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Acronyms

CSIR-FRI	Council for Scientific and Industrial Research – Food Research Institute
EMC	Equilibrium moisture content
GAB	Guggenheim-Anderson-de Boer
GLM	General linear model
HQYF	High Quality Yam Flour
HDPE	High density polyethylene
LDPE	Low density polyethylene
RVA	Rapid visco analyser
RVU	Rapid visco unit
SPSS	Statistical package for social scientist
TBC	Total bacteria count
TFC	Total fungi count
WAI	Water absorption index
WP	Work package

Summary

1.1 Ghana

A survey was conducted in various suburbs of Accra (Osu, Nungua, Accra central, La, Teshie, Pokuase, Agbogba, Madina, Legon, Haatso, Odorkor, Kaneshie, Banana-Inn, Bubuashie), Ghana, to determine consumers preference for local yam varieties to enable the team to select local yam varieties for processing High Quality Yam Flour (HQYF). A total of one hundred and sixty-nine (169) questionnaires were administered to respondents, 85 of whom were consumers and 84 were restaurants/road-side food vendors. Based on consumers' preference for local yam varieties, the team selected 5 varieties of yam for processing to set the parameters for processing yam into HQYF. The five varieties selected were *Pona, Asana, Lariboko, Ponjo*, and *Afase*. Tubers of Yam (*Asana* variety) were obtained from Abgogbloshie market, Accra, Ghana, for processing yam into HQYF. The tubers were divided into five lots after which each part was processed into HQYF with a different processing method. The dried yam samples obtained were then milled and analysed at the Chemistry laboratory of CSIR-Food Research Institute, Accra, Ghana. A standard methodology for processing HQYF was developed based on the five processing methods studied. The other four varieties of yam were processed using the standard method developed and the HQYF assessed for rheological/storage characteristics, nutritional composition, storage and packaging characteristics.

1.2 Nigeria

High quality yam flour (HQYF) as an alternative novel market for processed yam products in order to reduce levels of post-harvest losses and provide increased incomes for small-holder farmers was developed. A 4 x 2 x 2 factorial design was employed to study the effect of yam specie, processing and drying methods on the functional and pasting qualities of HQYF. The effect of storage condition (temperature and relative humidity) and packaging materials on storage stability of HQYF was also determined. Sorption isotherms of HQYF at different temperature and relative humidity were determined and the sorption data obtained was fitted into five sorption models. Findings showed that yam species, pre-treatment and drying methods significantly affected the functional properties of HQYF. Yam specie, pre-treatment and drying method had significant influence on the anti-nutritional and vitamin contents of HQYF. The anti-nutritional factors were significant reduced by blanching compared to sulphiting. Influence of storage conditions and packaging materials [high density polyethylene (HDPE), low density polyethylene (LDPE) and plastic container] on the quality attributes of HQYF was successfully established. Samples stored in plastic containers exhibited better storage stability as the increase in their moisture content and microbial contamination was minimal when compared with HDPE and LDPE. The potential use of the flour therefore depends on the storage conditions and packaging materials prior to use. The capacity for high quality yam flour to adsorb water was established at water activity range of between 0.11 and 0.96 at temperatures 25, 35 and 45 ^oC. The significant variation observed among HQYF samples could contribute significantly to selection and improvement of the yam varieties for specific food applications to stimulate their production and industrial utilization.

Key Findings

2.1 Ghana

Five popular local Yam varieties were randomly selected for setting the parameters for processing yam into High Quality Yam Flour (HQYF). The varieties selected were *Pona, Ponjo, Lariboko, Afase and Asana* – all of which are *Dioscorea rotundata* species*.* The *Asana* variety was randomly selected and processed using five (5) different processing methods. The results indicated that the best of the five methods was the one which involved the dipping of the Yams in metabisulphite solution followed by blanching and drying. This method was found to be suitable for preparing HQYF from all five varieties of yams assessed, since it did not impact negatively on the quality of the flour. It was also found out that drying yams at temperatures of $55^{O}C$ -$70^{O}C$ and drying times of 4.5-6.5 hrs produced flour for which the physico-chemical, pasting and nutritional characteristics were not compromised. After six months storage of the flour in two types of packaging material, the physico-chemical characteristics of HQYF were not significantly different from the freshly prepared flour. However the transparent plastic containers were found to preserve the quality of the product better than the polyethylene pouches. The sensory quality of products made from the HQYF was also found to be very acceptable. HQYF from *Pona* and *Ponjo* were however much preferred for preparation of fufu than *Afase*, *Lariboko* and *Asana*. HQYF from all the varieties were equally liked for the preparation of biscuits.

2.2 Nigeria

Effect of specie, pre-treatment and drying me*thod on the functional, pasting properties, anti-nutritional and vitamin contents *of High Quality Yam Flour

The study investigated functional properties, anti-nutritional and vitamin contents of high quality yam flour (HQYF) from tubers of four dioscorea species. The tubers were processed into HQYF using two pre-treatments (potassium metabisulphite: 0.28%, 15 min; blanching: 70 ºC, 15 min) and drying methods (cabinet: 60 ºC, 48 h; sun drying: 3 days). Significant varietal differences ($p<0.05$) were observed in pasting characteristics of flours among the four yam species. Drying method significantly ($p<0.05$) affected only the peak viscosity. The interactive effect of specie, pre-treatment and drying method on the functional properties were significant ($p<0.05$) except for emulsification capacity, angle of repose and least gelation concentration. The significant variation observed in most of the functional properties of the HQYF could contribute significantly to breeding programmes of the yam species for diverse food applications. Pastes of flour from *D. dumentorum* were stable compared to other samples, hence will have better applications in products requiring lower retrogradation during freeze/thaw cycles. The main and combined effects of specie, pre-treatment and drying method on the anti-nutritional composition of HQYF were significant ($p<0.05$) except for saponin. The low level of alkaloid (0.21 g/100 g) and phytate (13.43 g/100 g) in HQYF sample from D. *rotundata* in this study underscore its safety and availability of minerals for absorption in the body when consumed/used as food formulations. The main effect of specie as well as interactive effects of specie, pre-treatment and drying method significantly ($p<0.01$) affected the vitamin content of HQYF. The appreciable level of vitamin C (20.87-30.91 mg/100 g) detected in all the HQYF could indicate product of good nutritional quality for the consumers.

Influence of Storage Conditions and Packaging Materials on the Quality attributes of High Quality Water Yam Flour (HQYF)

The study investigated the quality attributes of HQYF packaged in three packaging materials [high density polyethylene (HDPE), low density polyethylene (LDPE) and plastic container] and stored under different storage conditions [relative humidity (36%, 56%, 75% and 96%) temperature (25±2, 35±2 and 45±2 ^{o}C)] for 12 weeks. The functional properties and proximate composition of the samples were determined at 4 weeks interval. Significant difference ($p<0.01$) were observed for moisture content of the samples. Interactive effect of Storage conditions and packaging materials was significant ($p<0.01$) on the proximate composition and pasting properties except breakdown viscosity, trough viscosity and pasting temperature. The interactive effect of storage time and storage temperature was significant ($p<0.01$) on all the functional properties except wettability. The potential use of the flour therefore depends on the storage conditions and packaging materials prior to use.

Adsorption Isotherms of high quality water yam flour

Adsorption isotherms of high quality water yam flour were determined by static gravimetric method using saturated salt solutions in the range of water activity between 0.11 and 0.96 at temperatures 25, 35 and 45^{o}C. The temperatures were chosen to simulate the ambient temperatures across Nigeria. The experimental sorption data were fitted to five models: Guggenheim-Anderson-de Boer (GAB), Peleg, Iglesias-Chirife, Exponential and Oswin and the differential enthalpy and entropy were determined. Equilibrium moisture content (EMC) decreased with increase in temperature at all the water activity. Peleg model gave the best fit all over the water activity range studied while the monolayer values, estimated from the GAB model, were found to decrease with increase in temperature. The differential enthalpy and entropy decreased with increase in moisture content, the isokinetic temperature was 371.32 K and the compensation theory was satisfied.

Deliverable Objectives

To develop and validate technologies and systems that allows production of high quality yam flour of acceptable quality providing a new market outlet for yam produced by small-holder households

Background

Cassava and yam are important food security crops for approximately 700 million people in the world. Post-harvest losses however are significant and come in three forms: (a) physical; (b) economic through discounting or processing into low value products and (c) from bio-wastes. The GRATITUDE project aims to reduce these losses to enhance the role that these crops play in food and income security. There are 3 impact pathways: 1. reduction of physical losses – focussing on fresh yams storage, 2. value added processing reducing physical and economic losses in yam and cassava and 3. Improved utilisation of wastes (peels, liquid waste, spent brewery waste) producing products for human consumption including snack foods, mushrooms and animal feed. The work has been divided into 7 work packages. This report focuses on work package 3. The key issue in WP3 centres mainly on the development of viable new processed products for yam and cassava that provide options of households to sell their produce for reasonable prices and result in reduced physical or economic losses.

Sixty per cent (60%) of fresh yams are currently considered to be lost after harvesting. Although there is some yam flour on the market in West Africa, there are issues on quality and the production at the SME level is limited. Urbanisation in West Africa is a driver of changing food habits and is therefore likely to offer an opportunity for composite flours or more convenient forms of traditional products. Therefore by converting some of this 60% loss into high quality yam flour should present value addition opportunities. This will be in collaboration with WP2 to ensure the approaches are economically viable and that markets exist and with WP5 to ensure that they are safe.

Various drying methods would be investigated at different combinations of time and temperature for drying yams for flour production that have been subjected to specified pre-treatments. The various flours produced would be subjected to physico-chemical, nutritional and sensory analysis in order to establish the pre-treatments, drying methods and conditions that produce the best quality flour for up-scaling and promotion. The ideal conditions established would be used to produce yam flour for the storage and packaging trials. The yam flour would be stored under different conditions of temperature and humidity in a variety of packaging materials. Product quality during storage would be assessed and related to storage time and packaging material in order to establish the most appropriate packaging requirement and shelf life of the product.

This study seeks to enhance our understanding and knowledge about functional and pasting properties of different yam species (*D. rotundata*, D. *alata*, D. *cayenesis* and D. *dumentorum*). These properties of the yam species and how they are related to product organoleptic properties is necessary to facilitate food quality improvement programmes and use in diverse food products. It will also enhance value addition through processing, as is currently possible for wheat-, maize- and cassava-based products. This will eventually increase its market demand and hence increase production/utilization, leading to poverty reduction for producers and processors. Potential new applications could include: as a replacement for starch in some applications, for the manufacture of confectionery, expanded use in food processing and also within certain industrial processes. Besides strengthening food stability, utilization of yam may also support the sustainable agricultural development in Ghana and Nigeria since this plant can be grown as intercropping crop with other plants.

Methodology

5.1 Ghana

5.1.1 Yam processing methods

One hundred tubers of Yam (*Asana* variety) were obtained from Abgogbloshie market, Accra, Ghana, for processing yam into HQYF. The 100 tubers were divided into five parts. The first part was processed by peeling and washing thoroughly, sliced thinly with a slicer and the sliced yam pieces placed in 0.5% Sodium Metabisulphite solution immediately for 3 minutes after which it was spread on a tray and placed in a pre-heated mechanical dryer set at 60^{o}C for 6 hours. The dried samples were milled into flour after cooling and analysed for physico-chemical/nutritional composition. The second part was treated in the same way as the first except for the drying which was done by spreading the samples on a granite constructed patio and dried using sun energy. The third set of sample was peeled, washed, sliced, soaked in 0.5% sodium metabisulphite solution for 3 minutes and blanched with steam for 5 minutes. The blanched samples were then dried in a mechanical dryer set at 60^{o}C for 6 hours. The dried samples were milled into flour after cooling and analysed for physicho-chemical/nutritional properties. The fourth part was treated in the same way as the third except for the drying which was done by spreading the samples on a granite constructed patio and dried using the sun energy. The fifth part of the yam bought was peeled, washed, sliced, and dried in the mechanical dryer set at 60^{o}C for 6 hours. The dried samples were milled after cooling and packaged. The processed HQYF samples were analysed for physicho-chemical/nutritional properties. Based on the results from the above trials, the four other varieties of yam were processed by peeling, washing, slicing, soaking in 0.5% sodium metabisulphite solution for 3 minutes, washing with clean water, blanched for 5 minutes, spread on a tray and placed in a mechanical preheated dryer (set at 60^{o}C) for 6hrs.

5.1.2 Physico-chemical properties of HQYF

The dried yam samples described in the processing methods in **5.1.2** were milled after cooling and 100Kg samples were delivered to the Chemistry Laboratory of CSIR-Food Research Institute, Accra, Ghana for physico-chemical analysis. The methods indicated below were used for the chemical analysis. Moisture – AOAC 925.10, Ash – AOAC 923.03, Fat – AOAC 920.39C, Protein – AOAC 984.13, Carbohydrate – By difference, Energy – Atwater Factor, Calcium – Permanganate Titrations, Phosphorous – Molybdenum Blue Colorimetric and Vitamin C – 2,6-dichlorophenolindophenol.

<u>5.1.3 Pasting Characteristics</u>

The viscoelastic properties and pasting characteristics of HQYF samples were determined using the American Association of Cereal Chemists' Method 22-10 (AACC, 1983) with slight modifications. Forty grams (40g) of HQYF dissolved in 420mls of water were measured using Brabender Viscoamylograph. The viscosity of the slurries were continuously monitored as they were heated from 50^{o}C at a rate of 1.5^{o}C/min to 95^{o}C, held at 95^{o}C for 15 min and cooled at a rate of 1.5^{o}C/min to 50^{o}C and held at 50^{o}C for 30 min. The pasting characteristics measured include; pasting temperature, peak viscosity, viscosity at 95^{o}C-HOLD and viscosity at 50^{o}C.

<u>5.1.4 Shelf life studies.</u>

Five hundred kilogram (500Kg) samples were packaged into polyethylene packs and transparent plastic containers and stored under room temperature (29–32^{o}C) condition. The physic-chemical composition of the stored samples was assessed after the six-month storage period and compared with those of the fresh product.

<u>5.1.5 Sensory evaluation</u>

A fifteen (15) member trained sensory panel from the CSIR-Food Research Institute, Accra, Ghana were used to carry out sensory evaluation on *fufu* and biscuit samples prepared from HQYF. The evaluation was done just after the flour was produced. Yam *fufu*, prepared from HQYF, were served to the panellists to score after observing/tasting/feeling. A control sample prepared by traditional method (from *pona* yam variety) was also served alongside the HQYF *fufu* samples. A nine point hedonic scale was used for scoring the sensory attributes of the samples. The attributes were appearance, taste, aroma, texture, mouth feel and overall acceptability. The scale for scoring ranged from 1 – 9 with 1 representing dislike extremely, 2 representing dislike very much, 3 representing dislike moderately, 4 representing dislike slightly, 5 representing neither like nor dislike, 6 representing like slightly, 7 representing like moderately, 8 representing like very much and 9 representing like extremely. Panellists were also asked if they would buy the samples if they were for sale. The data of the sensory work were analyzed using the Statistical Package for Social Scientists (SPSS) statistical tool.

5.1.6 Drying Temperature/Time treatments on HQYF

The five yam varieties studied were dried at different temperatures (55, 60, 62, 65 and 70^{o}C) in combination with different times (4.5, 5, 5.5, 6 and 6 hours). Physicho-chemical and rheological studies were carried out on the samples after drying and milling to find out if drying time and temperature could have some effect on the qualities of the HQYC samples.

5.2 Nigeria

5.2.1 Effect of specie, pre-treatment and drying method on the functional, pasting properties, anti-nutritional and vitamin contents of High Quality Yam Flour

Raw material sourcing

Four species (*D. rotundata*, D. *alata*, D. *cayenesis* and D. *dumentorum*) of fresh wholesome yam tubers were obtained from local markets in Abeokuta Ogun State, Nigeria.

Production of High Quality Yam Flour

Four species (*D. rotundata*, D. *alata*, D. *cayenesis* and D. *dumentorum*) of fresh undamaged yam tubers were obtained from local markets in Abeokuta, Ogun State. Each variety of the tuber was washed and peeled. The peeled samples were sliced with a vegetable slicer into 1 mm pieces and washed in clean water. The yam slices were divided into two equal parts with a part blanched in water bath maintained at 70 ^{o}C and the other part was sulphited by immersing them in 0.28% potassium meta-bisulphite. Each pre-treatment was done for 15 minutes. With respect to drying, each pre-treated yam slices were dried at 60 ^{o}C for 24 h. For sun drying, each pre-treated yam slices were dried on black polythene for 2 days in order to obtain the same moisture content in the flour. The dried samples was ground separately and sieved through a 250 μm mesh screen to obtain High Quality Yam Flour. The HQYF were kept separately in air-tight plastic container to prevent moisture absorption and stored at room temperature until analysed. The functional and pasting properties of the HQYF were determined using standard procedures and data obtained were analysed by subjecting them to general linear model (multivariate tests) and the means with significant differences were separated at 5% level.

Determination of functional properties

Water Absorption Index (WAI) was determined according to the method described by Anderson *et al.* (1969). The bulk density of the sample was determined using the method described by Akpapunam and Markakis (1981). Oil Absorption Capacity was determined by the method of Sosulki *et al.* (1962) as described by Nwosu *et al*. (2010). Least gelation concentration was determined using the method described by Adeleke *et al.* (2010). The method used by Nwosu et al. (2010) was used with slight modification for Foaming capacity and wettability. Dispersibility was determined by the method described by Kulkarni *et al*. (1991). Emulsification capacity was determined following the procedure of Adeleke *et al.* (2010).

<u>Angle of Repose:</u> This was determined using the method described by Olorunsola *et al*. (2012), 20 g quantity of flour was poured inside a funnel of orifice diameter 0.8 cm, clamped at a height of 10 cm. It was then allowed to flow freely. The height of the heap 'h' and the diameter 'D' was measured. The angle of repose, θ, was calculated using the equation:

$$\varphi = \text{Tan}^{-1}\,(2h/D)$$

<u>Pasting characteristics:</u> Pasting characteristics was determined with a Rapid Visco Analyser (RVA), (Tecmaster TCW3, Perten Instument, Australia). Three grams of flour was mixed in 25 ml of water in

a sample canister. The sample was thoroughly mixed and fitted into the RVA. With the use of the 12 min profile, the slurry was heated from 50 ºC to 95 ºC with a holding time of 2 min followed by cooling to 50 ºC with another 2 min holding time. Both heating and cooling was at a constant rate of 11.25 ºC/min with constant shear at 160 rpm. Corresponding values for peak viscosity, trough, breakdown, final viscosity, setback, peak time, and pasting temperature from the pasting profile were read on a computer connected to the RVA.

Determination of anti-nutritional factors

The gravimetric determination of alkaloids and total phenol contents followed procedure proposed by Harbone (1973). Extraction and determination of phytic acid was determined according to procedure of Wheeler and Ferrel (1979). The method of Swain (1979) was used for the determination of tannin contents of the differently processed yam flour. Oxalate was determined using methods described by Day and Underwood (1986) and The Spectrophotometric method of Brunner (1984) was used for saponin determination.

Vitamin Determination

The vitamin B_1 of the flour samples was determined according to the method of AOAC (2005). The vitamin B_2 of the flour samples was determined according to the method of AOAC (2005). The method of Guilarte *et al*. (1981) was used to determine vitamin B_6 content of all the flour samples. The method of AOAC (1980) was used to determine the vitamin C content of the flour samples.

Influence of Storage Conditions and Packaging Materials on the Quality attributes of High Quality Water Yam Flour (HQYF)

High Quality Yam Flour (HQYF) was packaged in plastic containers, high density polyethylene (HDPE) and low density polyethylene (LDPE) and stored in incubators at 4 relative humidity (36%, 56%, 75% and 96%) over three temperatures (25±2, 35±2 and 45±2 ºC) for 12 weeks to study the effect of storage conditions on the flour. The functional and pasting properties of the samples were evaluated at interval of 4 weeks during storage. The moisture content, protein, fat and ash content of the samples were determined using AOAC (1999) method. Total bacteria and fungi counts were determined using the pour-plate procedure for bacteria and fungi (ICMSF, 1988). Ten grammes from each sample were aseptically weighed into 90 ml of 0.1% (w/v) sterilized peptone water in a beaker and allowed to stand for 5 min with occasional stirring using a sterile glass rod. Portions (1ml each) of Serial decimal dilutions of 10^6 were plated on Nutrient Agar was used for determination of total viable bacterial count and Potatoes Dextrose Agar supplemented with 0.01% chlorophenicol for total viable fungal count. Dilutions of 10^6 were plated and incubated at 30 ºC for 3 days. The colonies that developed were enumerated and expressed as colony forming unit per gram (cfu/g) for bacteria and fungi. All experimental data obtained were subjected to the general linear model (GLM) procedure of SPSS (version 21) for the analysis of variance and Pearson's correlation was also determined. In all cases, α=0.05

Determination of Adsorption Isotherm during storage of HQYF

The equilibrium moisture content was determined by static gravimetric method (Sanni *et al.*1997) at water activity range between 0.11 and 0.96. Nine saturated salts solutions were employed to maintain constant water activity within the desiccators. The salts solutions used to maintain constant relative humidity of surrounding air, 11%-96%, were LiCl, CH_3COOK, $CaCl_2$, $Ca(NO_3)_2$, $Mg(NO_3)_2$,$NaNO_3$, NaCl, $K_2Cr_2O_7$ and K_2SO_4, The determination of sorption isotherms was carried at 25, 35 and 45°C to simulate variation in temperature in Nigeria. Thymol was placed in desiccators in which water activity was 0.75 and above in order to inhibit microbial growth. Triplicates of 3 g samples were placed above saturated salt solutions in desiccators and kept in incubators at desired temperature maintained to an accuracy of ±1 °C. The samples were weighed daily and equilibrium was considered to be attained when three consecutive values were obtained (±0.001 g). The equilibrium was obtained within 20-25 days. The equilibrium moisture content was calculated on dry basis.

Sorption isotherm models fitted with experimental data

Models	**Mathematical Equation**	
GAB	$m = \frac{X_m\, CKa_w}{[(1 - Ka_w)(1 - Ka_w + CKa_w}$	Guggenheim, 1966;Anderson,1946;de Boer, 1953
Peleg	$m = Aa_w^B + Ca_w^D$	Peleg, 1993
Exponential	$In\ m = In\ A + In\ Ba_w$	Lazarides, 1990
Oswin	$In\ m = In\ A + BIn(\frac{a_w}{[1 - a_w]})$	Oswin, 1946
Iglesias and Chirife	$In(m + [m^2 + m_{0.5}]^{0.5}) = A + Ba_w$	Iglesias and Chirife (1978)

Sorption isotherm modeling

Many models in literature are available for predicting sorption isotherms of foods, five of which were employed in this work. They are GAB, Peleg, Iglesias-Chirife, Oswin and Exponential, chosen because of their versatility in accurately predicting sorption isotherms of food materials. The parameters of the models were estimated using non-linear regression procedure of SPSS version 21. The goodness of fit for each of the model was assessed by using statistical parameters such as coefficient of determination (R^2) and mean relative percentage deviation (P%) . P is defined as

$$P = 100/n \sum_{i=1}^{n} \frac{|(Xexp - Xcal|}{Xexp} \quad (1)$$

The GAB model contains three parameters, X_m, C and K which are a function of temperature. X_m is the monolayer moisture content, C is a constant related to heat of sorption of the first layer and K is associated with heat of sorption of the multilayer. The influence of temperature on C and K can be calculated from Arrhenius equations (Kim and Bhowmik, 1994).

$$C = Co \exp\left[\frac{H_M - H_N}{RT}\right] \quad (2)$$

$$K = Ko \exp[(H_L - H_N)/RT] \quad (3)$$

Net Isosteric Heat of Sorption and Differential Entropy

The net isosteric heat of sorption (q_{st}) for specific moisture content was calculated from the experimental data using the Clasius-Clapeyron equation (Tsami, 1991).

$$q_{st} = -R\left[d \frac{In\ a_w}{\left(\frac{1}{T}\right)}\right] \quad (4)$$

The net isosteric heat of sorption was calculated from the slope of the plot of In a_w versus $1/T$ at constant moisture content. This approach assumes that isosteric heat of adsorption can be considered constant with temperature and requires the determination of sorption isotherms at more than two temperatures.

The differential entropy of adsorption was calculated from Gibbs-Helmholtz equation

$$S_d = \frac{(Q_{st} - G)}{T} \quad (5)$$

$$G = RT In(a_w) \quad (6)$$

Substituting equation (6) in equation (5), we have equation (7),

$$In(a_w)|_x = \frac{Q_{st}}{RT} - \frac{S_d}{R} \quad (7)$$

By plotting In (a_w) against the inverse of temperature, at constant moisture content, the S_d can be estimated from intercept (S_d/R).

Enthalpy-Entropy compensation theory

The isokinetic relationship or enthalpy-entropy compensation theory proposes a linear relationship between Q_{st} and S_d (Leffer and Grunwald, 1963).

$$Q_{st} = T_1 S_d + G \quad (8)$$

By plotting of Q_{st} against S_d , the isokinetic temperature (T_1) and the Gibbs free energy (G) at T_1 calculated using linear regression. T_1 is the temperature at which all reactions in the sorption sites proceed at the same rate.

A test of the compensation theory, as recommended by Krug *et al.* (1976) was carried out, which involves the evaluation of the isokinetic temperature with respect to the harmonic mean temperature T_{hm} defined as shown below:

$$T_{hm} = \frac{n}{\sum_{i=1}^{n} 1/t} \quad (9)$$

Where n is the number of isotherms

The theory can only be applied if $T_1 \neq T_{hm}$. If $T_1 > T_{hm}$ the process is enthalpy driven, if otherwise, the process is considered to be entropy driven.

6. Results

6.1 Ghana

6.1.1 Assessment of Yam processing methods

Observations on the processed HQYF samples from the methods used in **5.1.1** revealed marked dis-colouration of the samples that were not treated with sodium metabisulphite. These samples were thus disqualified straight away and were therefore not assessed for their physico-chemical properties. This indicates that the yams need to be pre-treated with sodium metabisulphite before drying in order to obtain an appealing colour of the yam flour. Other samples treated with sodium metabisulphite alone or with blanching had good looking HQYF. The best method identified was to wash the tubers whole, peel, wash peeled yam, slice yam thinly into pieces, dipping in 0.5% sodium metabisulphite for 3 minutes, rinsing in clean water, blanching for 5 minutes, spreading on drying trays and placing in a preheated dryer (60^{o}C) for 6 hours.

6.1.2 Physico-chemical properties of HQYF

Results obtained from the analysis of HQYF samples at the Chemistry Laboratory of CSIR-Food Research Institute is as shown in Tables G1 and G2. The results obtained showed reasonable levels of nutrients in processed HQYF and are very much comparable to literature results. The indication therefore is that the selected processing method does not affect the physicochemical properties or the nutrient levels of flour from the various cassava varieties worked on. There was a statistically significant difference between the five varieties of yam as determined by one-way ANOVA ($p = 0.000$). A Tukey post-hoc test revealed that *Pona* had statistically significantly higher levels of protein (4.4 ± 0.00) and calcium (37.5 ± 0.00) compared to the other four yam varieties. There were however no statistically significant differences between the Vitamin C levels of some of the yam varieties (*Asana, Pona and Lariboko*) compared to *Afaase* and *Ponjo*.

6.1.3 Pasting characteristics

The Brabender Viscoamylograph presents useful information on the hot and cold paste viscoelastic properties of starch-based foods. The pasting temperature is the temperature at which irreversible swelling of the starch granules occurs leading to the formation of a viscous paste in an aqueous solution. Starches with lower pasting temperatures are generally considered to be easier to cook. However, lower pasting temperatures are also associated with low paste stability, which is usually considered to be an undesirable property. Low pasting temperature and low paste stability indicate that fewer associative forces and cross-links are present within the starch granule (Afoakwa and Sefa-Dedeh, 2002).

The pasting temperature of yam varieties selected ranged between 76°C and 87°C as shown in Table G3. There was a statistically significant difference in pasting temperature between the five varieties of yam as determined by one-way ANOVA ($p = 0.000$). A Tukey post-hoc test revealed that *Afaase* had statistically significantly higher levels of pasting temperature (87°C) compared to the other four yam varieties. There were however no statistically significant differences between the pasting temperatures of *Pona and Ponjo. Pona* variety had the highest peak viscosity (219BU) during cooking whilst *Afaase* had the lowest peak viscosity(73BU). All yam varieties had relatively high peak viscosities except *Afaase*. There was a statistically significant difference in peak viscosities between the five varieties of yam as determined by one-way ANOVA ($p = 0.000$). A Tukey post-hoc test however revealed that there were no statistically significant differences between the peak viscosities of *Asana and Lariboko.*

6.1.4 Shelf life studies.

HQYF samples produced generally had no significant changes in nutritional composition and physical appearance over the six months storage period in plastic transparent containers and polyethylene pouches stored under room temperature (29–32°C), conditions as shown in Figures G1-G7. Neither the storage period nor the type of packaging significantly affected the quality of the flour. There was however some amount of moisture gain in the yam samples stored in polyethylene pouches compared to those stored in plastic transparent containers as shown in Figure G1. This goes to confirm the fact that the plastic containers are better packaging material for flour than the polyethylene pouches.

6.1.5 Sensory evaluation.

The mean sensory scores for the sensory attributes for *fufu* and biscuit made from HQYF are shown in Tables G4 and G5 respectively. The results indicate that the panellists liked *fufu* made with *Afaase* slightly, liked *fufu* made from *Asana, Pona, Lariboko* and *Ponjo* moderately but liked *fufu* made traditionally with *Pona* very much. There was a statistically significant difference in the overall acceptability of the *fufu* samples prepared from the five varieties of yam as determined by one-way ANOVA ($p = 0.000$). A Tukey post-hoc test revealed that the fufu prepared by traditional method had statistically significantly higher acceptability (8.20 out of 9) compared to the experimentals. Fufu prepared from *Ponjo* and *Pona* yam varieties (using HQYF) also had significantly higher acceptability scores; 7.53 and 7.20 respectively. There was however no statistically significant difference between the acceptability of *Asana* and *Lariboko* fufu samples. The two best liked fufu made with HQYF were therefore those made from *Ponjo* and *Pona* yam varieties. Ninety percent (90%) of panellists however said they will buy all *fufu* samples made from HQYF if they were commercially available.

The biscuits made with HQYF were liked moderately by all panellists. There was no statistically significant difference in the overall acceptability of the biscuit samples prepared from the five varieties of yam as determined by one-way ANOVA (p = 0.000). This means that all the yam varieties used in this study had equal opportunity of producing good biscuits. Ninety five percent (95%) of the panellists say they will patronise the biscuit samples if they were available for sale.

6.1.6 Drying Temperature/Time interactions on HQYF Quality

Results obtained from the analysis of HQYF samples treated with different drying temperatures and time are as shown in Tables G6 and G7. The results obtained from all treatments on HQYF showed comparable nutrient levels to those processed at single time of 6hours and temperature of 60^{o}C (Table G2). There were also no statistically significant differences between the results obtained for all treatments in relation to protein, fat, Vitamin C and carbohydrates. However, the Vitamin C levels reduce in value as the temperature of drying increases. The moisture of the samples reduces drastically with increase in temperature as expected. The indication therefore is that the temperatures of 55^{o}C to 70^{o}C and times of 4.5 to 6.5 hours of drying does not affect the physicochemical properties or the nutrient levels of flour from the various yam varieties worked on. Results obtained from the rheological studies also show no significant deviations from those processed at single time of 6hours and temperature of 60^{o}C (Table G2). There were also no statistically significant differences between the results obtained for all treatments in relation to pasting temperature, Peak viscosity, viscosity at 50^{o}C and oil absorption. However, there was a statistically significant difference in swelling power of the samples with different drying temperature and times. A Tukey post-hoc test revealed that 23 out of the 25 treatments are not significantly different. The two samples that were different were samples dried at 55^{o}C for 6.5 hours and that dried at 65^{o}C for 7.0 hours. No reason could be assigned to the difference.

6.2 Nigeria

6.2.1 Effect of specie, pre-treatment and drying method on the functional, pasting properties, antinutritional and vitamin contents of High Quality Yam Flour

Table N1 shows the result of functional properties of HQYF samples. Specie significantly ($p<0.05$) affect the functional properties of HQYF samples. The interactive effect of specie, pretreatment and drying methods on the functional properties was significant ($p<0.05$) except on emulsification capacity, angle of repose and least gelation concentration. HQYF from *D. dumentorum* exhibits higher water absorption index (2.86 g/g) than other varieties as shown in Table 1. Water absorption characteristics represent the ability of a product to associate with water under conditions where water is limiting (Singh, 2001). Oil absorption capacity of all the samples ranged between 7.53 and 7.96 g/g. High oil absorption capacity is desired in flavour retention, improvement of palatability, extension of shelf life of bakery or meat products, meat extenders, doughnuts, pan cakes, baked goods, and soup mixes, whereas water absorption capacity is desirable traits in food such as sausage, custards and dough because these are supposed to imbibe water without dissolution of protein thereby attaining body thickening and viscosity (Seena and Sridhar 2005). Therefore, HQYF from D. *alata* and D. *dumentorum* pretreated with potassium metabisulphite and dried using cabinet drier, with the highest value of oil absorption capacity and WAI respectively can be utilized for the production of such products listed above.

The least gelation concentration of the HQYF samples ranged between 2.00 and 5.00% (w/v). The least gelling concentration obtained for all the samples was lower than the values reported for *D.alata* varieties (30-50%w/v) by Udensi *et al*. (2008), cassava flour (22%w/v) by Udensi *et al*. (2005) and cocoyam flour (6.0-8.0%) by Ogunlakin *et al*. 2012. Depending on the relative ratios of different constituent like proteins, carbohydrates and lipids, different flour has different least gelation concentration (Sathe *et al*. 1982).

Bulk density of the flour samples ranged from 0.70-0.91g/cm^3 which is higher than 0.64-0.76 g/cm^3 reported for varieties of water yam flour by Udensi *et al*. (2008). The values obtained for bulk density is also compared to that obtained for sweetpotato flour (0.7453g/ml) used as thickener or as a base in foods like yoghurt (USDA, 2009), this also implies that HQYF could find use as a thickener in food industries to give body and mouth feel to food products. The high volume per gram of flour material is important in relation to its packaging, it is desirable to have high bulk density in that it offers greater packaging advantage, as greater quantity may be packed within a constant volume (Fagbemi 1999; Adepeju *et al*. 2011). Generally, higher bulk density is desirable for the greater ease of dispersibility and reduction of paste thickness which is an important factor in convalescent child feeding (Padmashree *et al*. 1987). Earlier study by Malomo *et al*. (2012) on dispersibility of yam flour (60.50%) had reported a similar result to (58.84%) the mean value obtained in this study. Dispersibility is a measure of reconstitution of flour in water. Highest value (69.17%) of dispersibility was recorded by the flour samples from *D. rotundata* and *D. cayenesis* hence; they will easily reconstitute to give fine consistency dough during mixing (Adebowale *et al*. 2008).

The values obtained for wettability ranged between 58.67 and 211 s. It was observed that wettability increased with blanching pretreatment. It has been earlier reported that during temperature process some of the starch in the flour may have gelatinized and in the process absorbed moisture and swelled up and consequently the flours processed from these blanched slices possess a reduced hydrophillic ability leading to reduced hydration capacity of flour and thereby increasing the values obtained for wettability as blanching temperature is doubled. This report is in agreement with the findings of Tagodoe and Nip (1994) who found that the gelatinization of taro starch increased the density of the taro flour and therefore showed a reduced ability to absorb moisture. Since lower values of wettability indicates faster reconstition properties blanching should be done at a lower temparature to produce flour in application which require fast water absorption. Emulsion capacity denotes the maximum amount of oil that can be emulsified by flour dispersion (Oluwalana *et al.* 2011). The values obtained varied between 55.83 and 66.70 g/ml which is lower compared to what was reported for a blend of sweetpotato and wheat 9.68-25.40 g/ml by Adeleke *et al*. (2010).

Foam capacity of treated water yam flour is higher than that of wheat and sweetpotato flour blend (Adeleke *et al*. 2010). Low foam capacity was observed in the flour from *D. alata* specie pre-treated with hot water blanching and dried using the two drying methods. These flour could be desirable in food processes where excessive foaming is not required as it reduces loss due to foam spilage or the need for including an extra steep or antifoaming agent to check foaming.

Table N2 shows the results of the pasting properties of HQYF from different species of yam tubers which undergo different pretreatment and drying methods. Significant difference ($P<0.01$) were observed in pasting characteristics of flours among the four species of yam tubers. Drying method significantly affected only the peak viscosity. The interaction between pretreatment and drying methods followed the same pattern as in variation between drying methods, while the interaction between specie, pretreatment and drying methods were not significant ($P>0.05$) except for peak and final viscosities.

Pasting temperature of the flour samples ranged between 69.9 and 88.4 ºC. These values are in agreement with pasting temperatures for *D. alata* and *D. rotundata* flours (85.89 and 79.88 ºC respectively) reported by Wireko-Manu *et al*. (2011). Pasting temperature has been described as the temperature above the gelatinization temperature when starch granules begin to swell and it is characterized by an increase in viscosity on shearing (Adebowale *et al*. 2005). Pasting temperature provides an indication of the minimum temperature required to cook the flour and this has implication for the suitability of other food (with different gelatinization temperature) in a food formula (Newport Scientific 1998). Highest pasting temperature was for HQYF from *D. dumentorum* dried using cabinet dryer with potassium metabisulphite method of pretreatment and lowest for *D. cayenesis* sun dried with blanching as the method of pretreatment. The high pasting temperature of *D. dumentorum* flour indicates the presence in this flour, of starch that is highly resistance to swelling and rupturing. Defloor *et al*. (1994) reported that attaining gelatinization at a lower temperature led to improved bread making quality.

The peak viscosity which is the maximum viscosity attainable during the heating cycle ranged between 181.83 and 506.81 RVU, the highest for cabinet dried *D. rotundata* flour that was pretreated with potassium metabisulphite and the lowest for *D. dumentorum* which undergo the same treatment. Peak viscosity indicates the water binding capacity of the starch. It is often correlated with the final product quality and also provides an indication of the viscous load likely to be encountered during mixing Maziya-Dixon *et al*. (2007). Peak viscosity relates with product quality hence significant difference observed among the yam species studied may influence their performance in product development. Time taken to attain peak viscosity ranged from 4.6-5.8 min, similar to that of *D. alata* and *D. rotundata* (4.73-7.00) reported by Wireko-Manu *et al*. (2011). The peak time is a measure of the cooking time (Adebowale *et al*. 2005).

As part of the pasting characteristics studied, the flour sample subjected to RVA was heated to 95 ºC and held at that temperature for a couple of minutes under mechanical shear stress. As a result of starch granule disruption and the leaching out of amylose into the solution, under mechanical shear stress, viscosity decreased. The period provides the minimum viscosity value in the constant temperature pasting profile. Trough is considered as a measure of the breakdown of hot starch paste. The ability of a paste to withstand heating and shear stress is an important factor for most food processing operations and is also a factor in describing the quality of starch gel, Madsen and Christensen (1996). High paste stability is a requirement for industrial users of starch, Bainbridge *et al*. (1996). This is because drastic changes in paste during and after processing could lead to undesirable textural changes.

Trough values obtained ranged between 94.44 RVU (for *D. dumentorum* pretreated with potassium metabisulphite and sun dried) and 404.86 RVU (for *D. alata* pretreated by blanching and dried using cabinet drier). Generally, the *D. alata* flour had higher trough, which indicates greater ability to withstand shear at high temperatures and higher cooked paste stability (Rasper 1969; Farhat *et al*. 1999). Starch with a low trough value would have greater need for cross-linking than one with a high value (Oduro *et al*. 2000). *D. alata* starch could therefore be targeted for industrial uses because of its hot paste stability. Breakdown (a measure of the ease with which the swollen granule can be disintegrated) values of flour samples ranged from 39.50-357.33 RVU. Lowest breakdown was observed in flour from *D. cayenesis* that was pretreated by blanching and dried using cabinet drier, thereby indicating the stability of the swollen granules against disintegration during cooking. The rate of starch breakdown depends on the nature of the material, the temperature and the degree of mixing and shear applied to the mixture (Newport Scientific, 1998). The ability of a mixture to withstand heating and the shear stress that is usually encountered during processing is an important factor for many processes, especially those requiring stable paste and low retrogradation or syneresis (Sanni *et al*., 2008).

The setback viscosity which is an index of the retrogradation of linear starch molecules during cooling ranged between 56.72 and 321.44 RVU which is slightly higher (86.52-210.94 RVU) than that reported by Jimoh *et al*. (2009). Setback has been correlated with the texture of various products. High setback is also associated with syneresis or weeping during freeze/thaw cycles (Adebowale *et al*. 2005). Sanni *et al*. (2004) reported that lower setback during the cooling of paste from starch or a starch-based food indicates greater resistance to retrogradation. Lowest setback value of flour from *D. dumentorum* indicates its lower tendency to retrograde. The smaller tendencies to retrograde are advantage in food products such as soup and sauce, which undergo loss of viscosity and precipitation as a result of retrogradation (Adebowale and Lawal, 2003) and for this reason HQYF from *D. dumentorum* variety may be suitable for products like soup mixes.

Final viscosity which indicates the ability of flour material to form a viscous paste, ranged from 157.11-649.58 RVU. Final viscosity has been reported as the most commonly used parameter to determine the ability of starch-based materials to form a viscous paste or gel after cooking and cooling as well as the resistance of the paste to shear force during stirring (Adebowale *et al*. 2005; Maziya-Dixon *et al*. 2007).

The anti-nutritional factors of the flour samples are presented in Table N4. The values ranged from 164.45-979.45, 122.45-440.30, 13.43-79.2, 1.61-13.0, 0.21-1.13 and 9.02-49.32 g/100 g for total phenol, tannin, phytate, saponin, alkaloid and oxalate, respectively. The main and combined effects of specie, pretreatment and drying methods on the anti-nutritional composition of the HQYF samples were significant ($p<0.05$) except for saponin which pretreatment had no significant effect on. The presence of anti-nutritional factors may adversely affect the nutritive value of the food.

Phenolic compounds inhibit the activity of digestive as well as hydrolytic enzymes such as amylase, trypsin, chymotrypsin and lipase Salunkhe (1982). Phenols are responsible for the bitterness and astringency associated with many foods (Bravo 1998) and also exhibits an inhibitory effect on fungi in vitro (Bonner and Varner 1965). Hence, Bitter yam (*D. dumentorum)* was expected to contain the highest levels of phenols because of its bitter taste and its resistance to fungal infection, which was observed in this study. Among the various species of *Dioscorea* studied, HQYF sample from the tubers of *D. alata* had the lowest (164.45 mg/100g) value. This value was found to be within the range (0.16-0.25%) of the earlier study reported by Udensi *et al*. (2010) in the tubers of *D. alata* varieties. Recently the presence of phenols (Farquer, 1996) have been suggested to indicates that *Dioscorea* species could act as anti-inflammatory, anti-clotting, antioxidant, immune enhancers and hormone modulators (Okwu and Omodamiro 2005).

Tannins have been reported to form complexes with proteins and reduce their digestibility and palatability (Eka 1985). However, their contents in foods are known to reduce through cooking Lewu *et al*. (2010). Tannin concentration in the HQYF samples studied ranged from 122.45-440.30 mg/100g. These values are relatively higher when compared with the earlier values reported for *Dioscorea rotundata* (20 mg/100g) by (Uka 1985), *Dioscorea alata* (46.50-180.25 mg/100g) by Udensi *et al*. (2010) and 20-255 mg/100g reported on various under-utilized *Dioscorea* tubers by Arinathan *et al*. (2009). The bitter characteristics of *D. dumentorum* may be due to the high level of tannin found in it. The trace quantities of tannin available in yam tubers act as a repellent against rot in yam.

Phytates and oxalates are known to adversely affect mineral bioavailability (Bhandari and Kawabata 2006). The value of phytic acid of the present study was found to range between 13.43 and 79.21 mg/100g which was low compared to 58.6-198 mg/100g found in some cultivars of *D. alata* by Wanasundera and Ravindran (1994). These values in yams are much lower than those of 400-2060 mg/100g reported for cereals and grain legumes Reddy *et al*. (1982). Oxalate levels were also very low (9.02-49.32 mg/100g) relative to the 483-781 mg/100g reported by Wanasundera and Ravindran (1994) but higher (0.20-0.63 mg/100g) than that reported by Polycarp *et al*. (2012).

The availability of alkaloids in the tubers of Dioscorea species indicates that yam tubers cannot be eaten raw. The level of alkaloid (0.21-1.13 g/100g) obtained in this study was lower compared to that reported for different yam varieties by Okwu and Ndu (2006). The high content (1.13 g/100g) of alkaloids in *D. dumentorum* lends credence to the reports of toxicities associated with its use (Eka 1998). However, the low level (0.21 g/100g) of alkaloid obtained was within the range (0.12-0.55%) of that reported by Udensi *et al*. (2010). This underscored the safety of the *D. alata* flour studied when consumed, since most alkaloids are known to be toxic and can cause a wide range of physiological changes in the body when consumed (Harbone, 1973). However, simple processing such as cooking removes the alkaloids present in most cultivated species of yams as reported by Osagie and Opoku (1992).

Saponins and alkaloids are considered important due to their toxicity in yams (Okwu and Ndu 2006). This toxic metabolite occurs in varying concentration in yam tubers. The saponin content obtained in this study ranged from 1.61-13.01 mg/100g and lower than 2.98-19.46 mg/100g reported by Okwu and Ndu (2006). *D. dumentorum* sample had the highest saponin content of 13.01 mg/100g while *D. cayenesis* had the least content of saponin (1.61 mg/100g). The high level of saponin found in *D. dumentorum* sample may be responsible for the bitter yam's characteristic bitter taste. Saponins natural tendency to ward off microbes makes them good candidates for treating fungal infections. These compounds served as natural antibiotics, which help the body to fight infections and microbial invasion (Sodipo *et al*. 2000).

The vitamin content of the HQYF samples is presented in Table N5. From the multivariate ANOVA results, the main effect of specie as well as interactive effects of specie, pretreatment and drying method significantly ($p<0.05$) affected the vitamin content of HQYF samples. The result obtained showed that combination of pre-treatment and drying methods had no significant ($p>0.05$) effect on all the vitamins studied except for vitamin B_6. The interactive effect of specie and drying method was significant ($p<0.05$) on the vitamins.

The vitamin C content reported in this study was higher than the value reported for plantain flour 6.30 mg/100g (Adetuyi and Komolafe 2011), "Gbodo" yam flour and "Elubo ogede" plantain flour (Jonathan *et al*. 2011), and was lower than the vitamin C value (16.72-35.20 mg/100g) reported for flours of different water yam (*Dioscorea alata*) flour (Udensi *et al*. 2008). Ascorbic acid (vitamin C) activates the functions of all the cells. It is a powerful antioxidant. It favours the absorption of iron in the intestine, protects against infections, neutralizes blood toxins and intervenes in the healing of wounds (Roger, 1999).

The mean ranges of vitamins thiamine and vitamin C in cultivated Nigerian yams according to a comprehensive report by Osagie (1992) are 0.01-0.11 mg/100g and 4.00-18.0 mg/100g. These values were lower than that obtained in this study as presented in Table N5. Thiamine (vitamin B_1) functions as a co-enzyme in the phosphogluconate pathway. Thiamine is needed for proper digestion. The Riboflavin (vitamin B_2) content of the HQYF samples ranged from 0.44-4.55 mg/100g and was lower than that reported for different varieties of *Dioscorea species* by Okwu and Ndu (2006). Pyridoxine (vitamin B_6) plays an essential role in amino acid transmission (McCormick, 1997, Combs, 1999). The quantity of pyridoxine in the HQYF samples ranged between 2.00 and 4.34 mg/100g.

6.2.2. Packaging and storage conditions of HQYF

The effect of storage conditions and packaging materials on the functional properties of high quality water yam is presented in Table N6. The mean values of bulk density, water absorption index, water binding capacity, oil absorption capacity and wettability ranged between 0.67 and 0.80 g/ml, 1.41 and 2.24, 62.03 and 128.00%, 0.13 and 0.53, and 53.67 and 80.37 s, respectively. The functional properties were significantly ($p<0.01$) affected by storage conditions and packaging materials. The interactive effect of storage conditions and packaging was not significant ($P<0.01$) on all the functional properties determined.

The bulk density, water absorption index, water binding capacity and oil absorption capacity decreased with storage period. The bulk density of food product is affected by particle size and it is an important tool in determining packaging materials and material handling during food processing (Karuna *et al.*, 1996). The decrease in bulk density was more prominent in samples stored in LDPE and HDPE and was affected by storage time, storage temperature, relative humidity. Wettability of the flour was affected by storage temperature and packaging materials ($p<0.01$).Wettability of flours is an important indicator of instant characteristics of dried flours. The slight increase in wettability indicates a slight reduction in instant characteristics of the flour. The decrease in water absorption index could be due to reduced ability of the flour to retain water within its matrix and which ultimately affects the ability to form paste. The decrease in water binding capacity could be due to the loose association between amylose and amylopectin in the native granules of starch and weaker associative forces maintaining the granules structure (Lorenz and Collins, 1990). The reduction in oil absorption capacity as storage progresses could probably be due to the reduced ability of the flour to entrap fat to its apolar chain of its protein (Wang and Kinsella, 1976).

Moisture content is an important parameter to be determined during storage of foods. The effect of storage conditions and packaging materials on proximate composition of high quality water yam flour is presented in Table N7. The mean values of the moisture content of flour ranged between 8.30 and 16.59%. The moisture content of the flour packaged in LDPE increased more followed by that of flour packaged in HDPE; this is due to the high rate of water vapour incursion into the packaging materials. Similar trend have been reported by Swain *et al.* (2013) for dried sweet pepper packaged in HDPE. The result also indicated that storage temperature, relative humidity and packaging materials affected moisture adsorption of high quality water yam flour. At higher relative humidity level (75% and 98%), the moisture increase were more prominent. The moisture content of food is an indicator of shelf stability, the lower the moisture content the better the storage stability of the food (Sanni *et al.*, 1997).

The mean values for protein, fats and ash content ranged between 4.25 and 5.77%, 0.02 and 5.58%, and 1.12 and 1.48%, respectively. The protein and ash content decreased slightly with storage while the converse was observed for fat content. The protein and ash of the flour in the 3 packaging materials hover around their initial values for up to 8 weeks and then decreased significantly by the end of 12 weeks of storage. The interactive effect of storage conditions (temperature and relative humidity) and packaging materials was significant ($p<0.01$) on protein, fat and ash contents.

Table N8 shows the effect of storage conditions and packaging materials on pasting properties of high quality water yam flour. The mean values of peak viscosity, trough viscosity, breakdown viscosity, final viscosity, setback viscosity, peak time and pasting temperature ranged from 95.52 - 429.42 RVU, 76.25 - 328 RVU, 3.30 - 101.42 RVU, 13.52 - 160.92 RVU, 4.92 - 6.57 min and 81.38 - 86.34 ^{o}C, respectively. The interactive effect of storage conditions (temperature and relative humidity) was significant ($P<0.01$) on all the pasting properties except trough viscosity, breakdown viscosity and pasting temperature.

There were gradual decrease in peak, trough, breakdown, final and setback viscosities with storage time. The decrease was more observed in samples stored at higher relative humidities for all the packaging materials investigated. Peak viscosity is the maximum viscosity attainable during heating of starch. It is a measure of the ability of starch to swell freely before breakdown (Sanni *et al.*, 2004). The reduction in peak viscosity with storage time indicates degradation of starch granules with storage. The peak viscosities obtained are comparable with those reported by Wireko-Manu *et al.* (2011) for water yam. The relatively high viscosity recorded for the flour after storage indicates the flour could be suitable for products requiring high gel strength and stability. The trough viscosity, an indicator of the ability of the paste or gel to withstand mechanical stress at constant temperature as more starch granules and amylose leach out into the solution, decreased with storage time. The highest trough viscosity was observed in sample stored at 36% relative humidity. Trough viscosity is accompanied by breakdown viscosity which the minimum viscosity that is observed when a paste is subjected to cooling at constant temperature. The breakdown viscosity observed for the samples at the end of storage indicate an appreciable breakdown of starch granules.

The effect of storage conditions and packaging material on microbial stability of high quality water yam flour is represented in Figures N1 to 3, which are the plot of counts (bacteria and fungi) against storage time at different temperature and relative humidity. In each Figure, the plots are represented in four relative humidity- 36%, 56%, 75% and 96% at constant temperature. An increase in both bacterial and mould load was observed for the samples, the increase ranged from 0.10-2.05×10^6 cfu/g and 0.00-0.50×10^6 cfu/g for total bacterial count (TBC) and total fungi count (TFC) fungi counts, respectively. The largest increase was observed in samples stored at higher relative humidity (75% and 96%). Length of storage time led to an appreciable increase in bacteria and mould growth. Mould growth increased at any interval during storage as relative humidity increased. Low storage temperature and relative humidity resulted in lower microbial counts during storage; therefore, the storage of the flour at 35 and 45 ^oC under high relative humidity (75% and 96%) makes them vulnerable to microbial contamination as more colonies were observed in samples stored at these storage conditions irrespective of the packaging materials. Similar trends have been reported for storage temperature and relative humidity effect on mould growth by Samapundo *et al.* (2007) for corn. Three months storage of the flour resulted in 1.95×10^6 and 0.50×10^6 increase in bacteria and mould growth, indicating a significant ($p<0.01$) effect of storage time on microbial growth. Relative humidity had a significant ($p<0.01$) effect on both bacteria and mould counts while storage temperature had a significant ($p<0.01$) effect only on the bacteria count. Relative humidity in this study had a pronounced influence than storage temperature for microbial growth. The packaging materials had a significant ($p<0.01$) effect on bacteria count only. Microbial load in all packaged samples increased at the end of 12 weeks of storage. This could be associated with the relative permeability of the packaging materials to atmospheric gases such as oxygen, carbon dioxide and water vapour and also probably due to storage conditions employed in this work which are favourable for microbial growth (Akhtar *et al*., 2008). Plastic container exhibited a better protection against bacteria and mould attack, acting as an effective barrier to moisture. The microbial contamination of foods requires sufficient moisture, and mould generally portends to thrive at lower moisture than bacteria and yeast (Akhtar *et al*., 2008).

6.2.3 Adsorption Isotherms of High Quality Yam Flour

Figure N4 shows the sorption isotherms of high quality water yam flour at 25, 35 and 45ºC. A careful study of the isotherms indicates that at lower water activity, equilibrium moisture content (EMC) increased linearly with water activity but at higher water activity levels, the moisture content increased exponentially with water activity. Such similar trend has been reported by Moreira *et al.* (2008). The EMC decreased as storage temperature increases for any given water activity. This could be because at higher temperatures, the activation energy of the water molecules changes to higher energy levels, the bonds become less stable and break away from water-binding sites of foods (Moreira *et al.*, 2008). Similar trends for same temperature effects have been reported by Sanni *et al*. (1997) and Onayemi *et al.* (1987) for *lafun* and traditional yam flour (*elubo)*, respectively. Higher water activity resulted in progressively higher EMC values at constant temperature. At any particular EMC value, lower storage temperature results in lower a_w values which improves stability of the flour, thus an increased storage temperature could lead to microbial growth.

The coefficients for the sorption models for high quality water yam flour with the statistical parameters are shown in Table N9. A detailed study of Table N9 indicates that Peleg, GAB, Iglesias and Chirife models adequately described the experimental adsorption isotherms of high quality water yam flour due to their higher R^2 values. However, the use of R^2 only does not imply that the models fit the experimental data accurately, percentage deviation (P%) values are therefore necessary to make conclusive judgment. Based on this, Peleg and GAB could be said to adequately describe the experimental adsorption data of high quality water yam flour, with values ranging between 0.034 and 0.087%, and 0.1399 and 0.2197% respectively. The mean (P%) of both models were observed to be below 10%, which are generally accepted as good fit (Simal *et al*., 2007). Hence, Peleg satisfactorily predicts the sorption data of high quality water yam flour.

Monolayer moisture content using the GAB model parameter was observed to vary between 8.309 kg solid/kg and 10.739 kg solid/kg water db and it decreased with increase in storage temperature. Similar trends have been reported by Sanni *et al*. (1997) for *lafun* (fermented cassava flour). This trend could be ascribed to reduction in the number of active food materials due to chemical and physical damage caused by increased storage temperature. Monolayer moisture is sorption capability of the food materials; it is the minimum moisture content covering the hydrophilic sites on food materials surface and it is an important data for achieving minimum quality loss for long time storage. Therefore, at any given temperature, the safest water activity of food material is that corresponds to the lowest monolayer moisture content.

The net isosteric heat of sorption, the differential enthalpy, was calculated from the slope of a plot of In a_w versus *1/T* at constant moisture content. The results are shown in Figure N5. There was an exponential decrease in the net isosteric heat of sorption as the moisture content increases. Similar trends have been reported for *lafun* by Sanni *et al* (1997). The net isosteric heat of sorption measures the binding energy of the forces between water vapour molecules and the solids. The decrease in heat of sorption with increase in adsorbed water indicated that water-solid interactions are strongest at lower moisture content (active polar sites) which explains the high interactive energy between the water molecules and the flour (monomolecular layer). The energy required to remove these water molecules bounded to the flour, is high. As moisture content increases, the interaction reduces, lowering the net heat of sorption, hence, the water molecules behave as free water (available for microbial growth).

The differential entropy was calculated from the intercept of the plot of In a_w versus $1/T$ at constant moisture content. The results are shown in Figure N6. A strong relationship was found between differential entropy and moisture content which was similar with that of net isosteric heat of sorption. The differential entropy decreased with increase in moisture content. Differential entropy is the degree of disorderliness in a material. Sorption entropy of a material is proportional to the number of available sorption sites at any specific energy level. Decreasing moisture content restricts the movement of water in the material as the degree of orderliness increases. Similar results have been reported by Fasina (2006) for sweet potato.

The plot of Q_{st} against $S_{d,\,as}$ shown in Figure N7, depicts a linear relationship indicating that Enthalpy-Entropy compensation exists.

$$Qst = 371.32Sd - 719.06 \qquad R^2 = 0.9995$$

This implies that the compensation theory could be applied in the range of moisture contents studied. The isokinetic temperature was determined from the slope as T_1= 371.32 K, which is the temperature at which all the sorption reaction will take place at the same rate. The harmonic mean temperature was calculated as T_{hm}=307.78 K. Since this value is significantly different from T_1, the suitability of the isokinetic theory was confirmed and also, $T_1 > T_{hm}$ in all cases, hence, the processes can be characterized as enthalpy driven, which implies that only one mechanism of reaction is followed by all members of the reaction series. This further suggests that the microstructure of the flour is stable and does not suffer any changes during moisture sorption (McMinn *et al.*, 2005). The result obtained agrees with that reported for sweet potato flour by Fasina (2006).

The free energy ΔG is indicative of the affinity of sorbent for water, it provides a means of determining if the sorption process is spontaneous ($-\Delta G$) or non-spontaneous ($+\Delta G$). From Figure N7, the sorption process was spontaneous. McMinn *et al.* (2005) reported spontaneous sorption isotherms for starchy materials.

Conclusions

7.1 Ghana

The best method for processing yam into HQYF is by washing the tubers whole, peeling, washing of peeled yam, slicing yam thinly into pieces, dipping sliced yam in 0.5% sodium metabisulphite for 3 minutes, rinse, blanch, spread on drying trays and place in a preheated dryer (60^{o}C) for about 6hours to dry after which the samples are milled into flour and packaged. All five yam varieties used for this work had reasonable levels of nutrients and they could be used for *fufu* preparation as well as production of other pastries like biscuits. The methodology developed for the HQYF processing is being tried with the SME on the project for uptake. The HQYF samples had no significant changes in nutritional composition and physical appearance over six months storage period in plastic transparent containers and polyethylene packs stored under room temperature of (29– 32^{o}C).

7.2 Nigeria

The result of this study showed that species, pre-treatment and drying methods affected the functional properties of HQYF. The wide variation observed in functional characteristics of the flour samples serve as a database for the selection and improvement of the yam varieties for specific food applications to stimulate their industrial processing and utilization. Flours obtained in this study could serve well as a good binder or provider of consistency in food preparations such as semi solid beverages. Pastes of flour from *D. dumentorum* were relatively stable hence will have a lower tendency to undergo retrogradation during freeze/thaw cycles than flour from other varieties.

Specie, pre-treatment and drying method had a significant influence on most of the anti-nutritional and vitamin contents of the high quality yam flour. The anti-nutritional factors were significant reduced by blanching compared to sulphiting. The functional properties, proximate composition and microbial stability of HQYF were significantly affected by storage conditions and packaging materials. Samples stored in plastic containers exhibited better storage stability as the increase in their moisture content and microbial contamination was minimal when compared with HDPE and LDPE.

The adsorption isotherms of high quality water yam flour at 25, 35 and 45 ^{o}C have been presented. At lower water activity, equilibrium moisture content (EMC) increased linearly with water activity but at higher water activity levels, the moisture content increased exponentially with water activity. Peleg model was found to be the best for predicting the sorption isotherms of high quality water yam flour throughout the range of water activity studied. The monolayer moisture content decreased from 10.739 kg solid/kg water to 8.309 kg solid/kg water as temperature increased from 25 ^{o}C to 45 ^{o}C. The net isosteric heat of sorption was high at low moisture content and decreases as moisture content increases. Such analogous trend was observed for differential entropy. The plot of isosteric heat of sorption against differential entropy shows a linear relationship and the enthalpy-entropy compensation theory was satisfied.

The wide variation observed in the functional properties, proximate and anti-nutritional composition of the HQYF samples can contribute significantly to selection and improvement of the yam varieties for specific food applications to stimulate enhanced production and industrial utilization.

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Annex: Ghana

Annex G1 – Ghana – Experimental Results

Table G1: ***Physicho-chemical properties of HQYF prepared from Asana yam variety using different drying and treatment methods.***

Parameter	*Physico-Chemical Properties of HQYF produced using specified drying methods and treatment conditions*			
	Mechanical Drying		*Sun-Drying*	
	Un-Blanched	*Blanched*	*Un-Blanched*	*Blanched*
Moisture (g/100g)	6.40	9.10	12.20	12.40
Ash (g/100g)	2.12	2.21	2.00	1.89
Fat (g/100g)	0.20	0.10	0.10	0.10
Protein (g/100g)	3.76	3.92	3.55	3.46
Carbohydrate (g/100g)	87.52	84.67	84.80	82.15
Dietary Fiber	7.00	6.80	7.10	6.90
Energy (Kcal/100g)	366.90	355.30	360.10	343.30
Calcium (mg/100g)	15.60	12.80	15.70	17.20
Phosphorous (mg/100g)	41.80	59.00	47.80	41.80
Vit. C (mg/100g)	1.30	1.20	1.21	1.20

Table G2: Physicho-chemical properties of HQYF prepared from Different Yam varieties.

Parameter	Physicos-chemical properties of HQYF samples from specified yam varieties				
	Asana	***Pona***	***Lariboko***	***Afaase***	***Ponjo***
Moisture (g/100g)	8.5 ± 0.0^{c}	8.0 ± 0.1^{b}	8.4 ± 0.0^{c}	7.8 ± 0.0^{a}	9.0 ± 0.0^{d}
Ash (g/100g)	2.2 ± 0.2^{b}	2.0 ± 0.0^{a}	1.9 ± 0.0^{a}	2.8 ± 0.0^{c}	2.7 ± 0.0^{c}
Fat(g/100g)	0.2 ± 0.0^{a}	0.3 ± 0.0^{b}	0.2 ± 0.0^{b}	0.4 ± 0.0^{c}	0.3 ± 0.0^{b}
Protein (g/100g)	3.8 ± 0.0^{b}	4.4 ± 0.0^{d}	3.5 ± 0.0^{a}	3.9 ± 0.0^{c}	3.9 ± 0.0^{c}
Carbohydrate(g/100g)	87.5 ± 0.0^{e}	85.3 ± 0.0^{d}	83.1 ± 0.0^{a}	84.8 ± 0.0^{c}	83.2 ± 0.0^{b}
Dietary Fiber	7.0 ± 0.1^{ab}	6.8 ± 0.0^{ab}	6.8 ± 0.0^{ab}	7.1 ± 0.3^{b}	6.6 ± 0.0^{a}
Energy (Kcal/100g)	366.9 ± 0.0^{e}	361.7 ± 0.0^{d}	345.3 ± 0.3^{a}	359.3 ± 0.0^{c}	349.2 ± 0.0^{b}
Calcium (mg/100g)	15.6 ± 0.1^{a}	37.5 ± 0.0^{e}	33.5 ± 0.0^{d}	28.3 ± 0.00^{c}	16.3 ± 0.2^{b}
Phosphorous (mg/100g)	41.8 ± 1.0^{e}	3.0 ± 0.0^{a}	3.9 ± 0.0^{c}	3.3 ± 0.1^{b}	4.5 ± 0.2^{d}
Vit C (mg/100g)	1.3 ± 0.0^{a}	1.3 ± 0.0^{a}	1.2 ± 0.0^{a}	2.2 ± 0.1^{c}	1.8 ± 0.2^{b}

NB: Values on the same row with different superscripts are significantly different at $p<0.05$

Table G3: Viscoelastic properties of yam flour

Yam variety	Pasting Temp (°C)	Peak viscosity (BU)	Viscosity at 95°C (BU)	Viscosity at 50°C (BU)
Asana	77 ± 0.0^{b}	184 ± 0.0^{c}	183 ± 0.0^{c}	140 ± 2.0^{c}
Pona	76 ± 0.1^{a}	219 ± 2.0^{d}	219 ± 2.0^{d}	155 ± 5.0^{d}
Lariboko	79 ± 0.0^{c}	188 ± 2.0^{c}	188 ± 2.0^{c}	162 ± 2.0^{d}
Afaase	87 ± 0.2^{d}	73 ± 1.0^{a}	73 ± 1.0^{a}	76 ± 1.0^{a}
Ponjo	76 ± 0.3^{a}	177 ± 1.0^{b}	176 ± 1.0^{b}	116 ± 0.0^{b}

NB: Values on the same column with different superscripts are significantly different at $p<0.05$

Figure G1: Moisture content of HQYF from different yam varieties

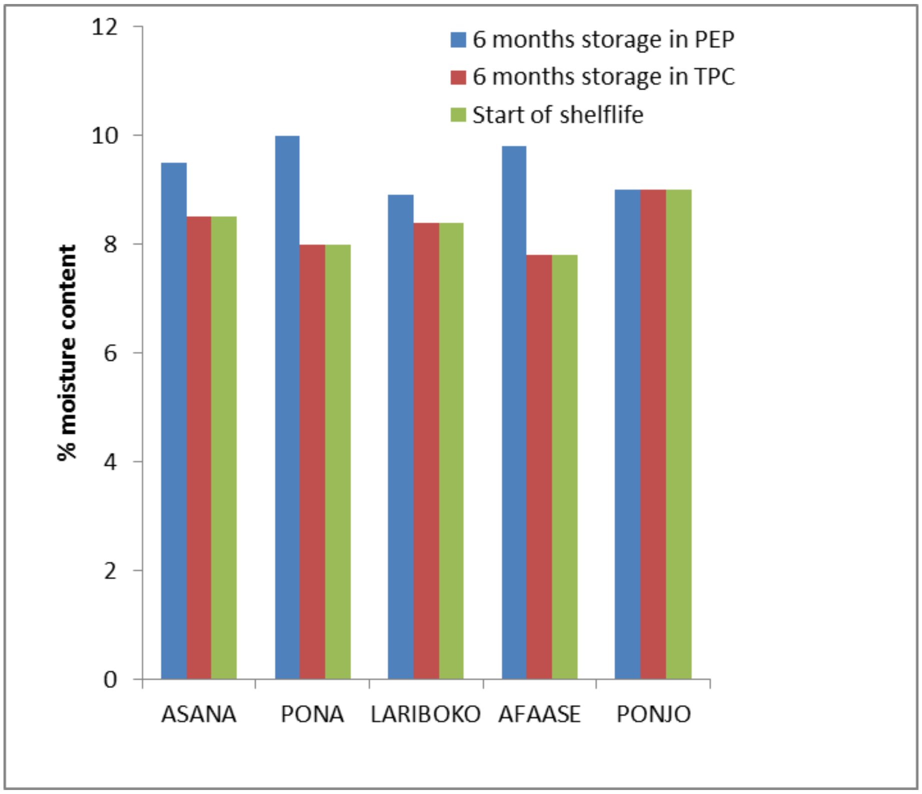

Figure G2: Ash content of HQYF from different yam varieties

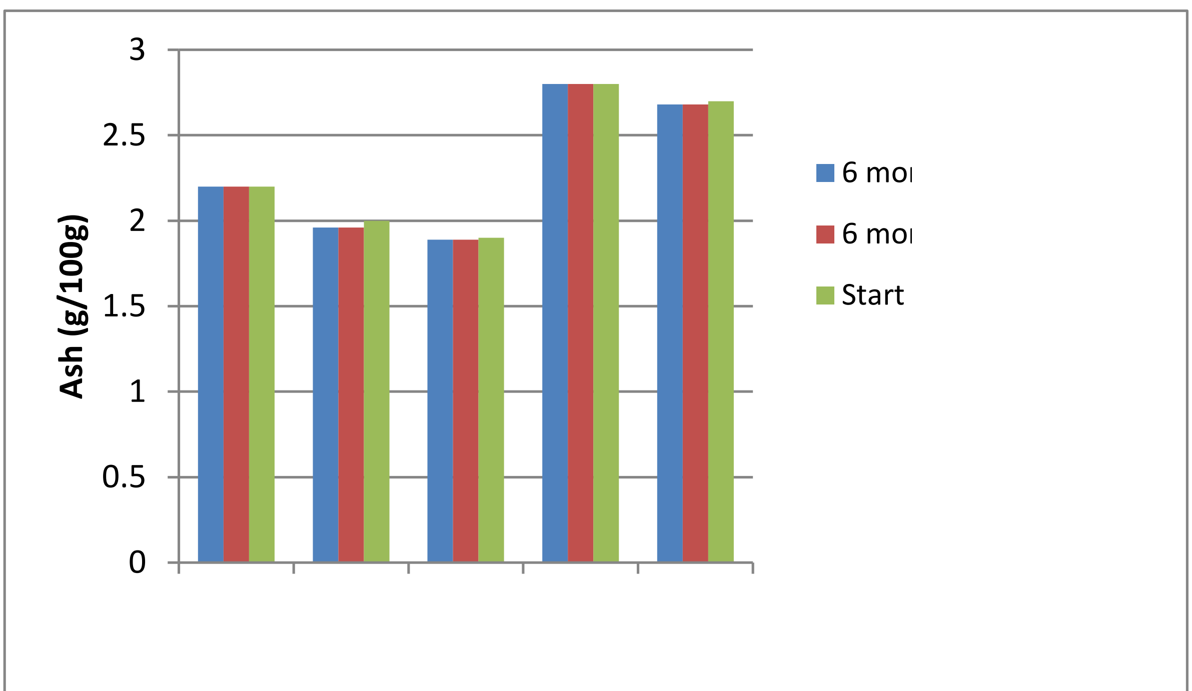

Figure G3: **Fat content of HQYF from different yam varieties**

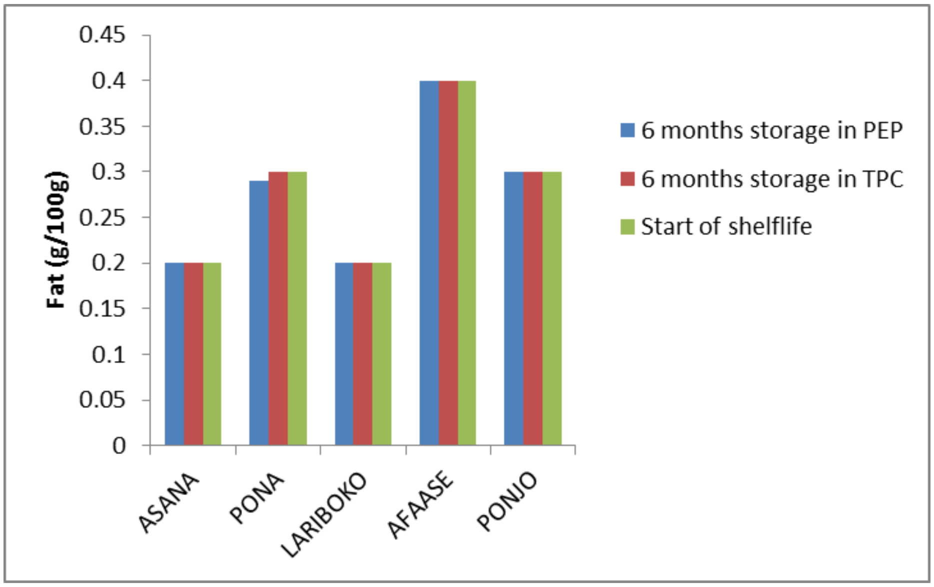

Figure G4: **Protein content of HQYF from different yam varieties**

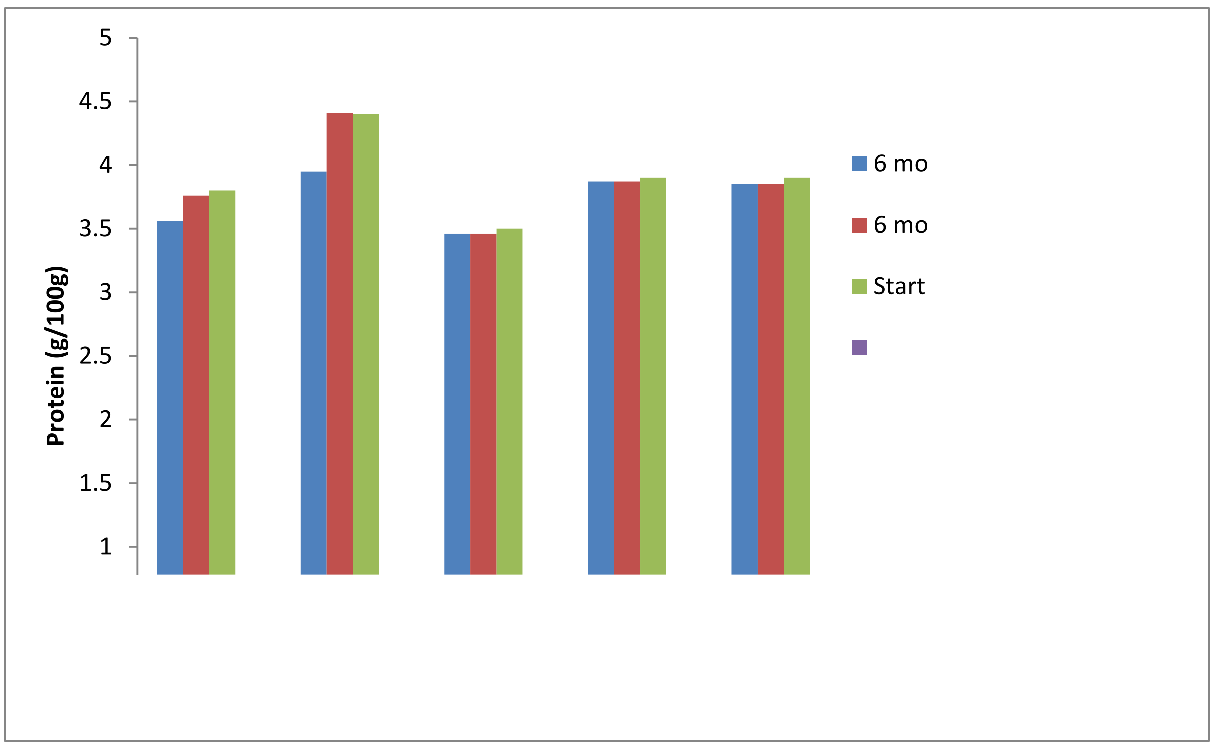

Figure G5: Calcium content of HQYF from different yam varieties

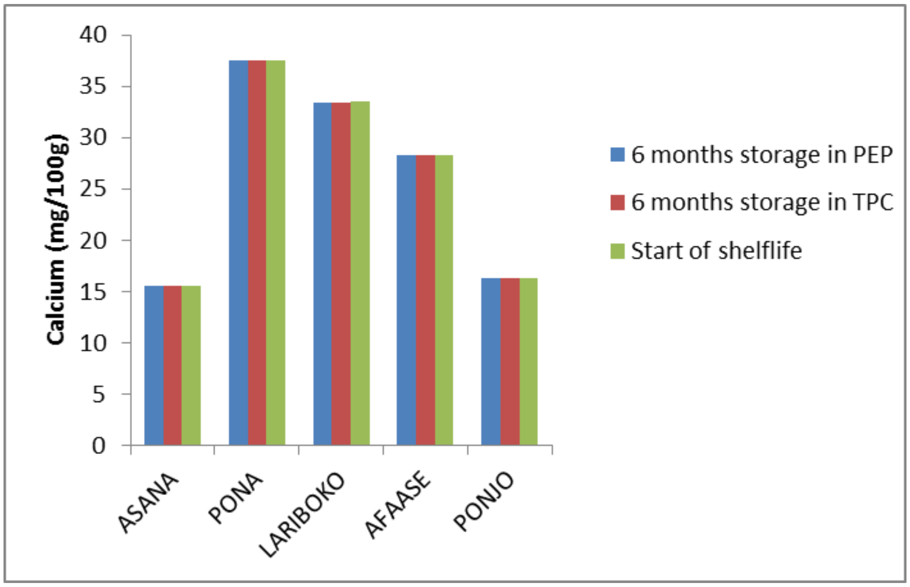

Figure G6: Phosphorus content of HQYF from different yam varieties

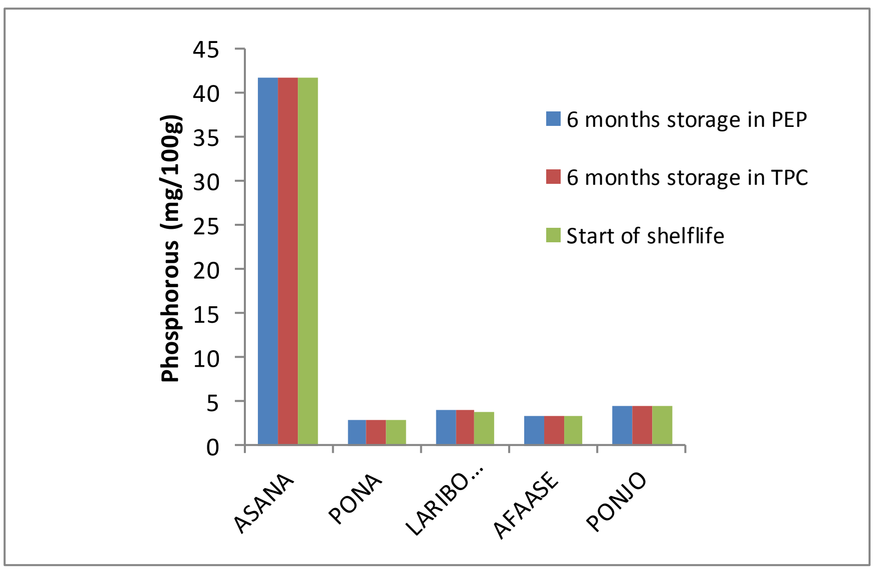

Figure G7: Vitamin C content of HQYF from different yam varieties

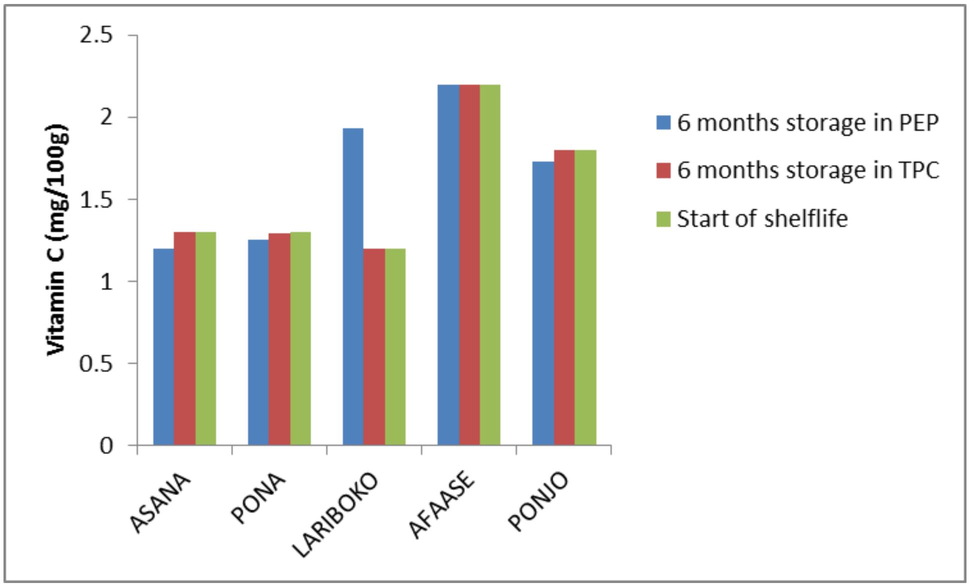

Table G4: Mean sensory scores for fufu samples produced from HQYF

Sensory Attribute	Sample					
	Asana	*Pona*	*Afaase*	*Lariboko*	*Ponjo*	*Control*
Appearance	6.87 ± 0.99	7.00 ± 1.36	6.00 ± 1.65	7.20 ± 1.37	7.73 ± 0.96	8.00 ± 1.00
Taste	6.80 ± 1.01	7.33 ± 1.05	6.60 ± 1.24	6.80 ± 0.94	7.40 ± 0.91	8.07 ± 0.80
Texture	6.93 ± 0.70	7.07 ± 0.88	4.67 ± 1.11	6.67 ± 1.23	7.53 ± 0.74	8.13 ± 0.92
Aroma	6.80 ± 1.08	7.27 ± 0.88	6.87 ± 1.25	7.00 ± 0.85	7.67 ± 0.82	7.73 ± 0.70
Mouth feel	6.73 ± 0.80	7.47 ± 1.19	6.80 ± 1.21	6.80 ± 1.15	7.53 ± 0.83	8.13 ± 0.74
Overall acceptability	**6.83 ± 0.70[b]**	**7.20 ± 0.86[c]**	**6.49 ± 1.30[a]**	**6.82 ± 1.08[b]**	**7.53 ± 0.92[d]**	**8.20 ± 0.77[e]**

NB: Values on the same row with different superscripts are significantly different at $p<0.05$

Table G5: Mean sensory scores for biscuit samples produced from HQYF

Sensory Attribute	Sample				
	Asana	*Pona*	*Afaase*	*Lariboko*	*Ponjo*
Appearance	6.47 ± 1.09	7.10 ± 1.06	5.80 ± 1.25	6.70 ± 1.03	6.73 ± 1.06
Taste	7.10 ± 1.31	7.53 ± 1.15	6.10 ± 1.20	6.20 ± 0.96	6.30 ± 0.95
Texture	6.63 ± 1.70	6.97 ± 1.08	6.67 ± 1.01	7.27 ± 0.93	6.83 ± 1.01
Aroma	6.90 ± 1.08	7.47 ± 1.28	6.77 ± 1.20	7.50 ± 1.25	7.07 ± 0.85
Mouth feel	7.43 ± 0.90	7.67 ± 1.11	6.90 ± 1.11	6.30 ± 1.05	6.53 ± 1.03
Overall acceptability	**6.98** ±1.06[a]	**7.02** ± 1.02[a]	**6.80** ± 0.95[a]	**6.85** ± 1.01[a]	**6.62** ± 0.96[a]

NB: Values on the same row with different superscripts are significantly different at $p<0.05$

Table G6: Physico-chemical properties of HQYC samples with different drying treat produced at different time-temperature interactions.

HQYF sample	Drying Temp (oC)	Drying Time (hrs)	Moisture (%)	Carbohydrates (g/100g)	Fat (g/100g)	Vitamin C (mg/100g)	Protein (g/100g)
1	55	9.0	8.34 ± 0.02[i]	85.8 ± 0.34	0.36 ± 0.02	1.55 ± 0.05	4.64 ± 0.09
2	55	8.5	8.37 ± 0.01[i]	85.5 ± 0.38	0.33 ± 0.01	1.54 ± 0.09	4.56 ± 0.09
3	55	7.5	8.69 ± 0.11[m]	86.8 ± 1.07	0.33 ± 0.02	1.48 ± 0.08	4.54 ± 0.09
4	55	7.0	9.15 ± 0.15[n]	87.3 ± 1.17	0.32 ± 0.03	1.38 ± 0.05	4.54 ± 0.26
5	55	6.5	9.81 ± 0.03[o]	86.6 ± 0.52	0.35 ± 0.03	1.51 ± 0.14	4.80 ± 0.06
6	60	9.0	8.03 ± 0.04[h]	85.9 ± 1.53	0.33 ± 0.04	1.41 ± 0.04	4.68 ± 0.02
7	60	8.5	8.20 ± 0.03[i]	86.6 ± 0.38	0.36 ± 0.03	1.47 ± 0.09	4.63 ± 0.15
8	60	7.5	8.55 ± 0.04[k]	85.9 ± 0.03	0.35 ± 0.03	1.43 ± 0.08	4.59 ± 0.05
9	60	7.0	12.73 ±0.06[r]	86.1 ± 1.24	0.32 ± 0.03	1.41 ± 0.04	4.70 ± 0.12
10	60	6.5	13.25 ±0.02[s]	86.3 ± 0.95	0.38 ± 0.02	1.40 ± 0.05	4.63 ± 0.16
11	62	8.0	6.70 ± 0.05[e]	85.6 ± 1.89	0.36 ± 0.02	1.45 ± 0.05	4.46 ± 0.23
12	62	7.5	7.10 ± 0.02[f]	86.2 ± 1.14	0.37 ± 0.02	1.45 ± 0.05	4.60 ± 0.15
13	62	7.0	7.32 ± 0.03[f]	86.6 ± 0.95	0.32 ± 0.01	1.38 ± 0.02	4.65 ± 0.18
14	62	6.5	8.42 ± 0.02[j]	86.6 ± 0.49	0.31 ± 0.01	1.38 ± 0.08	4.67 ± 0.12
15	62	6.0	10.90 ± .11[p]	85.5 ± 0.37	0.35 ± 0.02	1.40 ± 0.05	4.65 ± 0.10
16	65	8.0	6.48 ± 0.01[e]	86.7 ± 1.20	0.35 ± 0.00	1.36 ± 0.02	4.57 ± 0.03
17	65	7.5	7.48 ± 0.05[g]	86.0 ± 0.58	0.31 ± 0.01	1.34 ± 0.01	4.60 ± 0.06
18	65	7.0	7.83 ± 0.03[h]	86.0 ± 0.71	0.34 ± 0.01	1.27 ± 0.04	4.30 ± 0.21
19	65	6.5	12.11 ± .01[q]	85.0 ± 0.58	0.35 ± 0.03	1.33± 0.03	4.50 ± 0.10
20	65	6.0	12.31 ± .05[q]	86.4 ± 0.87	0.36 ± 0.02	1.30 ± 0.00	4.57 ± 0.20
21	70	6.5	4.47 ± 0.05[a]	85.9 ± 0.07	0.37 ± 0.01	1.33 ± 0.03	4.71 ± 0.15
22	70	6.0	4.85 ± 0.02[b]	86.6 ± 0.35	0.32 ± 0.01	1.28 ± 0.08	4.53 ± 0.12
23	70	5.5	5.33 ± 0.04[c]	86.4 ± 0.90	0.34 ± 0.03	1.30 ± 0.01	4.53 ± 0.19
24	70	5.0	5.96 ± 0.01[d]	85.7 ± 0.41	0.35 ± 0.05	1.37 ± 0.01	4.70 ± 0.15
25	70	4.5	5.97 ± 0.10[d]	86.3 ± 0.98	0.36 ± 0.01	1.29 ± 0.02	4.70 ± 0.26

NB: Values in the same column with different superscripts are significantly different at $p<0.05$. Values in same column with no superscripts are not significantly different from each other.

Table G7: Rheological properties of HQYC samples produced at different time-temperature interactions.

HQYF sample	Drying Temp (oC)	Drying Time (hrs)	Swelling power	Oil absorption	Pasting temp (oC)	Peak viscosity (BU)	Viscosity at 50oC (BU)
1	55	9.0	7.03 ± 0.03[abc]	1.45 ± 0.03	76.4 ± 0.33	374.5 ± 10.0	183.5 ± 16.5
2	55	8.5	6.08 ± 0.08[abc]	1.45 ± 0.01	76.7 ± 0.17	385.5 ± 9.5	194.0 ± 16.0
3	55	7.5	6.95 ± 0.03[abc]	1.48 ± 0.01	76.3 ± 0.15	395.0 ± 14.0	220.5 ± 9.5
4	55	7.0	6.97 ± 0.09[abc]	1.43 ± 0.02	76.1 ± 0.15	387.5 ± 10.5	181.0 ± 25.0
5	55	6.5	7.23 ± 0.03[bc]	1.42 ± 0.02	76.5 ± 0.18	385.0 ± 11.0	167.0 ± 11.0
6	60	9.0	6.70 ± 0.06[a]	1.51 ± 0.01	76.6 ± 0.21	409.5 ± 20.5	183.0 ± 27.0
7	60	8.5	6.70 ± 0.10[a]	1.47 ± 0.01	76.7 ± 0.18	402.5 ± 12.5	215.0 ± 15.0
8	60	7.5	6.70 ± 0.06[a]	1.45 ± 0.02	76.3 ± 0.35	424.5 ± 25.5	236.0 ± 20.0
9	60	7.0	7.17 ± 0.03[abc]	1.45 ± 0.01	76.6 ± 0.12	384.0 ± 16.0	207.0 ± 11.0
10	60	6.5	7.00 ± 0.06[abc]	1.45 ± 0.01	76.6 ± 0.34	382.0 ± 14.0	168.0 ± 21.0
11	62	8.0	7.03 ± 0.03[abc]	1.45 ± 0.01	76.6 ± 0.07	396.5 ± 18.5	231.0 ± 17.0
12	62	7.5	7.03 ± 0.07[abc]	1.46 ± 0.03	76.7 ± 0.24	385.5 ± 4.5	203.5 ± 6.5
13	62	7.0	7.07 ± 0.09[abc]	1.47 ± 0.02	76.3 ± 0.27	387.0 ± 1.0	225.0 ± 3.0
14	62	6.5	6.70 ± 0.06[a]	1.42 ± 0.03	76.6 ± 0.12	381.0 ± 3.0	204.0 ± 6.0
15	62	6.0	7.00 ± 0.31[abc]	1.44 ± 0.01	75.7 ± 0.33	447.5 ± 44.5	235.0 ± 10.0
16	65	8.0	6.77 ± 0.09[ab]	1.46 ± 0.02	76.5 ± 0.18	383.0 ± 19.0	210.0 ± 11.0
17	65	7.5	7.07 ± 0.09[abc]	1.46 ± 0.02	76.7 ± 0.18	381.5 ± 8.5	206.5 ± 6.5
18	65	7.0	7.27 ± 0.03[c]	1.43 ± 0.02	76.5 ± 0.29	397.5 ± 10.5	222.0 ± 12.0
19	65	6.5	7.17 ± 0.03[abc]	1.45 ± 0.02	76.6 ± 0.10	403.5 ± 8.5	230.5 ± 20.0
20	65	6.0	7.17 ± 0.03[abc]	1.45 ± 0.03	76.4 ± 0.26	380.5 ± 4.5	244.0 ± 34.0
21	70	6.5	6.80 ± 0.10[ab]	1.45 ± 0.031	76.8 ± 0.42	392.5 ± 5.5	233.0 ± 3.0
22	70	6.0	6.78 ± 0.09[ab]	1.41 ± 0.02	76.1 ± 0.07	376.5 ± 13.5	226.5 ± 8.5
23	70	5.5	6.70 ± 0.12[a]	1.47 ± 0.03	76.6 ± 0.31	380.0 ± 9.0	224.0 ± 6.0
24	70	5.0	6.93 ± 0.03[abc]	1.42 ± 0.02	76.1 ± 0.19	377.0 ± 10.0	234.5 ± 15.5
25	70	4.5	7.13 ± 0.03[abc]	1.42 ± 0.03	76.3 ± 0.17	391.0 ± 5.0	254.5 ± 15.5

NB: Values in the same column with different superscripts are significantly different at $p<0.05$. Values in same column with no superscripts are not significantly different from each other.

Annex N – Nigeria

Annex N1 – Nigeria Experimental Results (Tables and Figure)

Table N1: Effect of specie, pre-treatment and drying method on the Functional properties of HQYF samples

Variety	Pretreatment	Drying	Dispersibility (%)	Bulk density (g/cm^3)	Water Absorption Index	Foaming Capacity	Wettability (
Rotundata	Blanching	Cabinet	72.17	0.88	2.02	19.93	185.33
		Sun	69.17	0.86	2.28	20.20	75.67
	Potassium	Cabinet	70.50	0.83	1.90	23.66	210.67
		Sun	68.17	0.88	2.40	22.86	104.67
Dumentorum	Blanching	Cabinet	51.17	0.73	2.14	13.13	190.00
		Sun	51.83	0.72	2.26	13.53	185.00
	Potassium	Cabinet	27.83	0.77	2.86	12.78	211.00
		Sun	28.50	0.70	2.63	10.98	190.00
Alata	Blanching	Cabinet	62.83	0.88	2.32	5.05	140.00
		Sun	65.67	0.91	2.49	6.79	151.33
	Potassium	Cabinet	57.67	0.91	1.95	12.90	138.33
		Sun	65.50	0.86	2.59	9.88	134.00
Cayenesis	Blanching	Cabinet	52.83	0.91	2.59	13.33	125.67
		Sun	61.00	0.91	2.55	9.81	58.67
	Potassium	Cabinet	67.50	0.81	2.19	28.72	142.33
		Sun	69.17	0.86	2.12	31.11	124.67
			62.83-69.17	0.70-0.91	1.90-2.86	5.05-31.11	58.67-211.0
Range			58.84	.84	2.33	15.92	147.96
Mean			13.73	.07	.27	7.64	45.25
SD			23.33	8.66	11.70	48.01	30.58
CV			3.43	0.02	0.07	1.91	11.31
SE			*	*	*	*	*
p of variety			*	***	Ns	*	*
p of pretreatment			*	Ns	*	ns	*
p of drying method			*	***	*	*	*
p of variety x pretreatment			*	Ns	*	ns	*
p of variety x drying method			Ns	Ns	***	ns	*
p of pretreatment x drying method							
p of variety x pretreatment x drying method			*	***	*	*	*

*, *** significant at $p<0.01$ and $p<0.05$ respectively, ns not significant at $p>0.05$.

Table N2: Effect of specie, pre-treatment and drying method on the Functional properties of HQYF samples

Variety	Pretreatment	Drying	Emulsification	Oil Absorption Capacity	Angle of Repose (deg)	Least Gelation (%w/v)
Rotundata	Blanching	Cabinet	60.45	7.72	44.17	3.00
		Sun	64.61	7.71	42.53	5.00
	Potassium	Cabinet	61.49	7.79	43.34	5.00
		Sun	66.70	7.78	40.83	4.00
Dumentorum	Blanching	Cabinet	60.41	7.63	47.34	2.00
		Sun	57.29	7.62	47.07	2.00
	Potassium	Cabinet	59.25	7.76	47.41	3.00
		Sun	62.23	7.58	45.24	2.00
Alata	Blanching	Cabinet	57.07	7.73	41.62	3.00
		Sun	58.33	7.81	43.57	4.00
	Potassium	Cabinet	56.51	7.96	42.93	3.00
		Sun	59.23	7.81	48.14	4.00
Cayenesis	Blanching	Cabinet	57.64	7.69	40.90	4.00
		Sun	57.07	7.96	42.57	4.00
	Potassium	Cabinet	55.83	7.66	43.66	5.00
		Sun	58.53	7.53	42.08	4.00
		Range	55.83-66.70	7.53-7.96	40.83-48.14	2.00-5.00
		Mean	59.54	7.73	43.96	3.56
		SD	3.01	.12	2.39	1.03
		CV	5.06	1.55	5.45	28.93
		SE	0.75	0.03	0.60	0.26
		p of variety	*	*	*	***
		p of pretreatment	Ns	ns	Ns	Ns
		p of drying method	***	ns	Ns	Ns
		p of variety x pretreatment	Ns	*	Ns	Ns
		p of variety x drying method	Ns	*	***	Ns
		p of pretreatment x drying method	Ns	*	Ns	Ns
		p of variety x pretreatment x drying method	Ns	*	Ns	Ns

*, *** significant at p<0.01 and p<0.05 respectively, ns not significant at p>0.05.

Table N3. Effect of specie, pre-treatment and drying method on the Pasting Properties of HQYF samples

Variety	Pretreatment	Drying	Peak (RVU)	Trough (RVU)	Breakdown (RVU)	Final Viscosity (RVU)	Setback (RVU)	Peak Time (min)	Pasting Temperature (ºC)
Rotundata	Blanching	Cabinet	430.14	211.06	219.08	427.72	216.67	4.7	80.9
		Sun	462.03	183.11	278.92	329.31	146.19	4.8	81.0
	Potassium	Cabinet	506.81	149.47	357.33	359.97	210.50	4.6	70.1
		Sun	428.97	164.61	264.36	347.64	183.03	4.9	79.5
Dumentorum	Blanching	Cabinet	267.14	139.25	127.89	200.58	61.33	4.7	86.5
		Sun	371.06	226.78	144.28	339.25	112.47	4.7	85.4
	Potassium	Cabinet	181.83	100.39	81.44	157.11	56.72	4.9	88.4
		Sun	186.75	94.44	92.31	160.33	65.89	4.9	87.6
Alata	Blanching	Cabinet	491.14	404.86	86.28	588.67	183.81	5.0	82.0
		Sun	491.64	309.97	181.67	600.28	290.31	4.7	81.6
	Potassium	Cabinet	434.17	344.31	89.86	582.92	238.61	5.5	81.8
		Sun	496.08	285.19	210.89	606.64	321.44	4.8	80.8
Cayenesis	Blanching	Cabinet	303.61	264.11	39.50	427.69	163.58	5.6	71.1
		Sun	455.14	397.50	57.64	649.58	252.08	5.8	69.9
	Potassium	Cabinet	440.75	209.92	230.83	378.89	168.97	4.9	70.3
		Sun	421.75	198.75	223.00	281.50	82.75	4.6	71.4
		Range	181.83-506.81	94.44-404.86	39.50-357.33	157.11-649.58	56.72-321.44	4.6-5.8	69.9-88.4
		Mean	398.1	230.2	167.8	402.4	172.1	4.9	79.3
		SD	106.5	96.8	91.6	163.2	81.6	.4	6.6
		CV	26.7	42.0	54.6	40.5	47.4	7.1	8.3
		SE	26.6	24.2	22.9	40.8	20.4	0.1	1.6
		p of variety	*	*	*	*	*	*	*
		p of pretreatment	Ns	*	*	*	ns	ns	Ns
		p of drying method	***	Ns	ns	Ns	ns	ns	Ns
		p of variety x pretreatment	*	Ns	*	***	ns	*	Ns
		p of variety x drying method	Ns	***	ns	Ns	ns	***	Ns
		p of pretreatment x drying method	*	Ns	ns	Ns	ns	ns	Ns

	p of variety x pretreatment x drying method	***	Ns	ns	***	ns	ns	Ns

*, *** significant at p<0.01 and p<0.05 respectively, ns not significant at p>0.05.

Table N4: Antinutritional composition of HQYF samples as affected by specie, pre-treatment and drying method

Variety	Pretreatment	Drying	Phenol (mg/100g)	Tannin (mg/100g)	Phytate (mg/100g)	Saponin (mg/100g)	Alk (g/
Rotundata	Blanching	Cabinet	232.60	152.10	19.31	2.89	0
		Sun	180.10	132.80	19.17	3.62	0
	Potassium	Cabinet	472.95	122.45	31.64	5.95	0
		Sun	426.45	200.15	13.43	3.44	0
Dumentorum	Blanching	Cabinet	573.75	220.90	66.62	6.14	0
		Sun	817.30	410.00	74.07	12.43	1
	Potassium	Cabinet	979.45	213.90	72.79	13.01	1
		Sun	873.65	440.30	61.92	9.36	1
Alata	Blanching	Cabinet	209.95	132.00	79.21	3.57	0
		Sun	164.45	142.65	37.53	3.75	0
	Potassium	Cabinet	574.20	242.45	33.31	3.41	1
		Sun	553.95	230.15	38.28	2.16	1
Cayenesis	Blanching	Cabinet	226.85	185.80	28.51	5.75	0
		Sun	513.60	149.60	51.36	3.65	0
	Potassium	Cabinet	258.95	198.90	14.69	4.00	0
		Sun	421.80	218.30	15.50	1.61	0
Range			164.45-979.45	122.45-440.30	13.43-79.21	1.61-13.01	0.21
Mean			467.50	212.03	41.08	5.29	0
SD			255.97	91.90	23.29	3.44	0
CV			54.75	43.34	56.69	64.90	4
SE			63.99	22.98	5.82	0.86	0
p of variety			*	*	*	*	
p of pretreatment			*	*	*	Ns	
p of drying method			*	*	*	*	
p of variety x pretreatment			*	*	*	*	
p of variety x drying method			*	*	*	*	
p of pretreatment x drying method			*	*	***	*	
p of variety x pretreatment x drying method			*	*	*	*	

*, *** significant at p<0.01 and p<0.05 respectively, ns not significant at p>0.05.

Table N5: Vitamin contents of HQYF samples (mg/100g) as affected by specie, pre-treatment and drying method

Variety	Pretreatment	Drying	Vitamin B_1	Vitamin B_2	Vitamin B_6	Vitamin C
Rotundata	Blanching	Cabinet	0.29	1.39	2.27	29.05
		Sun	0.29	4.55	3.56	26.98
	Potassium	Cabinet	0.36	1.16	2.08	25.77
		Sun	0.18	0.97	2.00	27.09
Dumentorum	Blanching	Cabinet	0.93	1.20	3.36	23.99
		Sun	0.37	1.06	4.34	22.17
	Potassium	Cabinet	1.05	0.46	3.95	21.82
		Sun	0.95	3.48	3.70	23.23
Alata	Blanching	Cabinet	0.47	1.39	2.36	25.16
		Sun	0.57	0.44	2.92	20.87
	Potassium	Cabinet	0.36	1.19	2.73	24.10
		Sun	0.39	1.75	2.40	21.41
Cayenesis	Blanching	Cabinet	0.31	2.36	2.09	23.00
		Sun	0.60	1.77	2.03	30.91
	Potassium	Cabinet	0.41	3.52	2.96	28.83
		Sun	0.37	2.57	2.44	24.60
Range			0.18-1.05	0.44-4.55	2.00-4.34	20.87-30.91
Mean			.49	1.83	2.82	24.93
SD			0.25	1.13	0.73	2.87
CV			51.51	62.14	25.72	11.52
SE			0.06	0.28	0.18	0.72
p of variety			*	*	*	*
p of pretreatment			***	ns	Ns	***
p of drying method			*	*	*	ns
p of variety x pretreatment			*	*	*	ns
p of variety x drying method			*	*	*	*
p of pretreatment x drying method			ns	ns	*	ns
p of variety x pretreatment x drying method			*	*	***	*

*, *** significant at $p<0.01$ and $p<0.05$ respectively, ns not significant at $p>0.05$.

Table N6: effect of storage conditions and packaging materials on the functional properties of high quality water yam flour

Storage Time	Temperature	Relative Humidity	Packaging Material	WAI	WBC(%)	OAC	BD (g/ml)	WET (sec)
0	Zero Week	Zero week	Zero week	2.24	128.00	0.53	0.80	63.50
4	25	36%	Plastic	1.67	72.15	0.43	0.78	62.16
			HDPE	1.71	83.45	0.42	0.77	57.30
			LDPE	1.73	82.38	0.39	0.77	69.12
		56%	Plastic	1.58	72.15	0.41	0.77	62.64
			HDPE	1.70	71.91	0.40	0.76	53.67
			LDPE	1.70	74.41	0.43	0.76	65.06
		75%	Plastic	1.66	73.33	0.42	0.77	67.72
			HDPE	1.82	74.17	0.44	0.75	61.85
			LDPE	1.66	79.17	0.38	0.75	71.85
		96%	Plastic	1.68	96.55	0.38	0.76	67.16
			HDPE	1.73	92.71	0.39	0.75	65.06
			LDPE	1.76	87.38	0.35	0.75	67.65
	35	36%	Plastic	1.70	89.17	0.40	0.76	66.98
			HDPE	1.78	83.57	0.39	0.75	62.22
			LDPE	1.74	81.07	0.36	0.74	73.99
		56%	Plastic	1.72	82.15	0.39	0.75	67.56
			HDPE	1.78	80.48	0.37	0.73	58.54
			LDPE	1.79	73.22	0.40	0.73	69.98
		75%	Plastic	1.82	80.84	0.40	0.74	72.54
			HDPE	1.78	75.24	0.42	0.73	66.54
			LDPE	1.84	70.48	0.35	0.72	76.52
		96%	Plastic	1.84	85.48	0.36	0.74	71.96
			HDPE	1.75	74.88	0.37	0.72	69.98
			LDPE	1.73	82.27	0.32	0.72	72.57
	45	36%	Plastic	1.78	68.22	0.39	0.75	68.95
			HDPE	1.84	73.81	0.38	0.72	64.19
			LDPE	1.78	79.17	0.35	0.72	75.91
		56%	Plastic	1.78	72.38	0.37	0.72	69.48
			HDPE	1.82	74.29	0.36	0.71	60.56
			LDPE	1.86	75.36	0.38	0.71	72.05
		75%	Plastic	1.77	62.03	0.38	0.72	74.47
			HDPE	1.75	75.72	0.40	0.70	68.40
			LDPE	1.74	74.05	0.34	0.70	78.80
		96%	Plastic	1.69	72.86	0.34	0.72	74.26
			HDPE	1.90	69.53	0.36	0.70	72.01
			LDPE	1.67	66.79	0.31	0.70	74.54
8	25	36%	Plastic	1.60	69.55	0.33	0.75	63.91
			HDPE	1.58	68.42	0.32	0.74	59.05
			LDPE	1.56	68.13	0.29	0.73	70.87
		56%	Plastic	1.55	69.22	0.32	0.74	64.34
			HDPE	1.54	68.15	0.30	0.72	55.40
			LDPE	1.54	67.47	0.33	0.72	66.81
		75%	Plastic	1.53	68.62	0.33	0.73	69.43
			HDPE	1.52	67.46	0.35	0.72	63.56
			LDPE	1.51	67.02	0.28	0.71	73.46
		96%	Plastic	1.51	68.33	0.29	0.73	68.72
			HDPE	1.50	67.42	0.30	0.71	66.57
			LDPE	1.48	66.90	0.25	0.71	69.30
	35	36%	Plastic	1.58	69.52	0.31	0.74	67.58
			HDPE	1.56	68.39	0.30	0.73	62.72
			LDPE	1.54	68.10	0.28	0.73	74.54
		56%	Plastic	1.53	69.19	0.30	0.73	68.06
			HDPE	1.52	68.12	0.29	0.72	59.06

			LDPE	1.52	67.44	0.31	0.72	70.53
		75%	Plastic	1.51	68.59	0.31	0.73	73.05
			HDPE	1.50	67.48	0.33	0.71	67.08
			LDPE	1.50	66.99	0.26	0.71	76.98
		96%	Plastic	1.49	68.30	0.27	0.72	72.49
			HDPE	1.48	67.39	0.28	0.71	70.49
			LDPE	1.46	66.87	0.23	0.71	73.02
	45	36%	Plastic	1.57	68.05	0.37	0.72	70.00
			HDPE	1.54	68.84	0.36	0.71	65.29
			LDPE	1.53	67.87	0.33	0.70	76.96
		56%	Plastic	1.52	68.75	0.35	0.71	70.53
			HDPE	1.51	67.84	0.34	0.70	61.56
			LDPE	1.51	67.00	0.36	0.69	73.05
		75%	Plastic	1.49	68.34	0.36	0.70	75.52
			HDPE	1.49	67.11	0.38	0.69	69.55
			LDPE	1.48	66.77	0.32	0.69	79.65
		96%	Plastic	1.47	68.00	0.32	0.70	75.26
			HDPE	1.47	66.95	0.33	0.68	73.01
			LDPE	1.44	66.66	0.29	0.69	75.54
12	25	36%	Plastic	1.57	69.53	0.22	0.73	65.03
			HDPE	1.55	68.40	0.18	0.72	60.37
			LDPE	1.53	68.11	0.18	0.71	72.05
		56%	Plastic	1.52	69.20	0.21	0.72	65.56
			HDPE	1.51	68.13	0.19	0.71	56.48
			LDPE	1.51	67.45	0.21	0.71	67.93
		75%	Plastic	1.50	68.60	0.21	0.72	70.55
			HDPE	1.49	67.44	0.23	0.70	64.88
			LDPE	1.48	67.00	0.17	0.70	74.78
		96%	Plastic	1.48	68.31	0.17	0.71	70.04
			HDPE	1.47	67.40	0.18	0.70	68.00
			LDPE	1.45	66.88	0.13	0.70	70.52
	35	36%	Plastic	1.56	69.50	0.21	0.73	68.52
			HDPE	1.53	68.37	0.24	0.72	63.56
			LDPE	1.52	68.08	0.24	0.71	75.48
		56%	Plastic	1.51	69.18	0.17	0.72	68.95
			HDPE	1.50	69.01	0.21	0.70	59.98
			LDPE	1.50	67.42	0.25	0.70	71.42
		75%	Plastic	1.48	68.58	0.26	0.71	74.03
			HDPE	1.48	67.41	0.19	0.70	68.06
			LDPE	1.47	66.97	0.20	0.69	78.36
		96%	Plastic	1.46	68.29	0.26	0.71	73.67
			HDPE	1.46	67.37	0.22	0.69	71.37
			LDPE	1.43	66.85	0.22	0.69	74.16
	45	36%	Plastic	1.54	67.99	0.19	0.71	70.82
			HDPE	1.51	68.78	0.25	0.69	65.96
			LDPE	1.50	67.81	0.23	0.69	77.83
		56%	Plastic	1.49	68.69	0.14	0.70	71.30
			HDPE	1.48	67.78	0.24	0.68	62.33
			LDPE	1.48	66.94	0.21	0.68	73.72
		75%	Plastic	1.46	68.28	0.25	0.69	76.39
			HDPE	1.46	67.05	0.22	0.68	70.52
			LDPE	1.45	66.71	0.17	0.68	80.37
		96%	Plastic	1.45	67.94	0.20	0.69	75.78
			HDPE	1.44	66.89	0.18	0.67	73.73
			LDPE	1.41	66.60	0.27	0.67	76.31
Range				1.41-2.24	62.03-128.00	0.13-0.53	0.67-.80	53.67-80.37
Mean				1.59	71.57	0.30	0.72	69.17
SD				0.14	8.19	0.08	0.03	5.63
P of ST				*	*	*	*	*Ns*

P of Temp	*Ns*	*	*ns*	*	*
P of RH	*	*	*	*	*Ns*
P of Pkg Mat	*Ns*	*ns*	*	*	*
P of STxT	*	*	*	*	*Ns*
P of StxRH	*Ns*	*	*ns*	*ns*	*Ns*
P of STxP	*Ns*	*ns*	*ns*	*ns*	*Ns*
P of TxRH	*Ns*	*	*ns*	*ns*	*Ns*
P of TxP	*Ns*	*ns*	*ns*	*ns*	*Ns*
P of RHxP	*Ns*	*ns*	*	*ns*	*Ns*
P of STxTxRH	*Ns*	*	*ns*	*ns*	*Ns*
P of STxTxP	*Ns*	*ns*	*ns*	*ns*	*Ns*
P of STXRHXP	*Ns*	*ns*	*ns*	*ns*	*Ns*
P of TxPxRH	*Ns*	*ns*	*ns*	*ns*	*Ns*
P of STxTxRHxP	*Ns*	*ns*	*ns*	*ns*	*Ns*

Values are mean of three replicates

**significant (P<0.01)*; *ns not significant (P>0.01)*

WAI- water absorption index; WBC-water binding capacity; OAC-oil absorption capacity; BD-Bulk density; WET-wettability

Table N7: effect of storage conditions and packaging materials on proximate composition of high quality water yam flour

Storage time	Temp	RH	Pkg Mat	Moisture Content %	Protein %	Fat %	Ash%
0	zero week	zero week	zero week	8.30	5.47	1.28	1.48
4	25	36	Plastic	9.45	5.02	0.65	1.27
			HDPE	9.58	5.46	1.10	1.24
			LDPE	10.01	4.74	0.27	1.26
		56	Plastic	9.50	4.66	0.41	1.25
			HDPE	9.72	5.25	0.13	1.28
			LDPE	10.23	4.68	0.33	1.29
		75	Plastic	9.67	4.92	0.31	1.27
			HDPE	9.80	4.53	0.07	1.24
			LDPE	10.41	4.81	1.20	1.31
		96	Plastic	9.71	5.77	1.05	1.24
			HDPE	9.82	4.68	0.98	1.26
			LDPE	10.40	5.15	1.22	1.30
	35	36	Plastic	9.46	4.76	0.37	1.27
			HDPE	9.60	4.59	0.65	1.22
			LDPE	10.04	4.38	0.03	1.24
		56	Plastic	9.57	5.16	1.83	1.29
			HDPE	9.79	5.29	0.25	1.25
			LDPE	10.50	4.97	1.41	1.19
		75	Plastic	9.71	4.60	1.10	1.20
			HDPE	9.86	4.94	1.26	1.23
			LDPE	10.63	5.03	0.37	1.28
		96	Plastic	9.78	4.63	0.27	1.27
			HDPE	9.90	4.95	0.84	1.23
			LDPE	10.77	4.48	0.81	1.22
	45	36	Plastic	9.62	4.58	0.96	1.20
			HDPE	9.69	5.53	0.02	1.27
			LDPE	9.72	4.25	0.51	1.26
		56	Plastic	9.89	5.29	0.93	1.22
			HDPE	9.96	4.47	3.88	1.19
			LDPE	10.59	5.06	0.62	1.24
		75	Plastic	9.79	5.30	0.96	1.20
			HDPE	9.88	4.58	0.93	1.21
			LDPE	10.68	5.11	0.88	1.17
		96	Plastic	9.81	4.80	0.65	1.20
			HDPE	9.90	5.14	1.31	1.23
			LDPE	11.10	5.07	0.97	1.27
8	25	36	Plastic	9.78	5.00	1.11	1.21
			HDPE	10.01	4.82	1.15	1.24
			LDPE	10.18	4.50	1.13	1.19
		56	Plastic	9.91	4.85	0.95	1.19
			HDPE	10.35	4.71	0.73	1.24
			LDPE	10.41	4.89	1.57	1.22
		75	Plastic	9.99	4.75	0.79	1.17
			HDPE	10.08	4.66	0.67	1.20
			LDPE	10.31	5.05	1.40	1.24
		96	Plastic	10.09	5.19	0.36	1.18
			HDPE	10.12	5.03	0.82	1.17
			LDPE	10.38	4.66	0.40	1.20
	35	36	Plastic	9.88	5.04	1.05	1.21
			HDPE	9.95	4.99	1.97	1.18
			LDPE	10.46	4.95	1.63	1.16
		56	Plastic	9.82	4.75	2.30	1.18
			HDPE	10.02	5.07	3.13	1.16
			LDPE	10.38	5.13	0.26	1.24
		75	Plastic	9.85	5.21	0.12	1.18
			HDPE	10.51	4.99	2.23	1.16
			LDPE	10.88	5.16	2.11	1.19
		96	Plastic	9.89	5.35	1.07	1.17
			HDPE	10.41	5.01	1.77	1.25
			LDPE	10.67	5.12	2.22	1.19
	45	36	Plastic	9.91	5.12	3.42	1.21
			HDPE	9.97	5.48	0.93	1.23
			LDPE	9.98	5.26	2.65	1.19
		56	Plastic	9.90	5.24	4.19	1.17
			HDPE	9.99	5.11	1.01	1.15
			LDPE	10.61	5.20	2.78	1.16
		75	Plastic	9.95	5.65	4.71	1.17
			HDPE	10.08	5.39	3.38	1.18
			LDPE	10.42	5.34	1.52	1.14
		96	Plastic	10.85	5.49	0.96	1.17
			HDPE	11.02	5.32	1.62	1.20
			LDPE	12.79	5.52	1.02	1.18
12	25	36	Plastic	10.09	4.47	2.49	1.19
			HDPE	10.13	4.47	1.66	1.22
			LDPE	10.23	4.61	2.15	1.17
		56	Plastic	10.41	4.45	4.44	1.17
			HDPE	10.47	4.41	5.58	1.22
			LDPE	10.91	4.44	1.53	1.20
		75	Plastic	10.66	4.46	2.59	1.15
			HDPE	10.95	4.39	2.67	1.18
			LDPE	11.06	4.39	2.40	1.22
		96	Plastic	10.77	4.56	2.25	1.16
			HDPE	11.03	4.45	2.75	1.15
			LDPE	12.01	4.39	1.12	1.18
	35	36	Plastic	10.89	4.66	2.17	1.19
			HDPE	11.04	4.63	2.34	1.16

		LDPE	12.84	4.67	1.89	1.14
	56	Plastic	10.96	4.68	3.10	1.16
		HDPE	11.18	4.62	1.28	1.14
		LDPE	13.07	4.54	1.56	1.22
	75	Plastic	10.97	4.50	1.41	1.16
		HDPE	11.28	4.47	3.73	1.14
		LDPE	14.21	4.60	2.58	1.17
	96	Plastic	11.02	4.76	1.65	1.15
		HDPE	12.79	4.64	3.20	1.23
		LDPE	14.69	4.64	2.38	1.17
45	36	Plastic	10.89	4.81	3.41	1.19
		HDPE	12.74	4.67	2.47	1.21
		LDPE	15.18	4.56	2.82	1.17
	56	Plastic	11.07	4.53	3.52	1.15
		HDPE	12.80	4.63	1.39	1.13
		LDPE	15.28	4.55	1.42	1.14
	75	Plastic	11.13	4.48	0.85	1.15
		HDPE	12.90	4.49	2.37	1.16
		LDPE	15.36	4.56	2.20	1.12
	96	Plastic	11.29	4.58	3.60	1.15
		HDPE	13.34	4.45	1.89	1.18
		LDPE	16.59	4.26	1.37	1.16
Range			8.30-16.59	4.25-5.77	0.02-5.58	1.12-1.48
Mean			10.67	4.85	1.62	1.20
SD			1.29	0.35	1.13	0.05
P of ST			*	*	*	*
P of Temp			*	*	*	*
P of RH			*	*	*	*
P of Pkg			*	*	*	*
P of STxT			*	*	*	*ns*
P of			*	*	*	*ns*
P of STxP			*	*	*	*
P of TxRH			*	*	*	*
P of TxP			*	*	*	*
P of RHxP			*	*	*	*
P of			*	*	*	*
P of			*	*	*	*
P of STXRHXP			*Ns*	*	*	*
P of			*	*	*	*
P of STxTxRHxP			*Ns*	*	*	*

Values are mean of three replicates

**significant (P<0.01)*; *ns not significant (P>0.01)*

Table N8: effect of storage conditions and packaging materials on the pasting properties of high quality water yam flour

Storage Time	Temperature	Relative Humidity	Packaging Material	Peak Viscosity (RVU)	Trough Viscosity (RVU)	Breakdown Viscosity (RVU)	Final Viscosity (RVU)	Setback Viscosity (RVU)	Peak time (Min)	Pasting Temperature (ºC)
0	Zero Week	Zero Week	Zero Week	429.42	328.00	101.42	488.92	160.92	5.14	81.95
4	25	36	Plastic	281.29	230.42	69.58	284.16	71.53	5.32	82.28
			HDPE	285.21	238.75	71.58	290.08	69.12	5.26	83.08
			LDPE	287.29	243.67	69.25	296.08	70.20	5.26	82.18
		56	Plastic	261.38	220.58	67.42	262.41	59.62	5.25	82.23
			HDPE	279.38	241.78	62.67	290.16	66.12	5.12	82.23
			LDPE	270.21	226.50	73.83	277.58	68.87	5.27	82.18
		75	Plastic	277.63	241.67	66.08	286.74	62.87	5.19	82.18
			HDPE	243.88	211.25	62.76	252.41	58.95	5.26	83.13
			LDPE	225.63	198.50	57.24	235.41	54.70	5.25	82.98
		96	Plastic	242.79	699.67	68.25	251.33	69.45	5.19	82.23
			HDPE	222.21	189.83	62.50	234.49	62.45	5.32	83.08
			LDPE	200.54	179.17	46.50	223.99	62.62	5.46	82.33
	35	36	Plastic	262.13	162.10	53.00	236.91	59.45	5.19	82.33
			HDPE	271.63	191.00	58.75	274.16	67.95	5.12	82.28
			LDPE	266.63	176.93	67.83	268.41	76.28	5.19	83.08
		56	Plastic	245.54	162.50	61.19	253.58	75.87	5.12	83.03
			HDPE	207.92	153.88	32.42	221.33	52.20	5.19	83.08
			LDPE	175.58	123.50	30.50	191.24	52.53	5.32	82.28
		75	Plastic	175.33	121.58	32.17	174.65	51.12	5.32	82.18
			HDPE	201.58	148.33	31.67	201.57	51.28	5.12	83.08
			LDPE	237.25	163.50	52.26	230.40	64.95	5.19	83.03
		96	Plastic	197.42	136.42	39.42	199.58	61.20	5.33	83.98
			HDPE	159.17	118.58	22.50	171.23	50.70	5.32	81.48
			LDPE	154.13	112.17	33.92	276.98	44.08	5.12	83.13
	45	36	Plastic	303.00	201.67	79.75	287.40	77.08	5.06	82.23
			HDPE	299.17	221.83	55.75	297.15	66.67	5.07	81.38
			LDPE	277.25	195.83	59.83	268.65	64.17	4.92	81.43
		56	Plastic	260.33	179.42	59.33	251.83	63.75	5.19	83.08
			HDPE	264.67	175.33	67.75	253.73	69.75	5.12	82.23
			LDPE	236.42	160.83	54.00	230.65	61.17	5.06	82.18
		75	Plastic	191.42	130.67	39.18	197.48	58.17	5.12	82.93
			HDPE	164.08	115.07	27.44	176.31	52.58	5.46	84.78
			LDPE	166.08	118.50	28.50	175.32	48.17	5.52	84.78
		96	Plastic	106.83	84.88	11.82	113.32	24.75	6.06	86.33
			HDPE	104.17	76.65	13.54	104.57	19.42	5.92	83.93
			LDPE	230.58	187.50	26.11	240.57	44.42	5.39	84.73
8	25	36	Plastic	282.17	228.73	50.56	288.75	59.47	5.29	83.83
			HDPE	290.17	222.32	64.98	286.50	63.64	5.35	84.68
			LDPE	291.75	234.98	53.90	298.34	62.80	5.29	83.03
		56	Plastic	271.67	199.82	68.98	268.17	67.80	5.35	83.83
			HDPE	280.08	220.15	57.06	281.59	60.89	5.29	83.68
			LDPE	269.25	206.15	60.23	269.09	62.39	5.29	82.98
		75	Plastic	270.33	211.48	55.98	273.59	61.55	5.29	82.98
			HDPE	240.17	187.90	49.40	240.84	52.39	5.29	83.83
			LDPE	220.17	170.73	46.56	222.92	51.64	5.29	83.78
		96	Plastic	238.92	182.82	53.23	241.50	58.14	5.15	82.88
			HDPE	213.67	163.90	46.90	220.17	55.72	5.29	83.83
			LDPE	192.25	166.32	23.06	226.67	59.80	6.02	83.78
	35	36	Plastic	287.92	214.07	70.98	278.50	63.89	5.29	84.68
			HDPE	291.75	208.23	80.65	278.59	69.80	5.22	82.93
			LDPE	281.75	208.15	70.73	273.75	65.05	5.15	83.78
		56	Plastic	254.25	184.73	66.65	253.09	67.80	5.15	83.78
			HDPE	214.17	160.98	50.31	217.25	55.72	5.29	85.38
			LDPE	192.50	153.98	35.65	200.50	45.97	5.22	83.08
		75	Plastic	235.83	176.48	56.48	238.34	61.30	5.15	83.88
			HDPE	185.42	151.57	30.98	192.50	40.39	5.35	83.83
			LDPE	155.33	131.82	20.65	165.17	32.80	5.75	82.98
		96	Plastic	194.33	147.48	43.98	202.59	54.55	5.35	85.48
			HDPE	125.75	111.32	11.56	136.17	24.30	6.29	83.68
			LDPE	122.58	107.23	12.48	135.17	27.39	6.02	83.68
	45	36	Plastic	307.50	222.40	82.23	292.75	69.80	5.15	82.78
			HDPE	286.17	201.48	81.81	273.17	71.14	5.22	83.73
			LDPE	307.58	237.82	66.90	305.59	67.20	5.09	82.18
		56	Plastic	286.00	214.65	68.48	279.50	64.30	5.09	83.83
			HDPE	276.17	197.73	75.56	267.50	69.22	5.22	83.73
			LDPE	266.83	201.07	62.90	263.09	61.47	5.22	83.78
		75	Plastic	228.75	168.32	57.56	224.50	55.64	5.22	83.78
			HDPE	182.25	139.40	39.98	192.84	52.89	5.29	83.88
			LDPE	154.67	121.65	30.15	175.42	53.22	5.42	85.53
		96	Plastic	157.42	128.07	26.48	175.59	46.97	5.75	85.13
			HDPE	104.42	92.15	9.40	116.50	23.80	6.22	86.33
			LDPE	100.08	92.98	4.23	108.92	15.39	6.55	82.98
12	25	36	Plastic	277.61	226.39	49.63	284.43	57.60	5.31	83.84
			HDPE	285.61	219.98	64.05	282.18	61.77	5.37	84.69
			LDPE	287.19	232.64	52.97	294.02	60.93	5.31	83.04

		56	Plastic	267.11	197.48	68.05	263.85	65.93	5.37	83.84
			HDPE	275.52	217.81	56.13	277.27	59.02	5.31	83.69
			LDPE	264.69	203.81	59.30	264.77	60.52	5.31	82.99
		75	Plastic	265.77	209.14	55.05	269.27	59.68	5.31	82.99
			HDPE	235.61	185.56	48.47	236.52	50.52	5.31	83.84
			LDPE	215.61	168.39	45.63	218.60	49.77	5.31	83.79
		96	Plastic	234.36	180.48	52.30	237.18	56.27	5.17	82.89
			HDPE	209.11	161.56	45.97	215.85	53.85	5.31	83.84
			LDPE	187.69	163.98	22.13	222.35	57.93	6.04	83.79
	35	36	Plastic	283.36	211.73	70.05	274.18	62.02	5.31	84.69
			HDPE	287.19	205.89	79.72	274.27	67.93	5.24	82.94
			LDPE	277.19	205.81	69.80	269.43	63.18	5.17	83.79
		56	Plastic	249.69	182.39	65.72	248.77	65.93	5.17	83.79
			HDPE	209.61	158.64	49.38	212.93	53.85	5.31	85.39
			LDPE	187.94	151.64	34.72	196.18	44.10	5.24	83.09
		75	Plastic	231.27	174.14	55.55	234.02	59.43	5.17	83.89
			HDPE	180.86	149.23	30.05	188.18	38.52	5.37	83.84
			LDPE	150.77	129.48	19.72	160.85	30.93	5.77	82.99
		96	Plastic	189.77	145.14	43.05	198.27	52.68	5.37	85.49
			HDPE	121.19	108.98	10.63	131.85	22.43	6.31	83.69
			LDPE	118.02	104.89	11.55	130.85	25.52	6.04	83.69
	45	36	Plastic	302.94	220.06	81.30	288.43	67.93	5.17	82.79
			HDPE	281.61	199.14	80.88	268.85	69.27	5.24	83.74
			LDPE	303.02	235.48	65.97	301.27	65.33	5.11	82.19
		56	Plastic	281.44	212.31	67.55	275.18	62.43	5.11	83.84
			HDPE	271.61	195.39	74.63	263.18	67.35	5.24	83.74
			LDPE	262.27	198.73	61.97	258.77	59.60	5.24	83.79
		75	Plastic	224.19	165.98	56.63	220.18	53.77	5.24	83.79
			HDPE	177.69	137.06	39.05	188.52	51.02	5.31	83.89
			LDPE	150.11	119.31	29.22	171.10	51.35	5.44	85.54
		96	Plastic	152.86	125.73	25.55	171.27	45.10	5.77	85.14
			HDPE	99.86	89.81	8.47	112.18	21.93	6.24	86.34
			LDPE	95.52	90.64	3.30	104.60	13.52	6.57	82.99
Range				95.52-429.42	76.25-328.00	3.30-101.42	104.57-488.92	13.52-160.92	4.92-6.57	81.38-86.34
Mean				229.55	180.94	50.08	234.36	56.70	5.36	83.49
SD				60.73	67.26	20.98	57.40	17.11	0.33	1.04
P of ST				*ns*	*ns*	*ns*	*	*	*	*
P of Temp				*	*	*	*	*	*	*
P of RH				*	*	*	*	*	*	*
P of Pkg Mat				*	*ns*	*	*	*	*	*
P of STxT				*ns*	*ns*	*	*	*	*	*ns*
P of StxRH				*	*ns*	*	*	*	*	*ns*
P of STxP				*	*ns*	*	*	*	*	*ns*
P of TxRH				*	*ns*	*	*	*	*	*
P of TxP				*	*ns*	*	*	*	*	*ns*
P of RHxP				*	*ns*	*	*	*	*	*
P of STxTxRH				*ns*	*ns*	*ns*	*	*	*	*ns*
P of STxTxP				*	*ns*	*ns*	*	*	*	*ns*
P of STXRHXP				*	*ns*	*	*	*	*	*ns*
P of TxPxRH				*	*ns*	*	*	*	*	*
P of STxTxRHxP				*	*ns*	*ns*	*	*	*	*ns*

Values are mean of three replicates **significant (P<0.01)*; *ns not significant (P>0.01)*

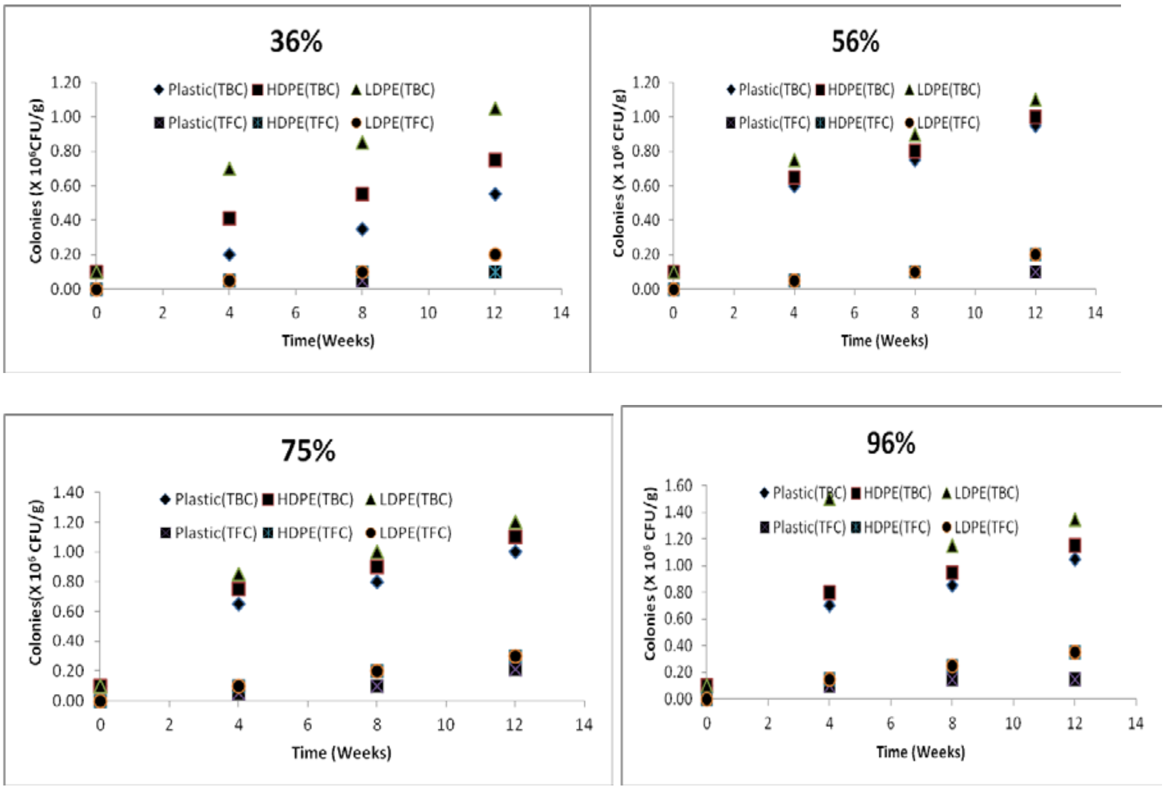

Figure N1: Effect of storage conditions and packaging materials on microbiological stability of high quality water yam flour at 25 °C. TBC-total bacterial count; TFC-total fungi count

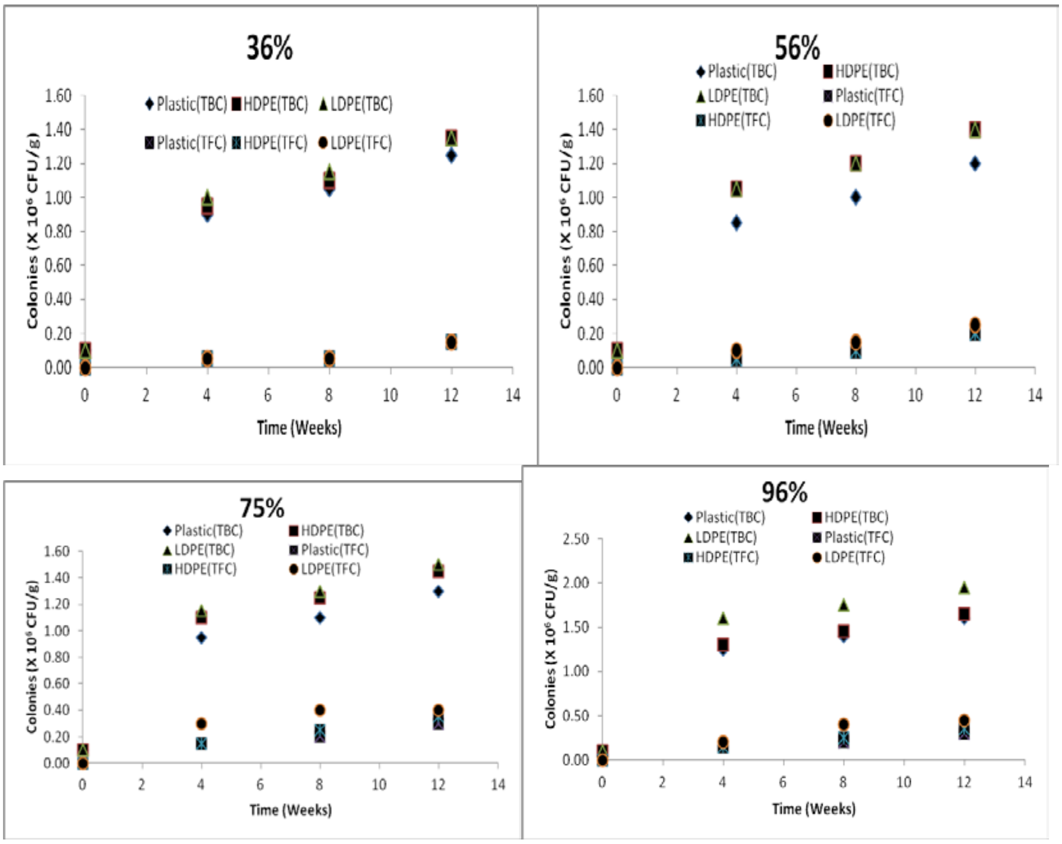

Figure N2: Effect of storage conditions and packaging materials on microbiological stability of high quality water yam flour at 35 ^{o}C. TBC-total bacterial count; TFC-total fungi count

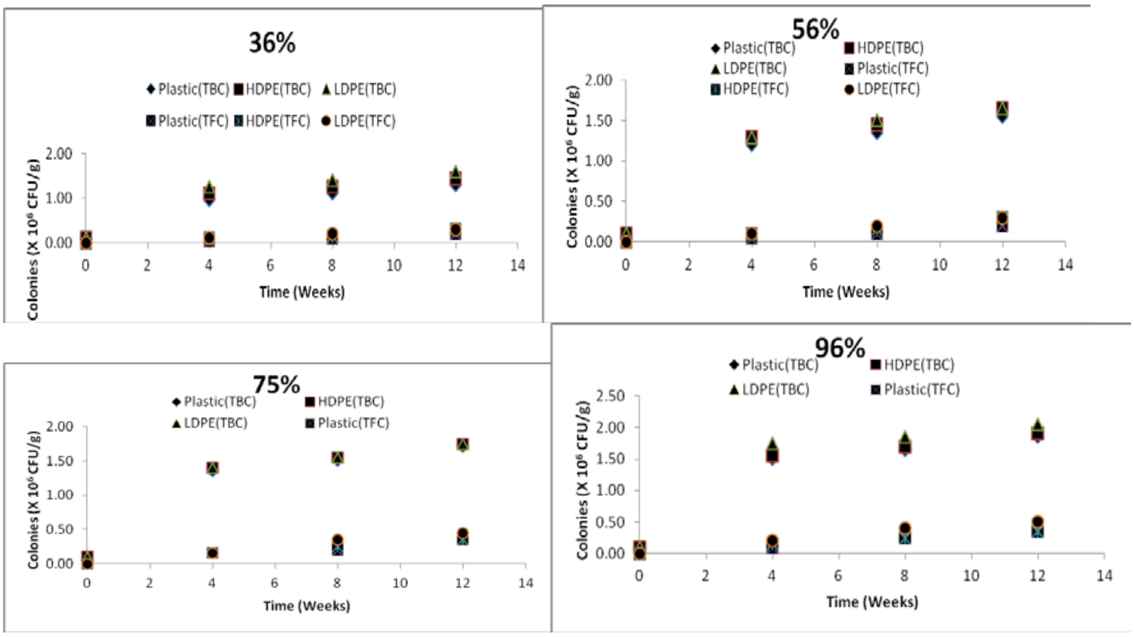

Figure N3: Effect of storage conditions and packaging materials on microbiological stability of high quality water yam flour at 45 °C. TBC-total bacterial count; TFC-total fungi count

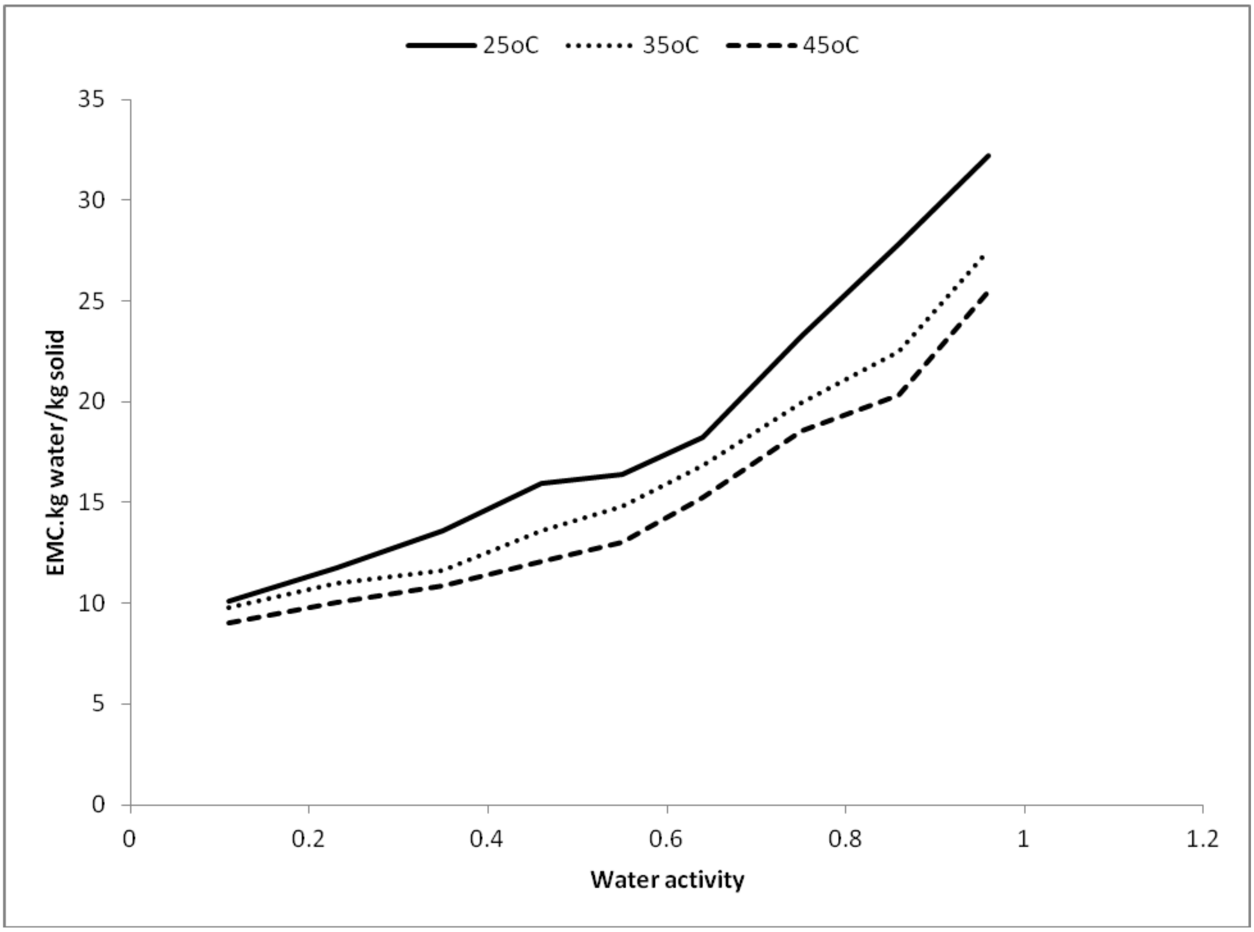

Figure N4: Sorption isotherms of High quality water yam flour

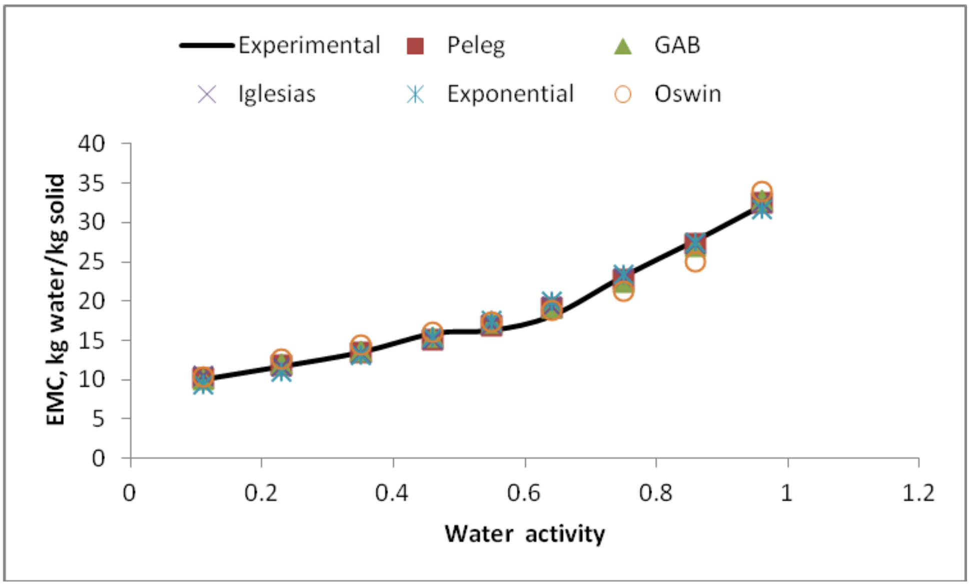

Figure N5: Comparison of experimental EMC with predicted EMC at 25 ºC

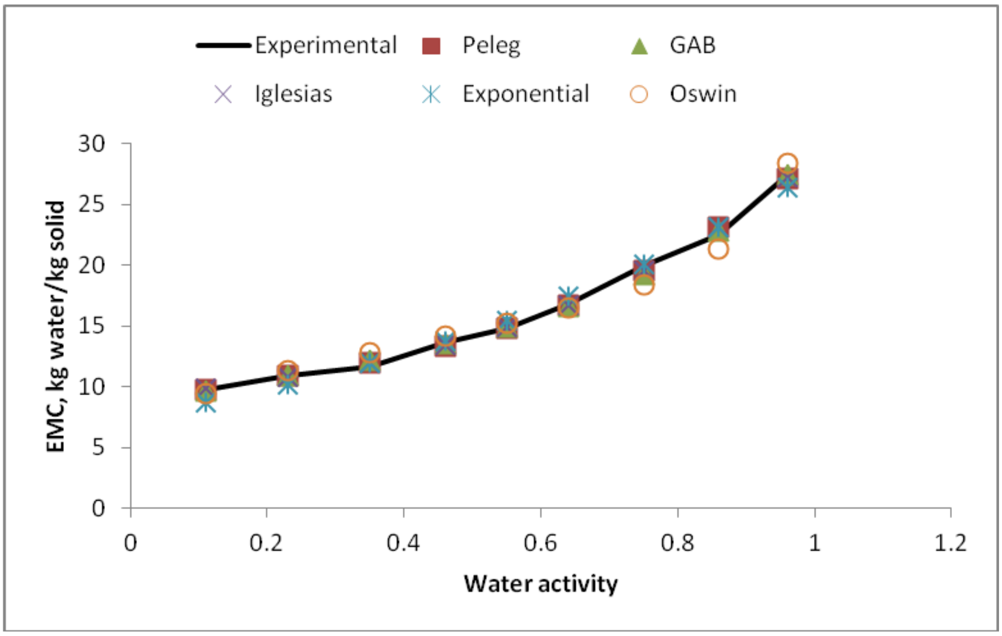

Figure N6: Comparison of experimental EMC with predicted EMC at 35 ºC

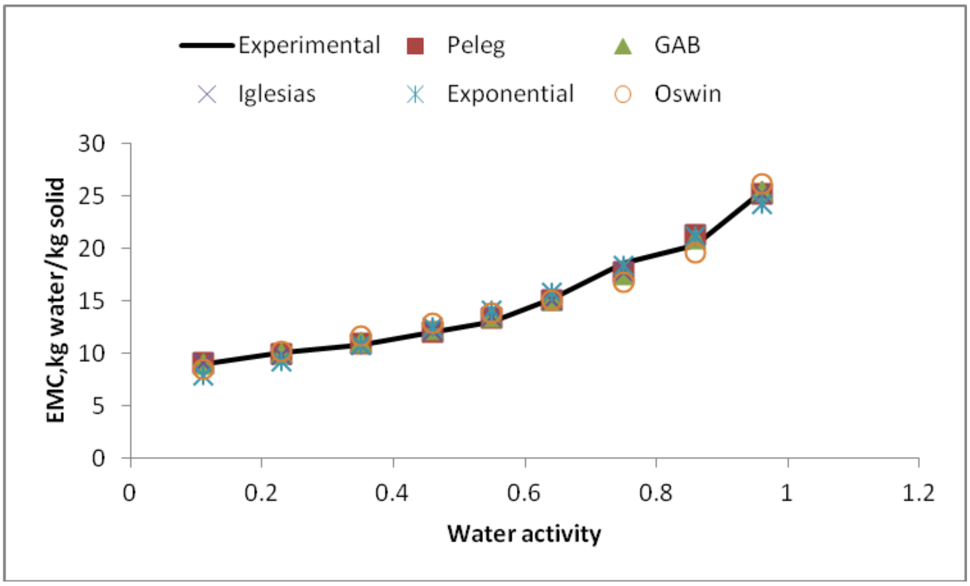

Figure N7: Comparison of experimental EMC with predicted EMC at 45 ºC

Table N9: Model parameter and statistical parameter of sorption isotherms of high quality water yam flour

Model Equation	Temperature		
	25ºC	**35ºC**	**45ºC**
GAB			
M_o	10.739	9.360	8.309
C	71.347	271.527	3.973×10^6
K	0.703	0.688	0.701
P(%)	0.2197	0.1399	0.1551
R^2	0.992	0.997	0.992
Iglesias and Chirife			
A	-0.189	-0.54	-0.896
B	2.214	2.272	2.524
$M_{0.5}$	-3.466	-3.493	-3.497
P(%)	0.1195	0.0356	0.0635
R^2	0.993	0.997	0.993
Oswin			
A	16.571	4.264×10^6	13.292
B	-0.226	3.631	0.214
P(%)	1.2744	0.6587	0.5458
R^2	0.96	0.962	0.973
Exponential			
A	7.965	9.182	6.807
B	-0.955	3.045	1.324
P(%)	0.6579	0.6186	0.7136
R^2	0.985	0.99	0.974
Peleg			
A	19.434	16.473	15.772
B	3.073	2.766	2.878
C	15.538	12.537	11.2
D	0.194	0.115	0.097
P(%)	0.0873	0.0335	0.0594
R^2	0.994	0.997	0.993

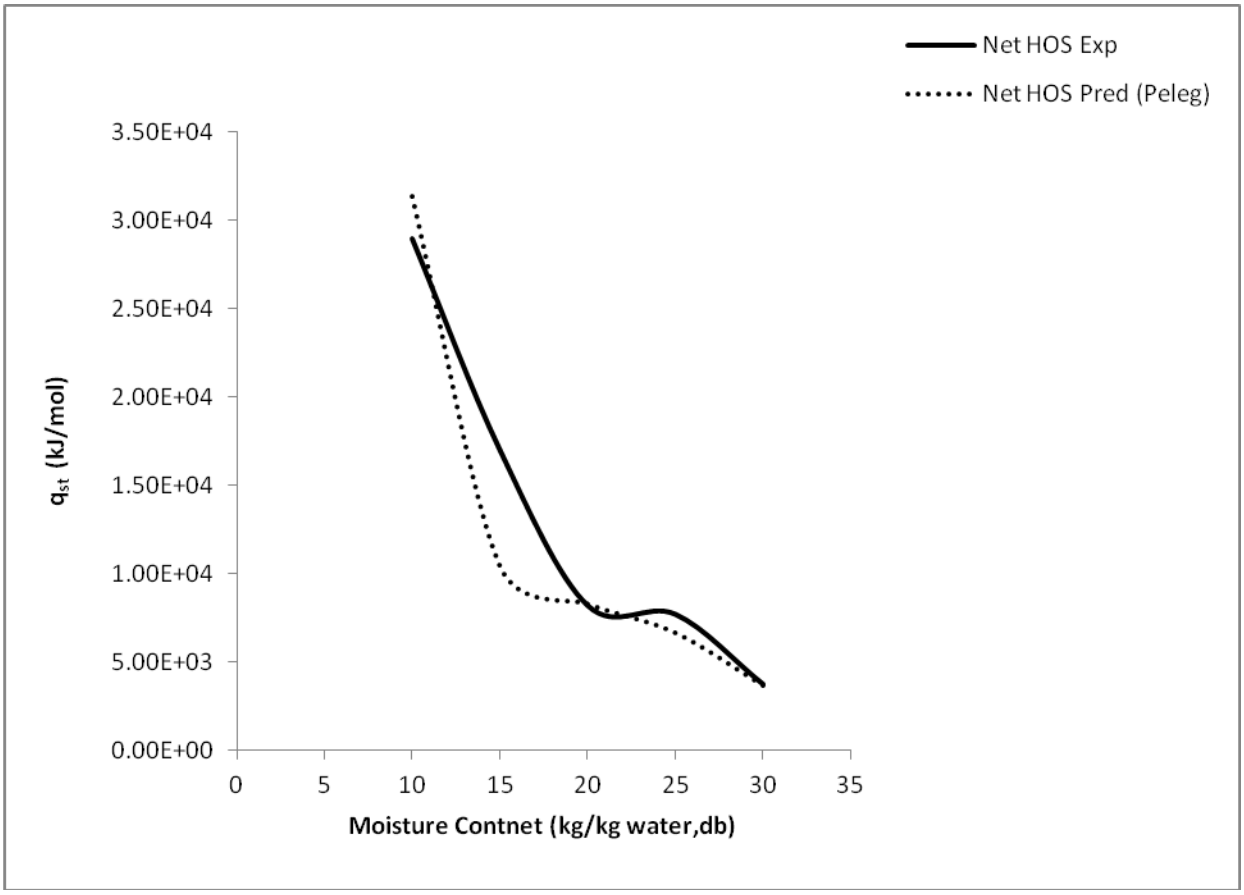

Figure N8: Effect of moisture content on the net isosteric heat of sorption for high quality water yam flour

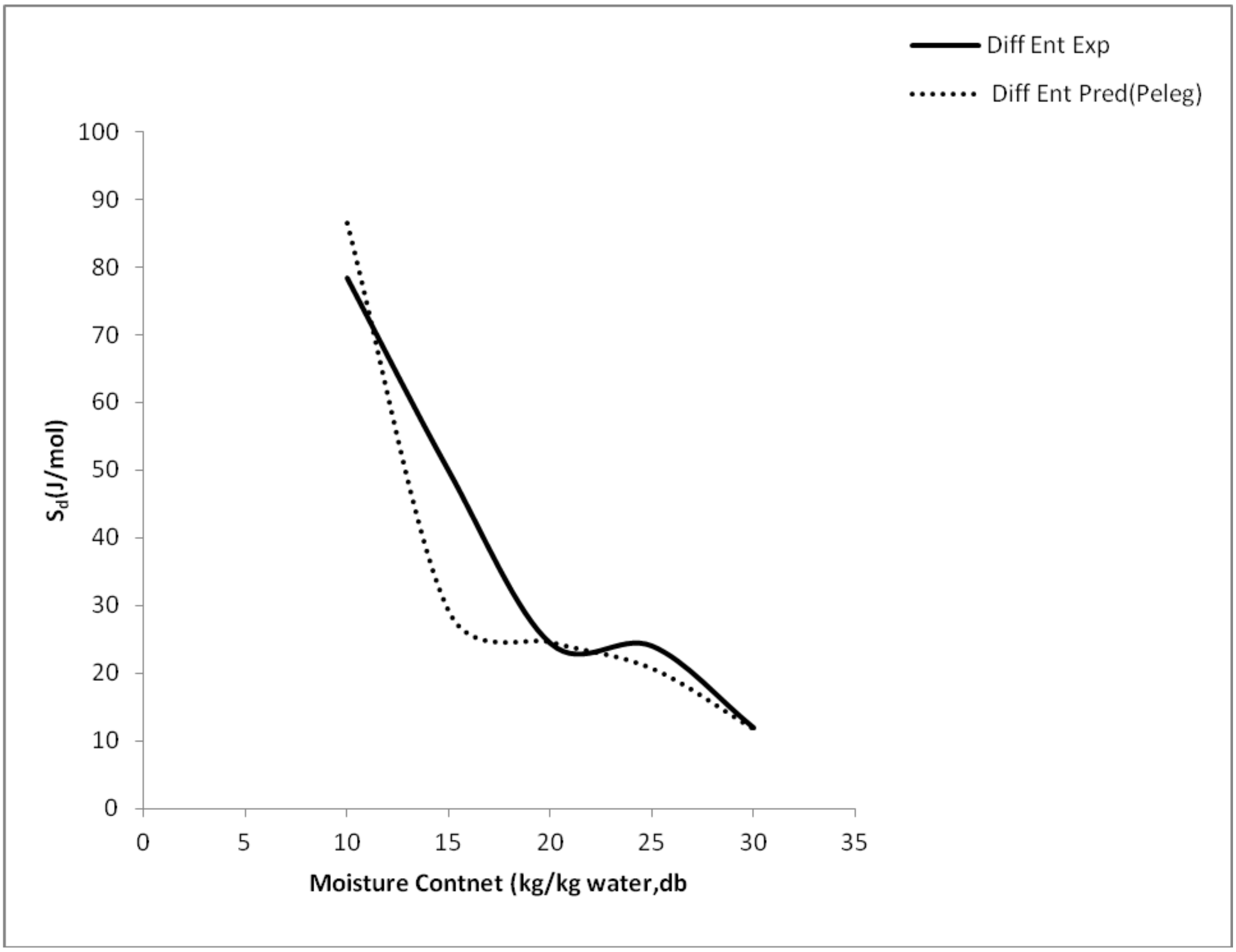

Figure N9: Effect of moisture content on differential entropy of high quality water yam flour

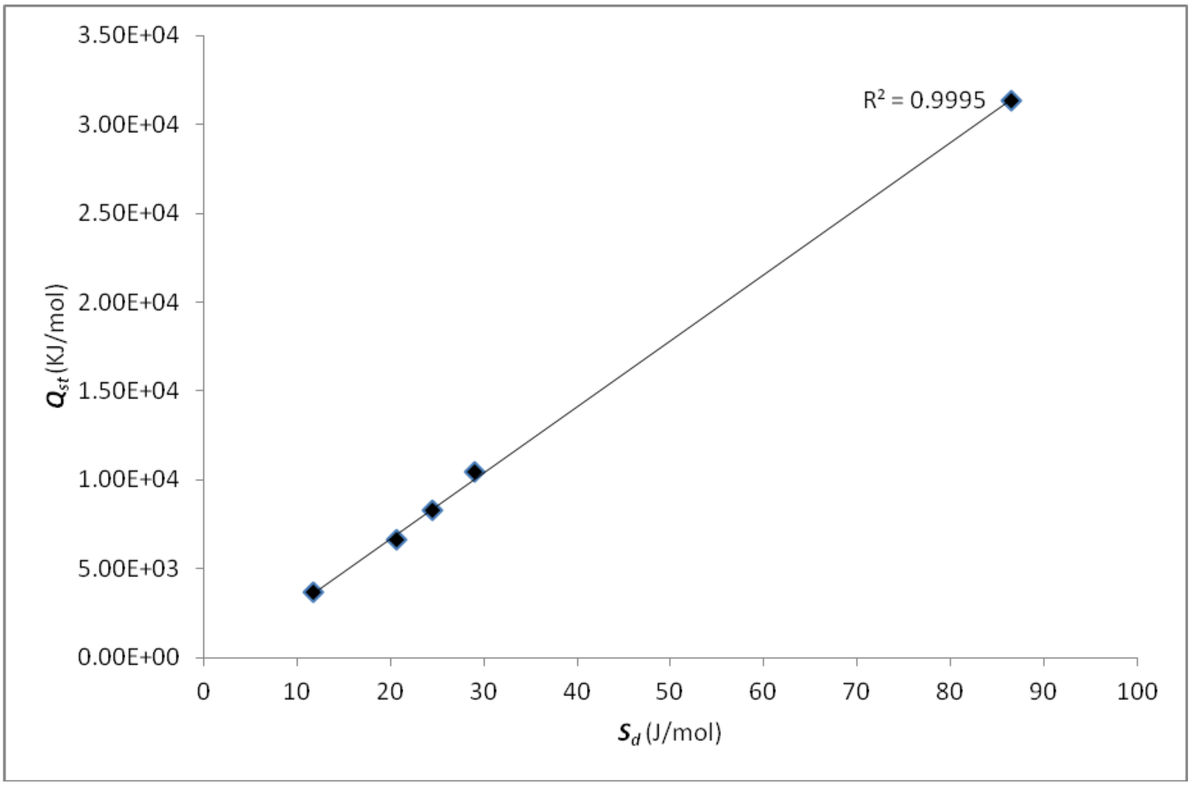

Figure N10: A plot of Q_{st} against S_d

Annex N2 – Processing of HQYFa

Peeling and slicing of yam tuber and soaking in potassium metabisulphite

Blanching and cabinet drying of yam slices

High quality yam flour (HQYF)