.

$$RAR = \frac{M_2 - M_1}{M_1} \times 100\% \qquad (7)$$

Where M_2 is the mass of wet pellets, M_1 is the initial mass of dry extrudate, and (M_2 - M_1) is the weight gain after immersion in water [21].

2.4.9 Water stability

The water stability of each formulation was determined for a period of 30 minutes. This was done by placing 10 pieces of each replicate into a nylon sieve, tied with a string, and inserted into a bowl containing pond water. After the duration elapsed, the remaining portion of the feed were sun-dried for 3 days and the weight were recorded as M_{30} representing final dry weights after 30 minutes immersion. Water stability was then calculated as follows:

$$Water\ Stability = \left(\frac{M_{30}}{M_1}\right) \times 100\% \qquad (8)$$

Where: M_{30} is weight of pellet after 30 minutes immersion and drying and M_1 initial dry weight of pellets [22].

2.5 Statistical Analysis

The physical and water absorption properties of the extrudate (mass, volume, density, surface area, water stability, Relative Absorption rate and Expansion ration) was depicted as function of the percentage of tuber crop (cassava, potato and cocoyam) in the feed formulation using Microsoft excel version 2016 and the equation that shows the relationship between the properties of the extrudate and the percentage of tuber crop was establish using regression analysis on Microsoft excel version 2016, the accuracy of the regression equation was obtained based on the coefficient of determination (R^2) value.

A 3×3×3 factor experiment design (3 types of tuber crop: Potato, cassava and cocoyam; 3 levels of percentage of starch: 40%, 70% and 100% of the feed constituents in 3 replicates) was used in determination of the physical properties of extrudates which include the mass, surface area, volume, true density, bulk density and porosity of the resulting extrudates.

3. RESULTS AND DISCUSSION

3.1 Physical Properties of the Extrudate as Function of Tuber Composition

3.1.1 Mass

Fig. 1 shows the graphical representation of the extrudate mass as a function of the percentage of tuber crop in the formulation. The mass of the extrudate increases linearly with increase in the percentage of cassava and potato in the formulation with a high coefficient of determination (R^2) of 0.9899 and 0.9887 at $p<0.01$ for cassava and potato-based formulation respectively whereas it decreases linearly with increase in the percentage of cocoyam in the formulation with a high coefficient of determination (R^2) of 0.9699 at $p<0.01$.

3.1.2 Surface Area

The surface area of the extrudate increases linearly with increase in the percentage of cassava and potato in the formulation with a high correlation value (R) of 0.9944 and 0.9932 at $p<0.01$ respectively (Table 1). Whereas, it decreases linearly with increase in the percentage of cocoyam in the formulation as shown in Fig. 2 with a high correlation value (R) of 0.9997 at $p<0.01$. These results indicated that the surface area of the fish feed extrudate increased with increase in the expansion ratio as a result of starch content present in the formulation with cassava having the largest surface area and the R value shows that there is high relationship between the surface area and the independent variable. These results were in agreement with [23,24,25] when determining the effect of extrusion process variables and legumes on starch extrudate behavior using different machines. The little bars indicate its standard deviations.

3.1.3 Volume

The volume of the extrudate increase linearly with increase in the percentage of cassava and potato in the formulation with a high coefficient of determination (R^2) of 0.9850 and 0.9865 at $p<0.001$ for cassava and potato-based formulation respectively. Whereas, it decreases linearly with increase in the percentage of cocoyam in the formulation with a high coefficient of determination (R^2) of 0.8583 at $p<0.001$ for cocoyam-based formulation as shown in Fig. 3. These results were agreement with those obtained by [23,24].

3.1.4 True density

The true density of the extrudate decreases linearly with increase in the percentage of cocoyam and potato in the formulation with a high coefficient of determination (R^2) of 0.9881 and 0.9936 at $P<0.01$ for cassava and potato based formulation respectively as shown in

Fig. 4, but increases linearly with increase in the percentage of cassava in the formulation a high coefficient of determination (R^2) of 0.9640 at P<0.001 for cocoyam based formulation. This result is in tandem with the findings of [26] while developing farm made floating feed for aquaculture species it was discovered that there is a direct relationship between true density of the tubers used for formulation and percentage of tuber used.

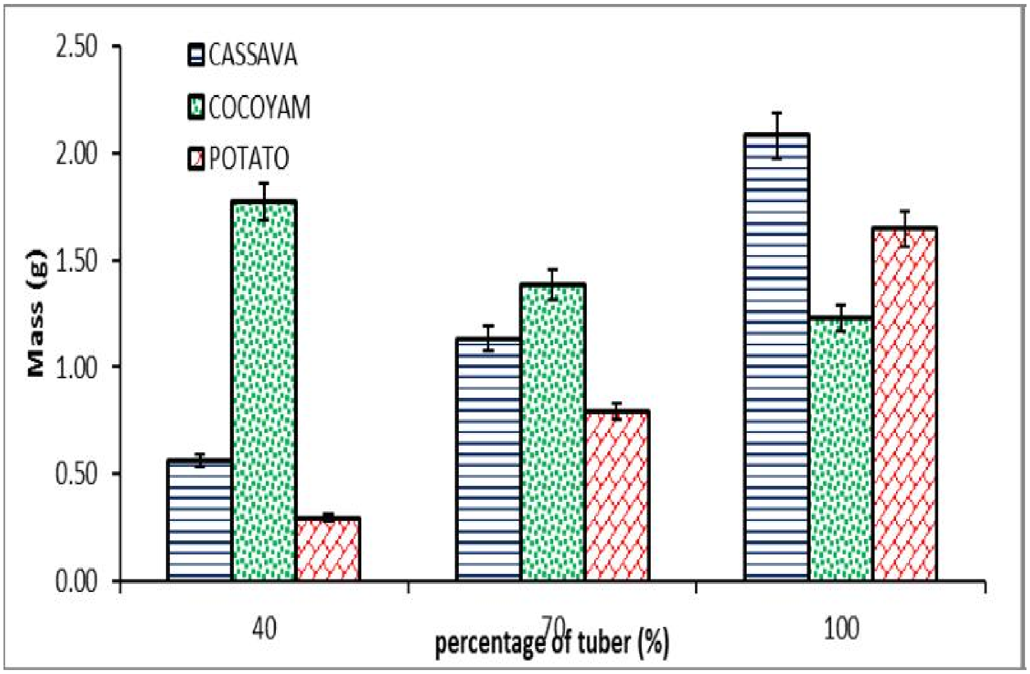

Fig. 1. The change in mass of extrudate with percentage of tuber crop

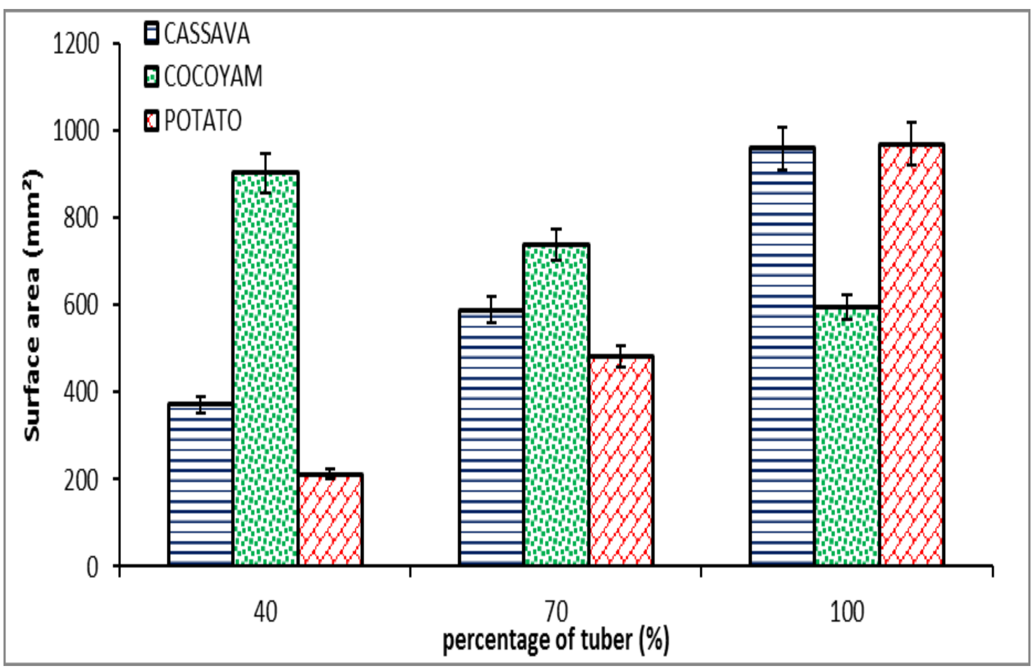

Fig. 2. The change in surface area of extrudate with percentage of tuber crop

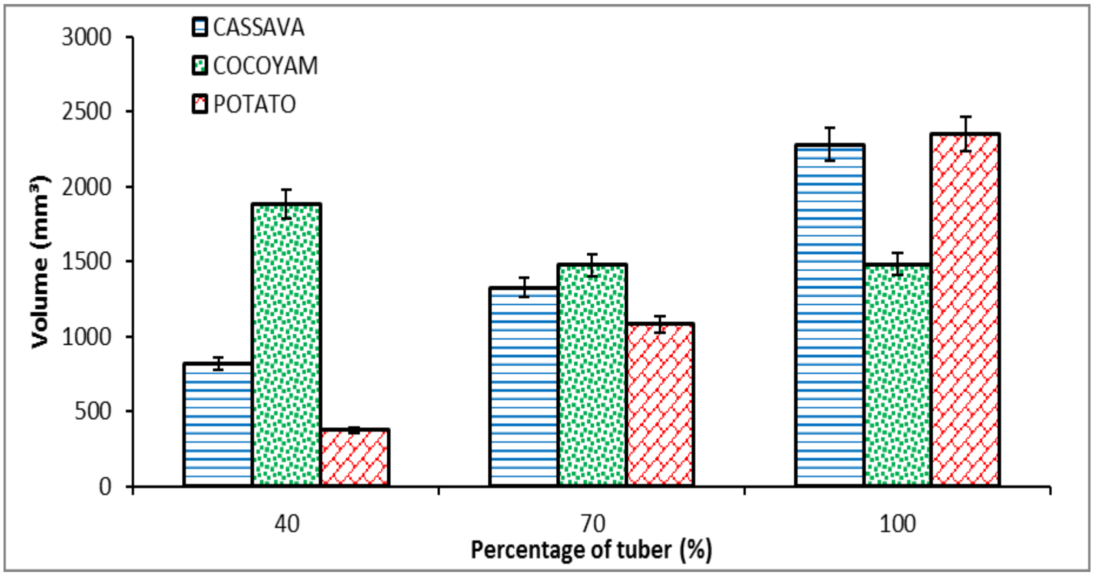

Fig. 3. The change in volume of extrudate with percentage of tuber crop

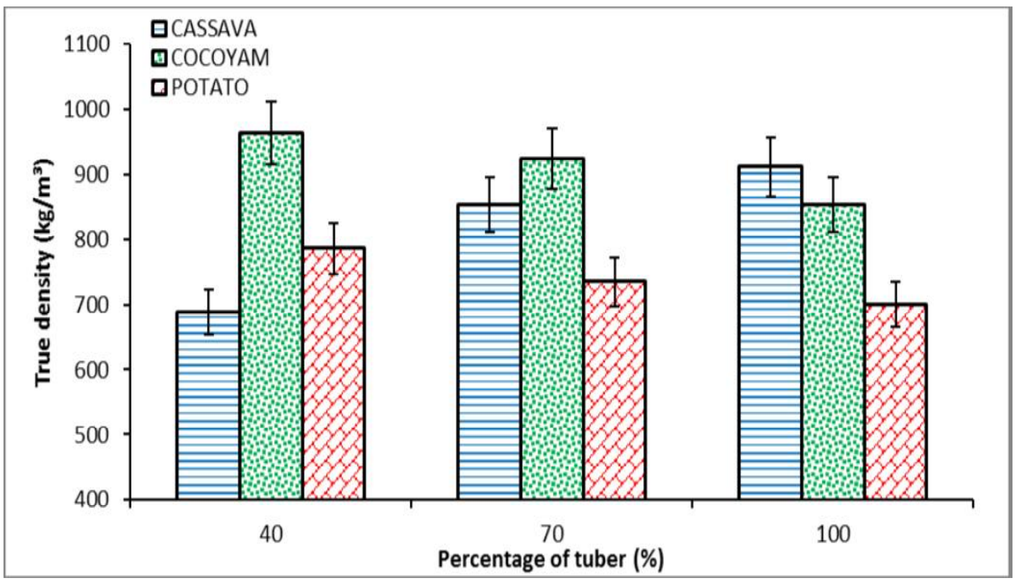

Fig. 4. The change in true density of extrudate with percentage of tuber crop

3.1.5 Bulk density

Fig. 5 shows that the bulk density of the extrudate increases linearly with increase in the percentage of tuber crop in the formulation with a high coefficient of determination (R^2) of 0.9138, 0.9996 and 0.9360 at $p<0.01$ for cassava, cocoyam and potato-based formulation respectively as shown in Table 1. There is a direct relationship between bulk density and floatability of fish feed extrudate which varies with the percentage of tuber crop used for formulation. Bulk density of the extrudate increase linearly with increase in percentage of tuber with cocoyam having the highest at 100% cocoyam and also the lowest at 40% cocoyam formulation base.

3.1.6 Porosity

The porosity of the extrudate decreases linearly with increase in the percentage of cocoyam and potato in the formulation with a high coefficient of determination (R^2) of 0.9957 and 0.9360 at $p<0.01$, for cassava and potato-based formulation respectively as shown in Fig. 6. In addition, the Porosity of the extrudate increases linearly with increase in the percentage of cassava in the formulation with a high coefficient of determination R^2 of 0.8061 at $p<0.01$ for cocoyam-based formulation.

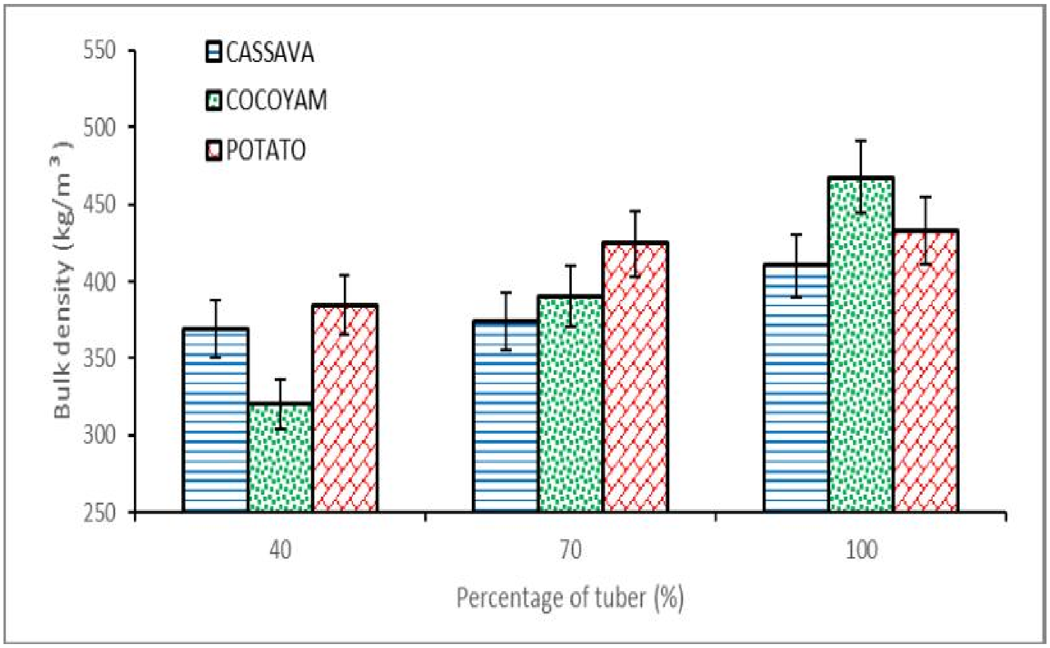

Fig. 5. The change in bulk density of extrudate with percentage of tuber crop

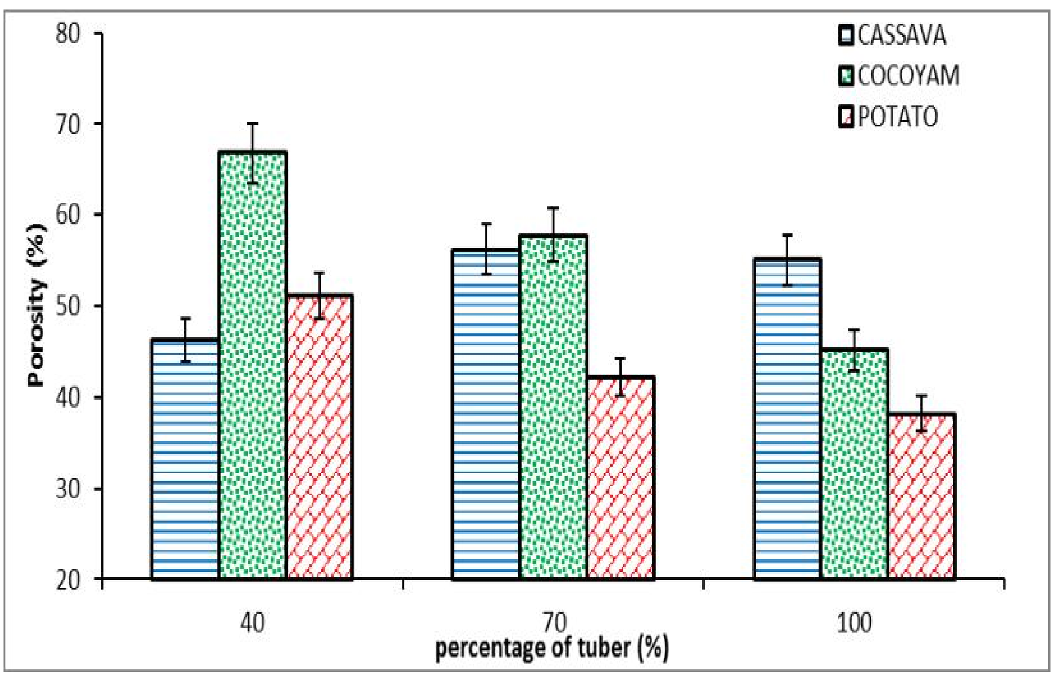

Fig. 6. The change in porosity of extrudate with percentage of tuber crop

3.2 Relative Absorption Rate

The relative absorption rate of the extrudate was presented in Fig. 7. The plots showed that there was a linear decrease in the relative absorption rate with increase in percentage of tuber for formulation with cassava, cocoyam and potato. The coefficient of variation in the relative absorption rate of the extrudate increased with increase in the percentage of tuber for cassava, the coefficient of variation reduced at 100% of cocoyam and 70% of potato. This condition was probably due to structural modification(s) of the fiber [27]. This result was consistent with the assertions of [2,26] that variation in the processing temperature directly proportional to the absorption rate of the extrudates.

3.3 Water Stability

The water stability of the extrudate increases linearly with increase in the percentage of tuber crops in the formulation (cassava-based formulation and cocoyam based formulation) with a high R^2 value of 0.4191 and 0.7416 at $p < 0.01$ for cassava, and cocoyam based formulation respectively as shown in Fig. 8, whereas it decreases nonlinearly with an increase in the percentage of tuber crops in the formulation (Potato based formulation) with of R^2 value of 0.6448at $P<0.01$. The changes appeared to be curvilinear and [26] also found a similar trend in WSI values as DDGS levels increased. Starch and/or fiber degradation was sufficient to increase the solubility [28]. Also, the stickiness of extruded starches is related to increased solubility.

3.4 Expansion Ratio

The statistical properties of the expansion ratio of the extrudate indicates that the mean increased significantly with increase in percentage of tuber from 40 – 100% for formulation with cassava, cocoyam and potato respectively. The highest expansion ratio (43.25) was found for 100% potato, whereas, the lowest expansion ratio (-8.75) was found for the treatment combination of 40% of cocoyam. Depending upon composition, it has been found that extrudates typically do not start to expand until a temperature of 100°C has been reached [5,28]. Studies done by [5,29] found an increase in expansion ratio with increasing temperature, but this behavior depends on composition. In addition, it has been shown that particle size of the ingredient blend, amylose content, degree of gelatinization and lipid level also have effects on the expansion ratio values [30,31]. Moreover, degree of expansion of extrudates is closely related to the size, number and distribution of air cells in the cooked material [32].

All the extrudate maintain a constant floatability that is not significantly different from one another after 20 min duration except for the extrudate

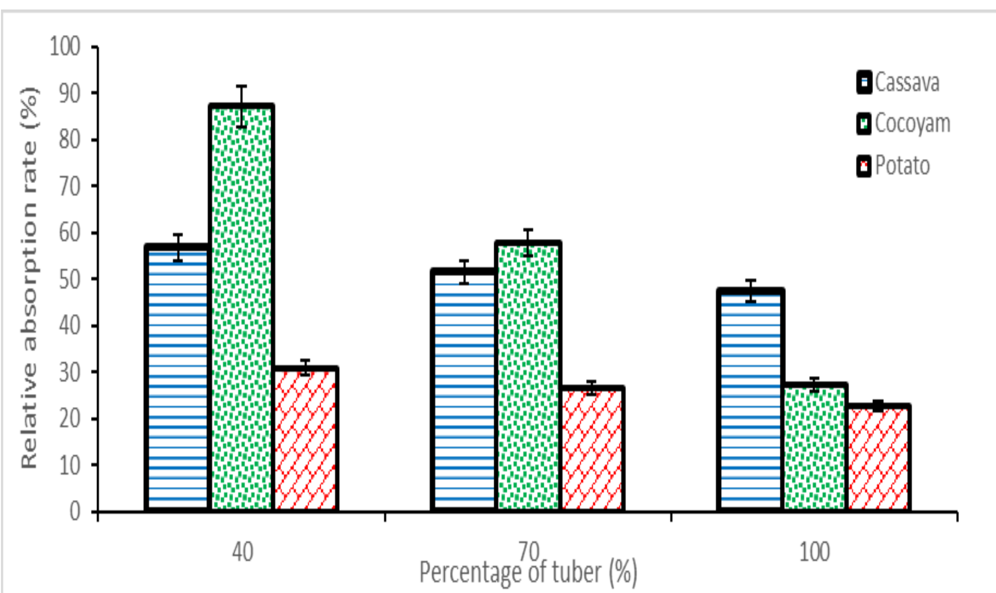

Fig. 7. The change in relative absorption rate of extrudate with percentage of tuber crop

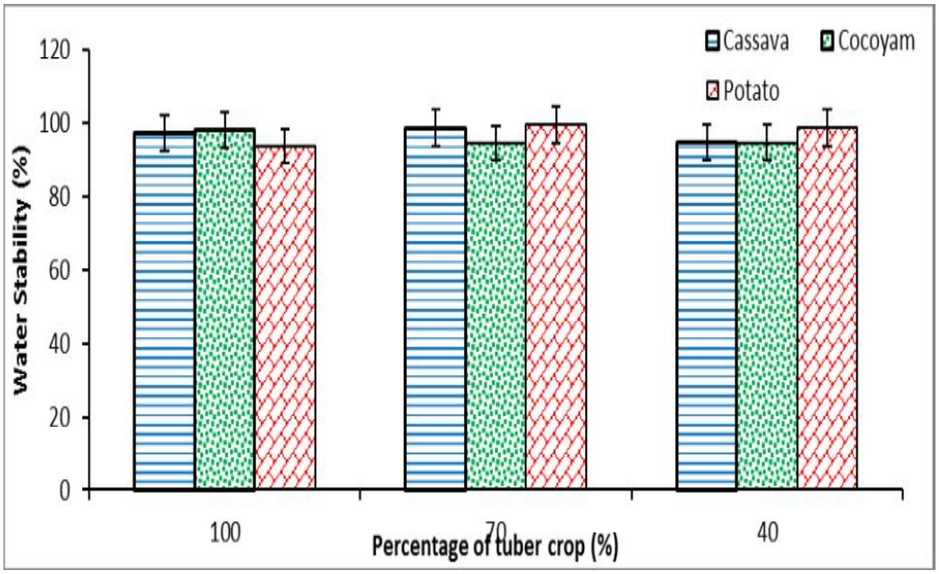

Fig. 8. The change in water stability of the extrudate with percentage of tuber crop

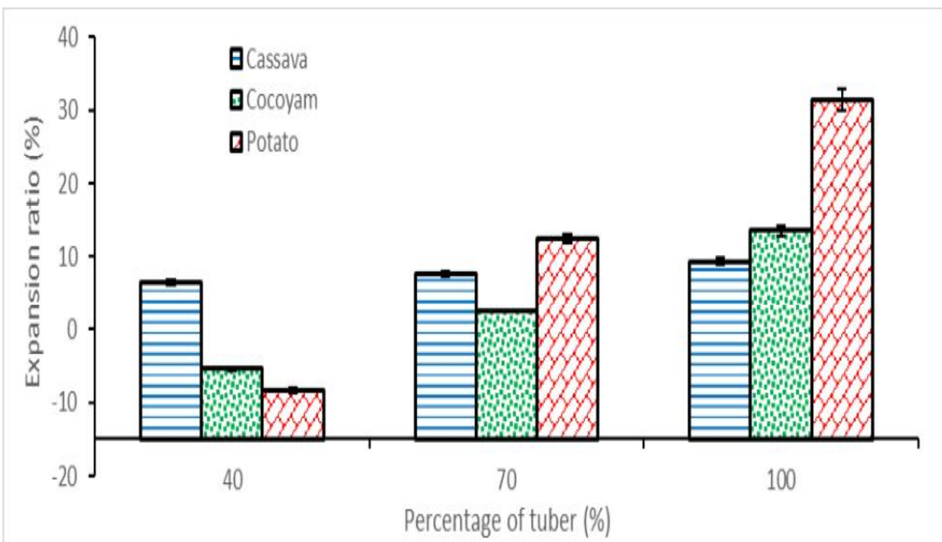

Fig. 9. The change in expansion ratio of extrudate with percentage of tuber crop

with 100% cassava and formulation with 100% of potato. 100% floatability was recorded for extrudate of the formulation with 40% of cocoyam, for its floatability throughout the period of observation.

4. CONCLUSION

Fish feed was produced from three different tuber crops (potatoes, cassava, cocoyam) as binder using existing fish feed extruder. The aim of adapting different percentage of these 3 tubers in the formulation serving as binder as it affects the resulting physical properties of the extrudate was investigated. The result indicates that cassava at 100% formulation has the highest mass followed by cocoyam at 40% formulation while potato at 40% formulation has the lowest. Surface area and volume of the extrudate increase linearly with increase in percentage of potato and cassava while there was a linear decrease in the volume and surface area as percentage of cocoyam increases. The true density of cocoyam and potato decreases as the percentage increases while that of cassava increases with increasing percentage. The bulk density of the extrudate increases linearly with an increase in percentage of the tubers while porosity of the extrudate decreases linearly with increase in percentage of cocoyam and potato in the formulation but with a linear increase with increases in percentage of cassava in the formulation. The relative absorption rate of the extrudate decreases with increase in percentage of tubers while the water stability of extrudate decreases non-linearly with an increase in the percentage of tuber. The expansion ratio of the extrudate for the three tubers increases linearly with an increase in percentage ratio of the tuber crop. The result from this study could be used to explore the possibility of interest of processors for the usage of tuber crops as binder for fish feed production.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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