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CASSAVA FLOUR SUBSTITUTION AND MOISTURE CONTENT VARIATION ON SOME QUALITY CHARACTERISTICS OF HEAT PUMP DRIED EXTRUDED FISH FEED

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ABSTRACT

This study examined the effect of substitution of maize with cassava flour at varying moisture contents on heat pump drying and some quality attributes including strength properties, durability index, microstructure and floatability. The samples identified as S_1- S_6, were prepared from various levels of cassava flour before being extruded at steady state at 3 moisture contents (30, 35, and 40% db) in a single screw cooking extruder. Drying was done with an open loop heat pump dryer while a scanning electron microscope (FEG-SEM) was used to study the microstructure of the fish feeds. Results showed that drying rates and pellet durability were proportional to the source and concentration of starch in the samples. Some of the samples floated in water. The Coefficient of performance (COP) of the heat pump used for the drying decreased with increase in ambient temperature; the average COP being 4.77. The thermal efficiency of the heat pump dryer was 92.45%. The scanning electron microscopy indicated that cassava substituted samples lack some elements required of fish feed. Also, extrusion cooking resulted in changes in mineral composition of fish feed blends.

Keywords: Fish feed, extrusion, heat pump drying, scanning electron microscopy, durability index, drying rate, COP.

INTRODUCTION

Nigeria's ecological and climatic conditions put the country at an advantage to produce a wide range of food products to attain food security. Despite this, a huge amount of money is spent annually by Nigeria government to import food for the masses of its people. Over one hundred and twenty five billion Naira (N125, 000, 000, 000) was spent buying fish every year (Adesina, 2014), talk less of machinery, fish feed and concentrates from abroad because of the need to improve protein intake of Nigerians. Also, production of fish in home environment (home stead fish pond) have been adopted as a means of improving family protein intake and income (Olagunju *et al* 2007). However, 60% of the cost of production of fish goes to fish feed (Gabriel *et al.* 2007). Availability of high quality fish feed is one of the greatest problems that affects the expansion of the small scale fish industries in Nigeria. Local production of high quality fish feed using local ingredients must be encouraged to replace the present dependence on imported ones. Also, cereal grains, which constitute the carbohydrate portion of fish feed are in high demand for human consumption There is the need to get local materials of lower price to replace this and other costly materials. Cassava production is highly favoured by the climatic conditions in Nigeria but a lot of post-harvest losses and glut of the commodity are usually experienced. Alternative utilization options for cassava would reduce its post-harvest losses and ensure its sustainable production.

Most dry and semi moist animal feed, pet and fish foods are produced through extrusion. Quality characteristics of fish feed include among others its strength properties, durability index, and its micro-structural characteristics and floatability. Importance of moisture content on fish feed compounding can never be overemphasized as it greatly affects the operation of extruders and also the energy costs. Moisture content is believed to serve as a binder during fish feed production. According to Wilson (2010), 'Optimal feedstock moisture content is essential to the development of interfacial forces and capillary pressure'. Therefore, there is the need to determine at what moisture content level will be best useful to the feed as much moisture will lead to higher drying costs and other changes in quality. Also, the durability of feed is an important quality as the feed is being stored, handled or transported from one place to the other as it is a measure of how much fine may be produced because of handling. Extruded floating feeds are preferred by many farmers because they allow observation of the feeding process, facilitate the inactivation and destruction of heat labile anti-nutritional factors and other contaminants and they are extremely stable in water. Up till now a lot of feed losses are being experienced due to inadequate storage and processing techniques.

Drying to produce high quality agricultural produce is yet a bottleneck in most Sub Sahara countries, especially Nigeria. Heat pump drying (HPD) systems improve energy efficiency and cause less fossil fuel consumption. Heat pump technology has been used for heating, ventilation and air-conditioning in domestic and industrial sectors in most developed countries of the world. However, HPD of agricultural products has been largely unexploited in Nigeria. Furthermore, since heat pump drying is a low temperature drying process, it will give a double advantage over the conventional, common and unreliable sun drying in the region.

According to Fazaeli *et al.* (2012), microscopy is used to study the influence of processing conditions and ingredients on food structure. Micro structural studies are indispensable in describing, forecasting, and control the behavior of food products and the organization of its components (Xiao and Gao, 2012). Food processing such as thermal and non-thermal processes can be thought of as altering the natural structure and the composition of food materials. Therefore, electron microscopy has been widely employed for evaluation of the microstructure of food and biological products and to improve on the quality of dried foods. This is because some of the structural elements contributing to the desirable properties of foods are below the range of 100μm range. Therefore, the objective of this study is to characterize Fish feed produced by extrusion and dried by heat pump drying technology by determination of their quality attributes.

MATERIALS AND METHODS

Sample Preparation

Cassava tubers (*Manihot esculenta* Crantz) TMS 30572, were sourced from experimental plots at the Federal College of Agriculture, Akure and processed into flour within 48 hours of harvesting. The materials were passed through a 300um sieve separately and the proximate analysis and moisture contents of samples were determined as described by Ahm et al (2014). Thereafter, samples were prepared from proven ingredients used in Nigeria for compounding fish feed and substituted with different proportions of cassava flour. The ingredients of the fish feed (K2 Feeds Mill, Akure) include fish meal, groundnut cake, soyabean meal, soya full fat, yellow maize, oyster shell, rice bran, vitamin premix and salt. Samples were prepared following the formula used by Gbadamosi *et al.* (2007). Cassava flour was supplemented in sample S1, S2, S3 and S4 in place of maize at 0, 110, 0 + 220g and 0 + 440g levels. This may represent respectively the different developmental stages carbohydrate requirement of fishes. Sample S1 with maize was used as control. The various formulas were ground in a local plate mill and passed through a 300um sieve. Thereafter, a 1000g portion of each formula was selected for further analysis. The moisture contents of the sample S2 were varied at 3 moisture contents d.b (30%, 35%, and 40%) by addition of proportionate water to the products before being extruded at steady state. These samples were identified as S2, S5, S6, respectively.

Experimental procedure and Data Collection

***Extrusion*:** An extruder was used in this study (Figure 1 and 2). The screw is of single flight, increasing diameter and tapering/ decreasing pitch with (L\D- 12:1, CR – 4.4:1, die diameter 6mm) configuration. Samples were fed into the extruder at a constant feed rate 10 kg/h, room temperature and screw speed of 150 rpm until steady state. The extrudates emerged as ribbons and later cut manually to a length of 10 cm each.

The extrudates from each extrusion run were identified separately as samples 1- 6 and one tenth of each portion selected for heat pump drying.

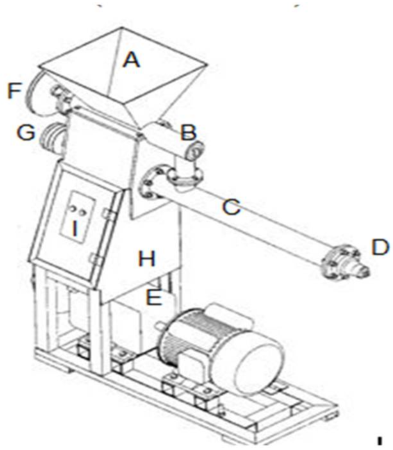

Figure 1: Isometric drawing of the extruder used- LEGEND A- Hopper, B- Feeding Conveyor, C- Extruder worm, D- Die Unit, E- Power train, F- Conveyor pulley, G- Extruder pulley, H-Extruder Housing, I- Control switch

Heat Pump Drying: The extruded fish feeds were dried with an experimental open loop laboratory air source heat pump dryer as described by Zhang and Huan (2013) set at 20 hertz condenser fan speed (1.95m/s) (Figure 3).Because of plenty of drying space, two samples were set on the drying tray for each drying run. Nevertheless, the initial and final weight of each sample was recorded before and after each drying trial.

All parameters of both the heat pump circuit and drying chamber were measured by T type thermocouples, temperature sensors, pressure sensors, humidity sensors and humidity-velocity-temperature anemometers. A digital balance scale was used to measure the fish feed samples mass loss during the drying process at 20 minutes interval to determine the drying curve. All experimental data were acquired by National Instruments modules and recorded by the Labview software. The coefficient of performance (COP) of the heat pump drying system was computed as follows in equations 1 – 3 using Engineering Equation Solver EES 4.0.

$$COP_{HP} = \frac{Q_H}{W_C} \quad (1)$$

$$Q_H = m_r(h_2 - h_3) \quad (2)$$

$$W_c = m_r(h_1 - h_0) \quad (3)$$

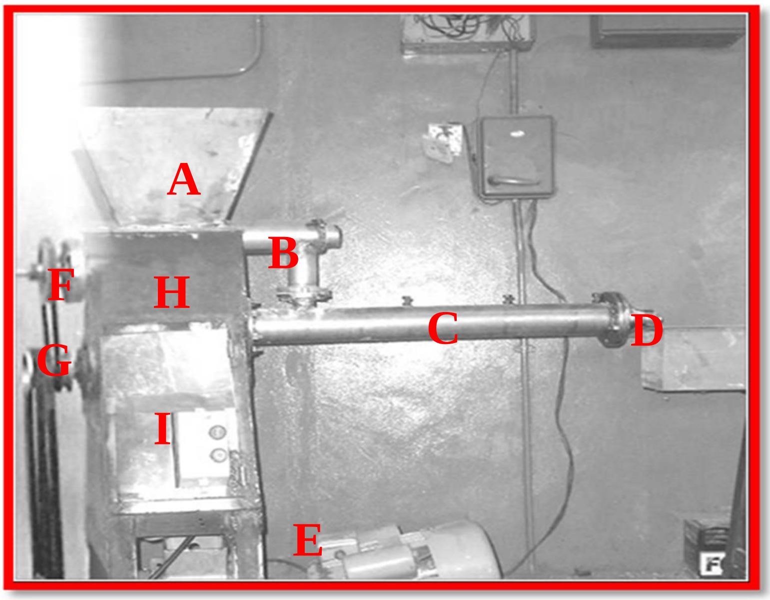

Figure 2: Picture of the extruder

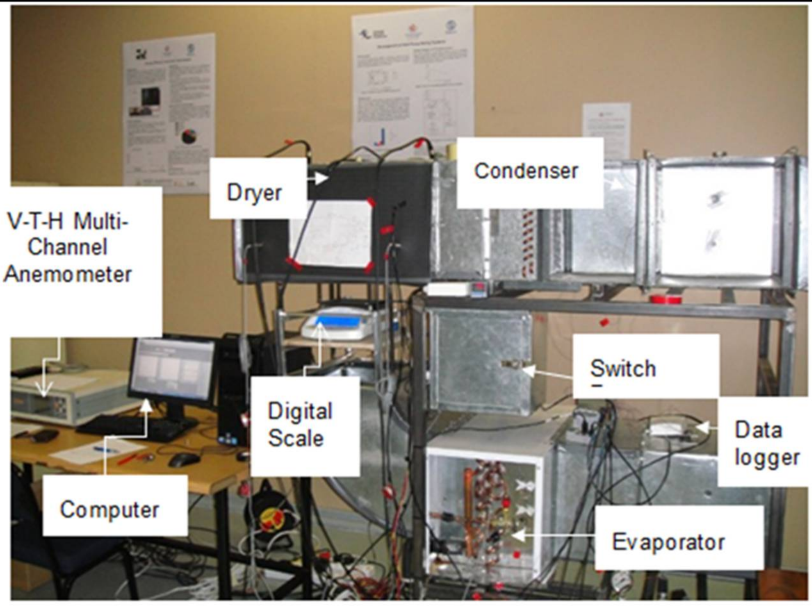

Figure 3: The HPD used

where
Q_H = heat rejected at the condenser
W_C = Energy consumption by the compressor
m = mass flow rate (kg/m3)
From Figure 4, h_2 = enthalpy at point 2 which is the entry of the condenser (kJ/kg)
h_3 = enthalpy at point 3 which is the exit of the condenser (kJ/kg)
h_1= enthalpy at point 1 which is the compressor injection enthalpy (kJ/kg)
h_0 = enthalpy at point 0 which is the compressor suction enthalpy (kJ/kg).
The drying rate of each sample was determined by equation 4.

$$\text{Drying rate} = \frac{m_t - m_{t+\Delta t}}{\Delta t} \tag{4}$$

where m_t is the mass at time t.

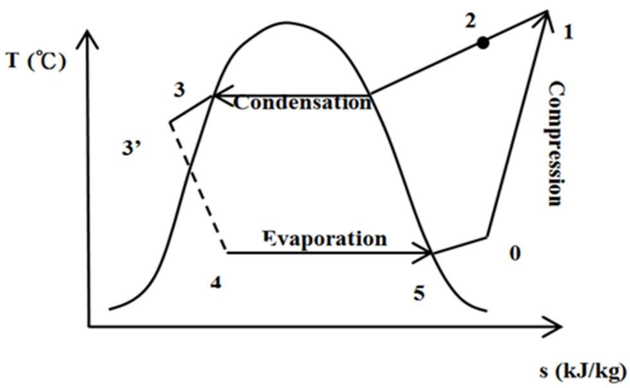

Figure 4: The ideal T-s diagram

Drying efficiency, η is defined by equation 5:

$$\eta = \frac{T_1 - T_2}{T_1 - T_a} \quad (5)$$

where T_1 is the inlet (high) air temperature into the dryer, T_2 is the outlet air temperature from the dryer, and T_a is the ambient air temperature.

After drying for approximately six hours, the remaining moisture within the samples was determined by the air oven method at 105°C for 12 hours.

Microstructural and EDS Characterization: A JSM 7600F Jeol ultra-high-resolution field emission gun scanning electron microscope (FEG-SEM) equipped with energy dispersive spectroscope (EDS) at the Microscopy and Tribo-electrochemical laboratory, Tswhane University of Technology, Pretoria, South Africa was used to study the microstructure and elemental composition of the Fish Feeds. Samples were dried and cut, ground and attached to SEM stub with a carbon tape. The samples on the stub were coated with platinum and examined using the SEM at 15kVaat different magnification (between 100-5000). However, due to electron charging of some of the samples, they were observed at 3.0 kV

Pellet Durability index (PDI): PDI of samples were determined using the tumbling box method (ASAE 1997) in equation 7.

$$PDI = \frac{Mass\ Retained\ on\ the\ Screen}{Total\ Mass\ of\ pellet} \quad (7)$$

In the absence of a standard tumbling box, some modifications according to Winowiski (1995) were made as follows: This method uses 500 g of sifted pellets. The pellets were placed in a box that revolved for a period of 10 min at a speed of 100 rpm. After testing, the pellets were screened on a mechanical sieve shaker with a sieve size of about 0.8 times the pellet diameter. The floatability of the samples was determined by dropping the samples in 10 litre bowl containing water to observe the time it would take the sample to sink.

RESULTS AND DISCUSSION

The effect of extrusion variables under study were quantified using some quality parameters.

Performance evaluation of the HPD system

The main parameters for quantifying HP performance for a drying system are: heating effect, work input, COP, discharge temperature and drying temperature. The study showed that the higher the ambient temperature, the less is heating effect. The discharge temperature increased when the ambient temperature was increasing. Also, drying temperature increased with increase in ambient temperature. Result also indicated that the COP decreased when the ambient temperature was increasing.

Effect of Variation of Moisture content

The study showed that feed moisture ≤ 25% d.b. blocked the rotation of the screw as there was no transition from the original floury nature to a melted state typical of most extrusion processing. This may be because the moisture content was not sufficient to soften the starch polymers and allow them to move freely in the mass, hence there was resistance to deformation and there was no expansion. The minimum moisture necessary to obtain steady flow of extrudate was 30%. Beyond 30% moisture content, the feed extrudates' response to extrusion was favourable. At 30% moisture, there was more dry matter in the sample. However, the optimum moisture content used was 35%. Also, the moisture loss (drying characteristics) of the samples are represented in Figure 5.

From Table 1, the lowest moisture was that of Sample 1 followed by Sample 2 because of much flashing of moisture during its extrusion. This shows that drying cost for samples 1and 2 would be reduced than those of other samples. The result showed that drying rates were proportional to the source and concentration of starch in the samples. Also, as an extrinsic property, drying by heated air is proportional to the mass or extent of the system; it therefore gets reduced in a corresponding ratio.

Pellet Durability

Durability is the abrasive resistance of the feed. Improvements in feed quality are measured by higher PDI %. From Figure 5, Samples 1, with maize only has better durability than sample 2.

Table 1: Final Moisture content (d.b)

Sample	Description	M.C (d.b) %
1	Normal 35	12
2	Maize + Cassava 35	12.1
3	Cassava 1	15
4	Cassava 2	17
5	Maize + Cassava 30	17
6	Maize + Cassava 40	20

Also, Sample 2 was less durable when compared to others with either only maize or cassava. From previous result (Fayose, 2012), Sample 1 had the nearest strength property to the imported Copen floating fish feed. This may be because corn starches possess higher amylose content (Fengwei *et al.* 2009). Hence, they tend to exhibit superior strength and toughness in the preparation of starch based materials. Sample 3 and 4 with cassava only and extra cassava levels respectively had higher durability indices. However, the sample with the initial highest moisture content (Sample 6) was the least stable among the samples.

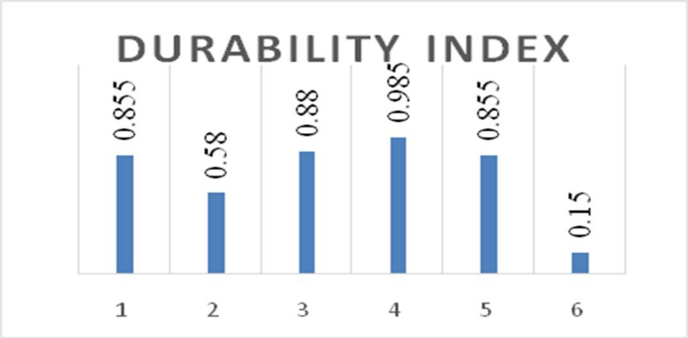

Figure 5: Pellet Durability Index of Samples

Drying characteristics of samples

From Figure 6, the drying rate for Day 1 is 0.0387 while those of days 2 and 3 are 0.02125 and 0.014, respectively. The difference in the rate of drying may be due to the thickness arising from the viscosity formation of the cassava substituted samples. This tends to obstruct the diffusion of water from the center to the surface of the extruded samples. Generally, the time required to dry any moist substance depends on its size or diameter, therefore it was expected that the drying rate for day 1 is the highest. During the falling rate period, the rate of drying is mainly controlled by the chemical composition and physical structure of the food. It was observed that there was no falling rate for day 3. The non-existence of a falling rate period may be explained by the fact that the surface of the samples was covered by free water regions, so that the evaporation of water took place at the surface at a constant rate. The thermal efficiency of the heat pump dryer was calculated to be 92.45%. This shows the advantage of heat pump dryers over hot-air dryers (Mujumdar and Jangam, 2011).

SEM Micrographs and EDS Profiles

The representative SEM micrographs are as presented in Figure5. The result of the SEM analysis indicated that expanded sample 1 has less rupture of cell walls than sample 2. Therefore sample 1 has stronger cell walls than sample 2. Sample 2, however, has a lot of pores due to ruptured cell wall and there were spaces and cracks within the sample. This is a confirmation of the previous study that Sample 1 is more ductile than sample 2 (Fayose, 2012). The cracks observed in the extruded samples might be due to the differences in stresses between the outer layer and the warmer center due to inappropriate cooling and this could lead to reduction of durability of the product. To prevent such occurrence in the future, the cooling of the samples must be carried out well (Karnnalin *et al*., 2012).

SEM was also carried out on the usual compressed pellet which is commonly used among fish farmers in Nigeria. The compressed pellets are characterized by sinking. Hence the tag “Sinking feed”. Many particles were seen the compressed pellet showing lack of melting of the particles due to no gelatinization. There were no pores seen in the compressed pellets showing lack of expansion. However, all the particles of the extruded samples were melted. The Sample 1 (the normal formula) and sample 2 (having equal portions of cassava mixed with maize) expanded during extrusion and exhibited some floating characteristics

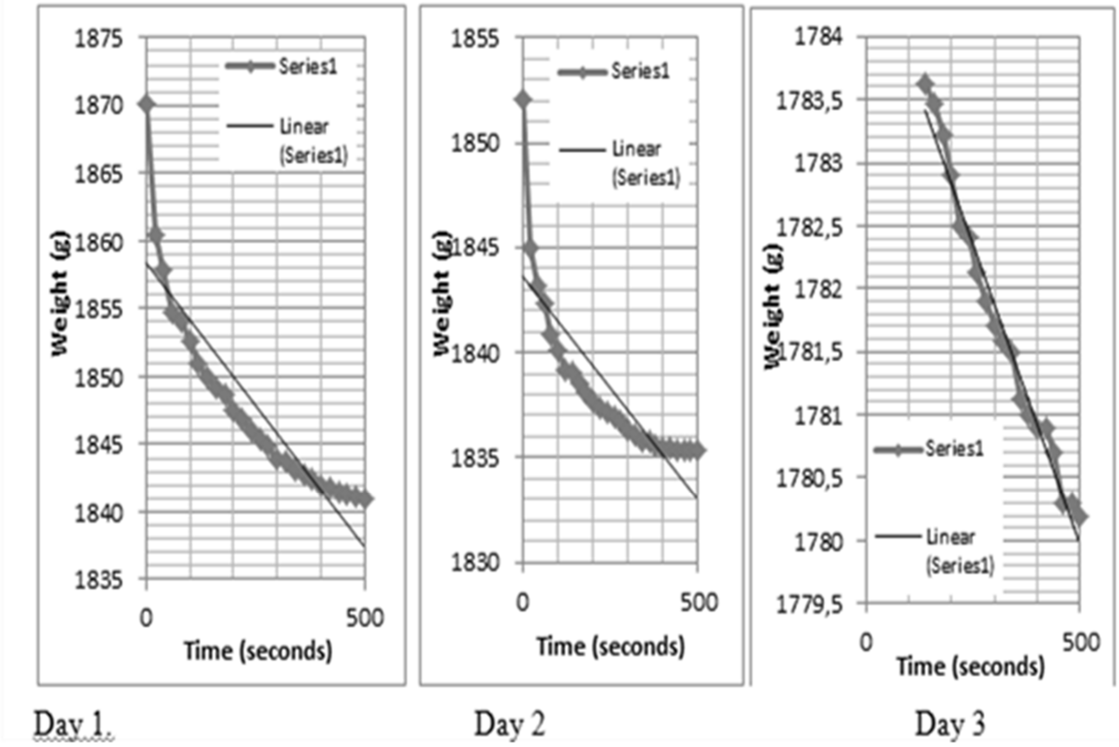

Figure 6: Drying curves for the different days of the experiment.

The moisture content of Sample 5 was not enough for its gelatinization. The scanning electron microscopy indicated that those samples compounded with cassava only lack some elements required of fish feed. Necessary fortification is advised if they are to be used for fish feeding. Also, extrusion cooking resulted in changes in mineral composition of fish feed blends. The composition of the maize + cassava samples are C, O, Na, K, Mg, P, S, Cl, K. while those with only cassava consist of C, O, P, Cl, K. The dispersion analysis conducted on different spots of the samples indicated that the mixing of the feed ingredients was not thorough as the element compositions at different spots were not uniform. Effort should be geared at mixing the ingredients in a more efficient equipment before extrusion in subsequent runs.

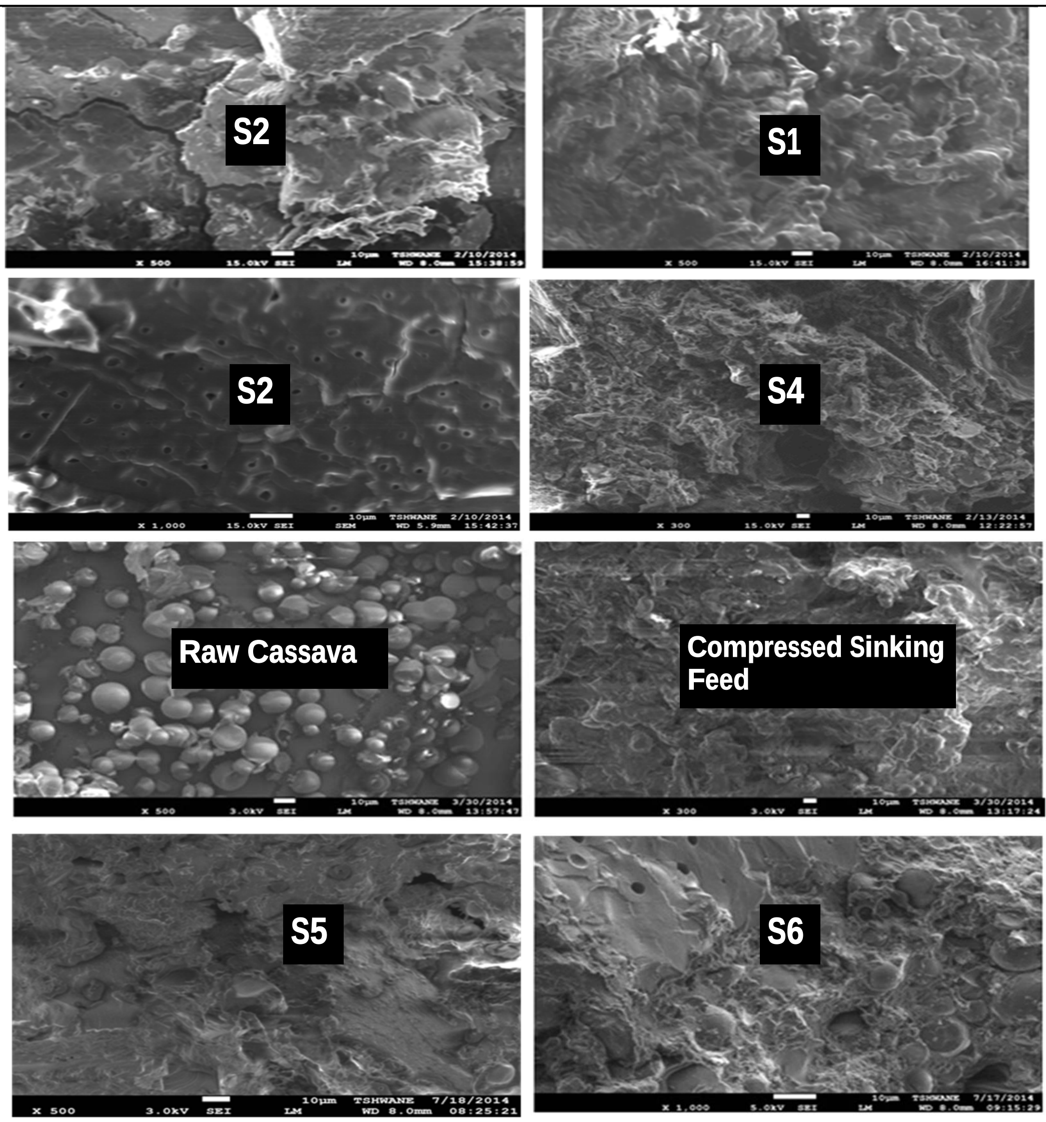

Figure 7: Micrographs of fish feed extrudate

CONCLUSION

The effect of Cassava Flour Substitution and Moisture Content Variation on some Quality Characteristics of Heat Pump Dried Extruded Fish Feed has been well studied. The result showed that drying rates were proportional to the source and concentration of starch in the samples. Also, the Coefficient of performance (COP) decreased with increase in ambient temperature, the average COP attained was 4.77. The thermal efficiency of the heat pump dryer was calculated to be 92.45%. Sample1, with maize will have better durability than all the other samples. Also, sample 1 has the nearest strength property to the imported Copen floating fish feed. The scanning electron microscopy indicated that cassava substituted samples lack some elements required of fish feed. Therefore, necessary fortification is advised if they are to be used for fish feeding. Moreover, extrusion cooking resulted in changes in mineral composition of fish feed blends.

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