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Proximate Composition and Pasting Properties of Modified Starches of White Yam, Trifoliate Yam and Sweet Potato

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Abstract: Starches extracted from selected roots and tubers (white yam, trifoliate yam and sweet potato) were physically and chemically modified through heat moisture treatment (HMT) and acetylation respectively before evaluating their proximate composition and pasting properties for exploitable potentials. Starch sample NSPS (Native starch of sweet potato) significantly ($p < 0.05$) had highest values in: moisture content (13.40%), protein content (0.58%); and lowest value in carbohydrate content (85.09%). Starch sample NTYS (native starch of trifoliate yam) significantly ($p < 0.05$) was highest in ash content (0.69%) and fat content (0.52%); whereas starch sample PSPS (heat moisture treated starch of sweet potato) significantly ($p < 0.05$) made lowest value in fat content (0.21%). Starch sample CWYS (aetylated white yam starch) significantly ($p < 0.05$) gave highest values in: carbohydrate content (88.41%), pasting temperature (63.08°C), pasting time (6.98 min.); and lowest values in: moisture content (10.45%), ash content (0.44%), protein content (0.30%), peak viscosity (299.22 RVU), trough viscosity (101.99 RVU) and final viscosity (377.55 RVU). Starch sample PWYS (heat moisture treated starch of white yam) significantly ($p < 0.05$) scored highest value in breakdown viscosity (238.46 RVU) but significantly ($p < 0.05$) had lowest value in setback viscosity (266.22 RVU). Starch sample NWYS (native starch of white yam) significantly ($p < 0.05$) took lead-values in peak viscosity (331.88 RVU), trough viscosity (131.11 RVU), final viscosity (403.13 RVU), setback viscosity (277.02 RVU) but significantly ($p < 0.05$) had lowest values in pasting temperature (59.79°C) and pasting time (6.10 min.). Starch sample CTYS (acetylated trifoliate yam starch) significantly ($p < 0.05$) had lowest value in breakdown viscosity (174.58 RVU). These results obtained highlighted the huge potentials of these starches in: the formulation of composite flours; and manufacture of confectioneries, salad cream, mayonnaise, texturizing agents, thickeners, stabilizers, fillers, flavouring agents, beverage and bakery products; and industrial energy and time savings.

Keywords: Native and Modified Starches, White Yam, Trifoliate Yam, Sweet Potato, Acetylation, Heat Moisture Treatment, Proximate Composition, Pasting Properties

1. Introduction

Commercial utilization of white yam, trifoliate yam and sweet potato for both domestic and industrial purposes is under exploited in Nigeria irrespective of their massive production. These crops are ignorantly neglected irrespective of their rich potentials in value addition, creation of domestic and industrial market niches. Unarguably, the major domestic

and industrial raw materials from yams and sweet potato are flour and starch whose applications are increasingly widening on daily basis. Though flour seems to receive greater attention by researchers, starch remains the active component of grain based flour, driving its nutritional quality and functionality, since 65-85% grain-based flour is starch [1-4]. Also formulations of composite flours with starches have shown better baking responses than those with flours [5, 6]. Starch as an additive for food processing, is typically used as thickeners and stabilizers in foods such as puddings, custards, soups, sauces, gravies, pie fillings, salad dressings, and to make noddles and pastas [7]. In human diet, starch remains the most important source of carbohydrates, and accounts for more than 50% of carbohydrate intake [8].

Starch, as an agro-sourced polymer, has become very popular recently due to its characteristics such as wide availability, low cost and compost-ability without toxic residue [9]. It is currently enjoying increased attention owing to its usefulness in different food and non-food applications. Starch is a complex carbohydrate that consists of amylose and amylopectin which are the determinants of physicochemical properties such as water-binding capacity, gelatinization temperature, swelling power, emulsifying stability, bulk density, and paste stability [10-12]. During cooking, starch gelatinization occurs due to heat and shear action. However, upon cooling, the disrupted amylose and amylopectin chains gradually re-associate into a different ordered structure in a process termed retrogradation [13]. Starch retrogradation is usually accompanied by increased viscosity of pastes, gel formation, syneresis, and increased degree of crystallinity [12, 14]. Characterization of the properties of starches is a prerequisite for their application. Thus physicochemical and pasting properties of flour and starch are vital information that enhances their effective and appropriate application in food systems [15, 16]. The pasting property is one of the important physicochemical properties of starch and it is affected by multiple factors [17]. Pasting properties of a food refer to the changes that occur in the food as a result of application of heat in the presence of water, and they affect texture, digestibility and end use of the food products [18]. Thus starch plays an important role in food industry especially because of its thickening and gel-forming properties [19]. For instance, texture of biscuits depends primarily on starch gelatinization and super-cooled sugars [20, 21]. According to Fan et al [17], pasting properties of barley starch are important characteristic from processing standpoint. It is obvious that a major processing index of roots and tubers, is their ability to gelatinize and form thick paste for human consumption [22, 23]. Thus starch as one of the major processing products of roots and tubers deserves investigation since the functionality and quality of starchy products mainly depend on starch properties and characteristics. Besides, researchers have revealed that pasting properties of starch are highly influenced by composition, proportion and structure of starch [17].

Starch can easily be modified chemically and physically and applied in diverse industries such as papers, textiles, adhesives, beverages, confectionery, building materials and pharmaceuticals [4, 6, 7, 24, 25]. According to Adebowale and Lawal [26] the application of starch in food systems are primarily governed by gelation, gelatinization, pasting, solubility, swelling, colour and digestibility. Depending on the end uses, one or more of the above mentioned, particularly detrimental properties may often be subjected to suitable modifications in order to produce various novel starch derivatives with improved properties. Food processors prefer starches with better behavioural characteristics than those provided by native starches [27]. The chemical and functional properties achieved by modified starches depend, inter alia, on starch source, reaction conditions (reactant concentration, pH, reaction time, and the presence of catalyst), type of substituent, degree of substitution (DS), and the distribution of the substituents in the starch molecule [6, 28-30]. Starch modification involves the alteration of physical and chemical characteristics of the native starch to improve its functional characteristics, and can be used to tailor starch to specific food applications [6, 31, 32]. The different ways of modifying native starch consist in altering one or more of the following properties: paste temperature, solids/viscosity ratio, starch paste resistance to reduction of viscosity by acids, heat and or mechanical agitation (shear), retrogradation tendencies, ionic and hydrophilic nature [9, 33, 34]. The purpose of the starch modification is to stabilize starch granules during processing and make it suitable for many foods and industrial applications. Interestingly, by characterizing starches of varying sources and modification treatments, their potentials can be exploited through differentiation and assignment of specialized roles.

Therefore, evaluation of the proximate composition and pasting properties of starches obtained from white yam, trifoliate yam and sweet potato after physically and chemically modifying them through heat moisture treatment and acetylation respectively in order to reveal their domestic and industrial potentials will be the focus of this work.

2. Materials and Methods

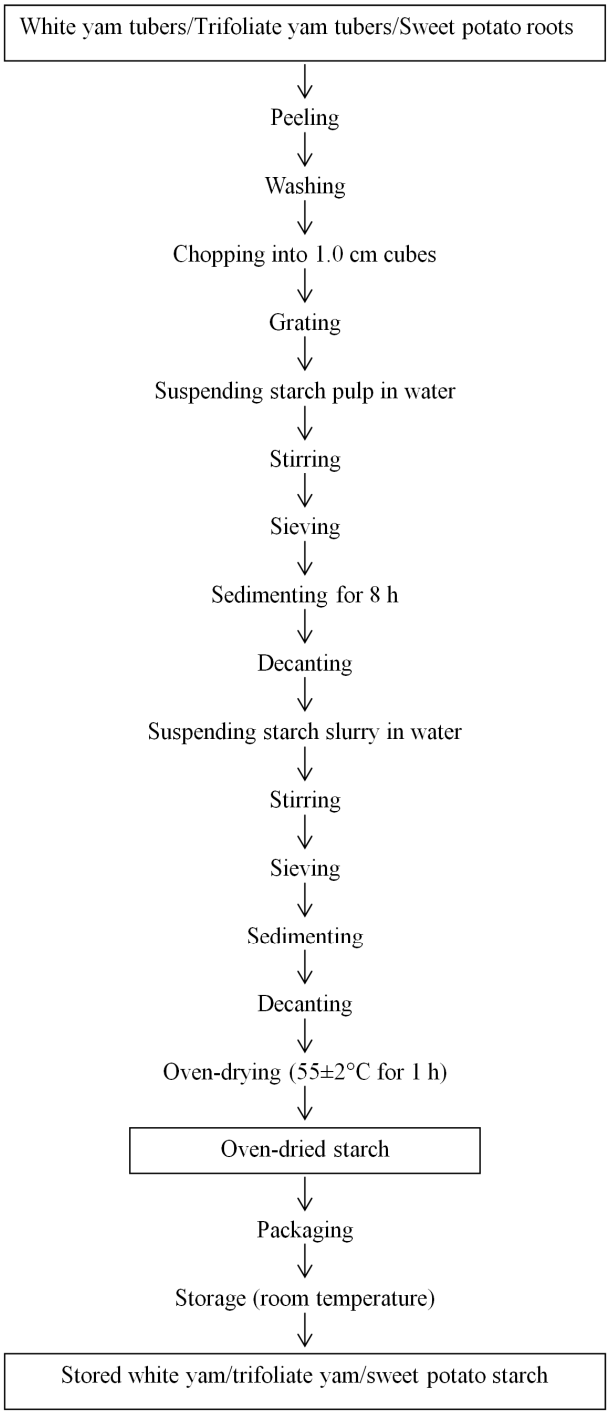
2.1. Materials

Fresh tubers of white yam (*Dioscorea rotundata*), trifoliate yam (*Dioscorea dumetorum*) and roots of sweet potato (*Ipomoea batatas*) were obtained from Benue State Agricultural Development Authority (BNARDA), Makurdi, Benue State, Nigeria. Water used was obtained from the Department of Chemistry laboratory, Benue State University, Makurdi, Benue State.

2.2. Methods

Starch extraction: Starch was extracted from cleaned, peeled and macerated roots and tubers of white yam/trifoliate yam/sweet potato using the methods of Onabolu et al. [35] and Kaur et al. [36] as shown in Figure 1. Two kilograms of peeled white yam tuber/trifoliate yam tuber/sweet potato root were washed thoroughly before grating, suspension in distilled water, stirring and subsequently sieving. The starch

slurry (filtrate) obtained was allowed to sediment for 8 h before the supernatant was decanted off. The processes of suspension in distilled water, stirring, sieving, sedimentng and decanting were repeated. The starch obtained from each selected root/tuber was oven dried at 55±2°C.



Source: Modified Kaur et al. [36]

Figure 1. *Flow chart for production of white yam/trifoliate/sweet potato starch.*

2.2.1. Modification of the Starches

Portions of oven dried starch from the white yam starch/trifoliate yam starch/sweet potato starch were physically and chemically modified through heat moisture treatment (HMT) and acetylation processes respectively.

(i). Heat Moisture Treatment (HMT)

The method of Lim et al [37] was used. Distilled water was sprayed onto 200g native white yam/trifoliate yam/sweet potato starch to adjust its moisture content to 20-25%. The starch/water mixture was extensively mixed with a blender and then the exact moisture content of the mixture was measured. The moisture adjusted starch (200 g) was transferred to a glass beaker and conventionally heated in an electric oven at 120°C for 1h. After the heat moisture treatment, the starch was dried to approximately 10% moisture content in a cabinet dryer (RXH-5-C model) at 40°C. The starch sample was ground and sieved through a 0.075 mm mesh screen into plastic bags and stored at room temperature (27°C) prior to analyses.

(ii). Acetylation

The method of Sathe and Salunkhe [38] was used. The native starch (100 g) was dispersed in 500 mL distilled water and stirred magnetically for 20 min. The pH of the slurry obtained was adjusted to 8.0 using 1.0 M NaOH. Acetic anhydride (10.2 g) was added over a period of 1 h, while maintaining a pH range of 8.0-8.5. The reaction proceeded for 5.0 min. after the addition of acetic anhydride. The pH of the slurry was adjusted to 4.5 using 0.5 M HCl. It was filtered through a 0.075 mm mesh screen, washed four times with distilled water and air-dried using a cabinet dryer (RXH-5-C model) at 30±2°C for 48 h. The acetylated starch was packaged in a polyethylene bag and stored at room temperature (27°C) for further analyses.

2.2.2. Determination of the Proximate Composition of Starch Samples

Proximate analyses were carried out on the starch samples to determine the moisture, ash, crude fibre, fat, protein and carbohydrate contents using the method outlined by the Association of Official Analytical Chemists [39].

(i). Moisture Content

The moisture content of the native/modified starch was determined by hot air oven method as described by AOAC [39]. The native/modified starch sample (2 g) was weighed into an empty dish. This was placed into the hot air oven to dry for 24 hours at 100°C. The dish and its contents were cooled in the desicator and their weights taken. The loss in weight was recorded as moisture content and expressed as percentage of the original weight of the sample. This experiment was carried out in triplicates.

$$\%\ Moisture\ Content = \left(\frac{W_2 - W_3}{W_2 - W_1}\right) X\ 100$$

W_1= weight of cooled empty dish;
W_2 = weight of empty dish + undried sample;
W_3= weight of dish + dried sample.

(ii). Ash Content

Ash content of the native/modified starch was determined using the method of AOAC [39]. The native/modified starch

sample (5 g) was weighed into empty crucible and then the sample was incinerated in a muffle furnace at 550°C until a light grey ash was observed and a constant weight obtained. The sample was cooled in the desiccator to avoid absorption of moisture and weighed to obtain ash content. The percentage ash content was expressed as percentage of the original weight of the sample on dry basis. The experiment was done in triplicates.

$$\%\ Ash\ Content = \left(\frac{W_3 - W_1}{W_2 - W_1}\right) X\ 100$$

W_1= weight of cooled empty crucible;
W_2 = weight of empty crucible + undried sample;
W_3= weight of crucible + dried sample.

(iii). Crude Fibre Content

Crude fibre of the native/modified starch was determined using the method of AOAC [39]. The native/modified starch sample (5 g) was weighed into a 500 ml Erlenmeyer flask and 100 ml of TCA digestion reagent was added. It was then brought to boiling and refluxed for exactly 40 minutes counting from the start of boiling. The flask was removed from the heater, cooled a little then filtered through a 15.0 cm number 4 Whatman paper. The residue was washed with hot water, stirred once with a spatula and transferred to a porcelain dish. The sample was dried overnight at 105°C. After drying, it was transferred to a desiccator and weighed as W_1. It was then burnt in a muffle furnace at 500°C for 6 hours, allowed to cool, and reweighed as W_2.

$$\%\ Crude\ fibre\ Content = \left(\frac{W_2 - W_1}{W_0}\right) X\ 100$$

W_1 = Weight of crucible + fiber + ash;
W_2 = Weight of crucible + ash;
W_0 = Dry weight of food sample.

(iv). Crude Fat Content

The soxhlet extraction method described by AOAC [39] was used in determining fat content of the native/modified starch. Two grams (2 g) of native/modified starch was weighed into a weighed flat bottom flask, with the extractor mounted on it. The thimble was held half way into the extractor and the weighed sample. Extraction was carried out using boiling point of 40-60°C. The thimble was plugged with cotton wool. At completion of extraction which lasted for 8 hours, the solvent was removed by evaporation on a water bath and the remaining part in the flask was dried at 80°C for 30 minutes in the air oven to dry the fat and then cooled in a desiccator. The flask was reweighed and percentage fat content calculated as follows:

$$\%\ Crude\ fat\ Content = \left(\frac{weight\ of\ fat}{weight\ of\ sample}\right) X\ 100$$

(v). Protein Content

The micro Kjeldahl method as described by AOAC [39] was used to determine crude protein. The native/modified starch sample (2 g) was weighed into the digestion flask. Ten grams (10 g) of copper sulphate and sodium sulphate (catalyst) in the ratio 5:1 respectively and 25 ml concentrated sulphuric acid were added to the digestion flask. The flask was placed into the digestion block in the fume cupboard and heated until frothing ceased giving clear and light blue green coloration. The mixture was then allowed to cool and diluted with distilled water until it reached 250 ml of volumetric flask. Distillation apparatus was connected and 10 ml of the mixture was poured into the receiver of the distillation apparatus. Also 10 ml of 40% sodium hydroxide was added. The released ammonia by boric acid was then treated with 0.02 N of hydrochloric acid until the green color changed to purple. Percentage of nitrogen in the sample was calculated using the formula below:

$$Nitrogen\ (\%) = \left(\frac{(Titre - blank)X14.008XNormalityX100}{Weight\ of\ Sample}\right)X100$$

$$\%\ Protein\ Content = \%\ N\ X\ 6.25$$

(vi). Carbohydrate Content

The carbohydrate content was calculated by difference method according to Ihekoronye and Ngoddy [40]. This was done by summing up the moisture, crude protein, crude fat, crude fibre and ash contents and then subtracting from 100.

$$\%\ Carbohydrate\ Content = 100 - (\%\ MC + \%CP + \%CF + \%CFb + \%A)$$

Where MC = Moisture content;
CP = Crude Protein;
CF = Crude fat;
CFb = Crude fibre;
A = Ash.

2.2.3. Pasting Properties of the Starch Samples

Pasting characteristics were determined using a Rapid Visco Analyzer (Newport Scientific Pty Ltd, Warie-wood NSW 2102, Australia). Starch sample (2.5 g) was weighed into a previously dried canister and 25 ml of distilled water was dispensed into the canister containing the starch sample. The suspension was thoroughly mixed and the canister was fitted into the Rapid Visco Analyzer as recommended. Each suspension was kept at 50°C for I min and then heated up to

95°C with a holding time of 2 min followed by cooling to 50°C with 2 min holding time. The rate of heating and cooling was at a constant rate of 11.85°C per min. Peak viscosity, trough viscosity, breakdown viscosity; final viscosity and setback viscosity were read from the pasting profile with the aid of thermocline for windows software connected to a computer (Newport Scientific, 1998).

2.2.4. Experimental Design

The experiments were fit into a one way Analysis of variance (ANOVA). Nine (9) treatments were generated in triplicates for each experiment on the proximate compositions, and pasting properties of the native and modified starches, yielding a total of twenty-seven (27) samples/experiment analyzed.

2.2.5. Statistical Analysis

Results of all determinations were expressed as means of triplicate values. Data were subjected to one-way Analysis of Variance (ANOVA), and the means were separated using Duncan's multiple range test to determine the significant differences at 5% probability ($p<0.05$). An IBM SPSS Statistical package (version 20.0) was used for all statistical analyses.

3. Results and Discussion

Table 1. *Proximate compositions (%) of native/modified starches of white yam, trifoliate yam and sweet potato.*

Starch Type	Moisture	Ash	Crude Fat	Protein	Carbohydrate
NWYS	13.20±0.28^{a}	0.56±0.03^{cd}	0.45±0.01^{b}	0.43±0.01^{de}	85.36±0.23^{ef}
NTYS	11.80±0.14^{c}	0.69±0.01^{a}	0.52±0.00^{a}	0.50±0.03^{c}	86.49±0.13^{d}
NSPS	13.40±0.14^{a}	0.63±0.00^{b}	0.30±0.01^{d}	0.58±0.00^{a}	85.09±0.16^{f}
PWYS	11.60±0.14^{c}	0.52±0.00^{e}	0.32±0.00^{d}	0.39±0.01^{fg}	87.17±0.13^{c}
PTYS	10.75±0.07^{e}	0.65±0.01^{b}	0.41±0.01^{c}	0.46±0.01^{d}	87.73±0.08^{b}
PSPS	13.15±0.07^{a}	0.59±0.03^{c}	0.21±0.01^{f}	0.54±0.03^{b}	85.51±0.04^{e}
CWYS	10.45±0.07^{e}	0.44±0.01^{f}	0.40±0.01^{c}	0.30±0.01^{h}	88.41±0.13^{a}
CTYS	12.20±0.14^{b}	0.57±0.00^{cd}	0.47±0.01^{b}	0.37±0.00^{g}	86.39±0.16^{d}
CSPS	11.20±0.00^{d}	0.55±0.00^{de}	0.25±0.00^{e}	0.42±0.00^{ef}	87.58±0.00^{b}

Values are mean± standard deviation of triplicate determinations
Values with different superscripts within the same column are significantly different at ($P<0.05$).
KEY:
NWYS= Native starch of white yam
NTYS = Native starch of trifoliate yam
NSPS = Native starch of sweet potato
PWYS = Physically modified (Heat moisture treated) starch of white yam
PTYS = Physically modified (Heat moisture treated) starch of trifoliate yam
PSPS = Physically modified (Heat moisture treated) starch of sweet potato
CWYS = Chemically modified (acetylated) starch of white yam
CTYS = Chemically modified (acetylated) starch of trifoliate yam
CSPS = Chemically modified (acetylated) starch of sweet potato.

3.1. Proximate Compositions of the Native, Heat Moisture Treated, and Acetylated Starches of White Yam, Trifoliate Yam and Sweet Potato

The results of the proximate composition of native, physically modified (heat moisture treated) starches, and chemically modified (acetylated) starches of white yam, trifoliate yam and sweet potato are presented in Table 1.

Moisture contents of the starch samples significantly ($p<0.05$) ranged from 10.45 to 13.40% with sample CWYS having the lowest value while sample NSPS had the highest value. This result is also an indication that the starch samples will keep well if properly stored under good conditions that discourage moisture absorption from the atmosphere which may eventually lead to caking and spoilage [41-43]. From studies, starches with moisture content less than 14% can resist microbial growth and hence are storage stable [44-46]. The moisture content of starch plays key role in determining its keeping quality and storage stability, as the lower the moisture content, the higher the storage stability [43, 47]. Besides, these starches may be utilized as binders and composite flour in food and baking industries due to their low moisture contents [47].

The starch sample NTYS significantly ($p<0.05$) recorded the highest ash content of 0.69% while the lowest value of 0.44% was observed in sample CWYS. Ash content is an indicator of amount of minerals in a food sample. The results of the ash contents of the starch samples are in agreement with reported specifications of less than 0.9% [48].

Crude fat contents significantly ($p<0.05$) ranged from 0.52% in NTYS to 0.25% in CSPS. These low crude fat contents observed in all the starch samples indicate they are not good sources of fat.

Protein contents of the starches significantly ($p<0.05$) varied between 0.58% in NSPS and 0.30% in CWYS. From the results, all the starch samples indicated they were poor sources of protein.

The carbohydrate contents of the starch samples ranged significantly ($p<0.05$) from 85.09% in NSPS to 88.41% in CWYS. The results indicated that all starch samples are good sources of carbohydrate and may constitute important energy source once included in diet [8, 47, 49]. Physical

modification (heat moisture treatment) improved significantly ($p<0.05$) the carbohydrate contents of all the native starches (i.e from 85.36 - 87.17% for white yam; 86.49-87.73% for trifoliate yam; 85.09-85.51%. for sweet potato). Chemical modification (acetylation) increased significantly ($p<0.05$) the carbohydrate contents of native starches of white yam (i.e from 85.36-88.41%) and sweet potato (i.e from 85.09-87.58%) but decreased insignificantly ($p<0.05$) the carbohydrate content of native starch of trifoliate yam from 86.49 to 86.39%.

Table 2. *Pasting properties of native, physically modified (HMT) and chemically modified (acetylated) starches of white yam, trifoliate yam and sweet potato.*

Starch Sample	Peak Viscosity (RVU)	Trough Viscosity (RVU)	Breakdown Viscosity (RVU)	Final Viscosity (RVU)	Setback Viscosity (RVU)	Pasting Temperature (°C)	Pasting Time (min.)
NWYS	331.88±0.66^{a}	131.11±0.14^{a}	200.77±0.67^{ab}	403.13±2.84^{a}	277.02±9.89^{a}	59.79±0.20^{f}	6.10±0.01^{e}
NTYS	309.09±0.95^{d}	124.15±0.72^{bc}	184.94±1.67^{ab}	394.85±0.45^{c}	269.21±0.93^{ab}	61.75±0.16^{c}	6.46±0.01^{c}
NSPS	313.51±0.69^{c}	123.67±3.31^{bc}	190.18±4.48^{ab}	398.65±0.66^{b}	274.77±2.67^{ab}	60.50±0.08^{d}	6.30±0.00^{d}
PWYS	318.18±0.21^{b}	129.23±0.15^{a}	238.46±70.07^{a}	395.39±2.15^{c}	266.22±1.93^{b}	60.27±0.01^{e}	6.33±0.01^{d}
PTYS	308.46±0.45^{de}	125.60±0.71^{b}	182.91±0.16^{ab}	395.69±0.81^{c}	270.14±1.45^{ab}	61.66±0.35^{c}	6.45±0.01^{c}
PSPS	311.99±0.16^{c}	122.23±0.01^{c}	188.89±1.10^{ab}	395.30±0.11^{c}	273.07±0.10^{ab}	60.50±0.01^{d}	6.38±0.02^{cd}
CWYS	299.22±1.40^{g}	101.99±1.39^{e}	196.13±1.7^{ab}	377.55±0.81^{f}	274.99±0.02^{a}	63.08±0.02^{a}	6.98±0.00^{a}
CTYS	301.65±0.47^{f}	114.94±0.86^{d}	174.58±18.48^{b}	385.60±0.54^{e}	272.08±0.46^{ab}	62.98±0.00^{a}	6.79±0.00^{b}
CSPS	307.27±0.70^{e}	112.82±0.57^{d}	194.74±0.10^{ab}	390.54±0.51^{d}	276.85±0.07^{a}	62.09±0.01^{b}	6.44±0.11^{c}

Values are mean± standard deviation of triplicate determinations
Values with different superscripts within the same column are significantly different at ($P<0.05$).
KEY: NWYS= Native starch of white yam; NTYS = Native starch of trifoliate yam; NSPS = Native starch of sweet potato;
PWYS = Physically modified (Heat moisture treated) starch of white yam;
PTYS = Physically modified (Heat moisture treated) starch of trifoliate yam;
PSPS = Physically modified (Heat moisture treated) starch of sweet potato;
CWYS = Chemically modified (acetylated) starch of white yam;
CTYS = Chemically modified (acetylated) starch of trifoliate yam;
CSPS = Chemically modified (acetylated) starch of sweet potato

3.2. Pasting Properties of Native and Modified Starches of White Yam, Trifoliate Yam and Sweet Potato

The results of the pasting properties of native, physically modified (HMT) and chemically modified (acetylated) starches of white yam, trifoliate yam and sweet potato are presented in Table 2. Pasting properties of starch are important functional properties relating to the ability of starch to act in paste-like manner [46, 50]. The pasting properties are used to predict the behavior of starch during cooking and after cooking.

The peak viscosities of the starches varied significantly ($p<0.05$) from 299.22 RVU in sample CWYS to 331.88 RVU in sample NWYS. Among the three starch sources, native starch of white yam (NWYS) had the highest peak viscosity of 331.88 RVU while the native starch of trifoliate yam (NTYS) had the lowest peak viscosity of 309.09 RVU. The differences in the values of the peak viscosity of these starch sources are attributable to their genetic variations: proportion of starch granules with distinct size, starch content, distribution of chain length, amylose and amylopectin content and ratio [17, 43, 46] For instance, higher peak viscosity of white yam starch is traceable to its larger granule size (28-47 μm) than the granule size (1-5 μm) of trifoliate yam starch [50-52]. According to Chen et al. [53] and Tsakama et al. [50] starches with larger granule sizes undergo gelatinization relatively faster than smaller fractions due to its less molecular bonding, thus aiding the attainment of sharper peaks as the swelling is almost uniform and spontaneous than in smaller granule fractions. Peak viscosity is often correlated with the final product quality and also provides an indication of the viscous loads likely to be encountered during mixing [54, 55]. From results, chemical and physical modifications of the starches through acetylation and heat moisture treatment respectively led to significant decreases of the peak viscosity values of the native starches. Heat moisture treatment (physical modification) significantly ($p<0.05$) decreased peak viscosity values of white yam native starch (NWYS) from 331.88 to 318.18 RVU in sample PWYS, sweet potato native starch (NSPS) from 313.51 RVU to 309.46 RVU; and insignificantly ($p<0.05$) decreased that of sweet potato native starch (NSPS) from 313 RVU to 311.99 RVU. Acetylation (chemical modification) significantly ($p<0.05$) decreased native starches of white yam, trifoliate yam and sweet potato from 331.88 - 299.22 RVU, 309.09 - 301.65 RVU and 313.51 - 307.27 RVU respectively. Peak viscosity of starch indicates the water binding capacity of a starch, viscous load likely to be encountered during mixing and ease of cooking starch [43, 50, 56]. Peak viscosity has been reported to be closely associated with the degree of starch damage. Thus, high starch damage will result in high peak viscosity [57, 58]. Starches with high peak viscosities such as NWYS (331.88 RVU), PWYS (318.18 RVU), NSPS (313.51 RVU) and PSPS (311.9 RVU) may be suitable for products requiring high gel strength, thick paste and elasticity [58].

The trough viscosity (i.e minimum viscosity attained by the gelatinized starch) significantly ($p<0.05$) recorded highest (131.11 RVU) in sample NWYS and lowest (101.99 RVU) in sample CWYS. Physical modification (HMT) insignificantly ($p<0.05$) decreased the trough viscosities of native starch of white yam from 131.11 RVU to 129.23 RVU, and native starch of sweet potato from 123.67 RVU to 122.23 RVU, but

insignificantly increased that of native starch of trifoliate yam from 124.15 RVU to 125.60 RVU. Chemical modification (acetylation) significantly ($p<0.05$) decreased the trough viscosities of all the native starches: white yam starch decreased from 131.11 to 101.99 RVU, trifoliate yam starch decreased from 124.15 to 114.94 RVU and sweet potato starch decreased from 123.67 to 112.82 RVU. The results obtained were lower in values than the results obtained by Arisa et al. [59] and Kiin-Kabari et al. [55] which ranged between 186.75 RVU and 259.25 RVU for blended unripe plantain flour, and between 178.44 RVU and 205.81 RVU for wheat-plantain flour enriched with bambara-groundnut protein concentrate, respectively. The hold period (Trough) sometimes referred to as shear thinning, holding strength or hot paste viscosity is a period when the samples are subjected to a period of constant temperature and mechanical shear stress [55, 60].

The breakdown viscosity values of the starches significantly ($p<0.05$) varied between 174.58 RVU (lowest) in sample CTYS and 239.46 RVU (highest) in sample PWYS. Physical modification (HMT) insignificantly ($p<0.05$) led to increase in the breakdown viscosity of the native starch of white yam (NWYS) from 200.77 to 238.46 RVU, but led to insignificant ($p<0.05$) decreases in those of the native starches of trifoliate yam (i.e from 184.94 to 182.91 RVU) and sweet potato (i.e from 190.18 to 188.89 RVU). The chemical modification (acetylation) led to insignificant ($p<0.05$) decreases in the breakdown viscosities of the native starches of white yam (i.e from 200.77 to 196.13 RVU) and trifoliate yam (i.e from 184.94 to 174.58 RVU), but insignificantly ($p<0.05$) increased that of native starch of sweet potato from 190.18 to 194.74 RVU. In the case of the three starch sources, white yam starches maintained the highest values (i.e 200.77 RVU, 238.46 RVU and 196.13 RVU) while the trifoliate yam starches maintained the lowest values (i.e. 184.94 RVU, 182.91 RVU and 174.58 RVU) for the three categories- native, physical modification (HMT) and chemical modification (acetylation) respectively. Breakdown viscosity, which is the difference between the peak viscosity and trough (hold) viscosity, measures the ability of starch to withstand collapse during cooling or the degree of disintegration of granules or paste stability [46, 55, 61, 62]. According to Ezeocha and Okafor [58] it is a measure of the ability of cooked starch to withstand shear-induced disintegration. Sample PWYS with the highest breakdown viscosity value of 238.46 RVU exhibited the lowest ability to withstand heating and shear stress during cooking while sample CTYS with the lowest breakdown viscosity value of 174.58 RVU displayed highest ability to withstand heating and shear stress during cooking [56, 63-65]. Low value of breakdown viscosity reflects better stability of starches under shear stress (i.e caused by stirring) and hot conditions. Hence, a higher breakdown viscosity results in reduced ability of the starch to withstand heating and shear stress during cooking [58, 63]. Amylose content is assumed to have a marked influence on the breakdown viscosity [66].

The final viscosity of the starches was significantly ($p<0.05$) highest (403.13 RVU) in sample NWYS and lowest (377.55 RVU) in sample CWYS. Physical modification through heat moisture treatment significantly ($p<0.05$) reduced the final viscosity values of native starches of white yam from 403.13 RVU to 395.39 RVU and sweet potato from 398.65 to 395.30 RVU, but insignificantly ($p<0.05$) increased that of the native starch of trifoliate yam from 394.85 to 395.69 RVU. Then chemical modification (acetylation) led to significant ($p<0.05$) decreases in the final viscosities of native starches of white yam from 403.13 to 377.55 RVU, trifoliate yam from 394.85 to 385.60 RVU and sweet potato from 398.65 to 390.54 RVU. Comparing among the starch sources, native starch of white yam recorded the highest value (403.13 RVU) of final viscosity while the native starch of trifoliate yam recorded the lowest value (394.85 RVU). The results correlate with results of Okafor and Ugwu [67] who reported final viscosity values of 284.50 RVU for French plantain and soy residue flour blends and 270.25 RVU for false horn plantain and soy residue flour blend. Besides, the results are similar to results of Kiin-Kabari et al. [55] who observed final viscosity range of 249.84 RVU to 342.81 RVU plantain flour and composite blends enriched with bambara groundnut protein concentrate. Final viscosity is used to determine a starch's ability to form a gel after cooking and cooling. It indicates the stability of cooked paste or gel. Less stability of paste is accompanied with high value of breakdown viscosity [68]. The difference between the final viscosity and trough viscosity is referred to as setback viscosity. Thus, the re-association between starch molecules during cooling is referred to as setback. This form of re-ordering of starch molecules is correlated with texture of various products [46, 58].

The setback viscosity values significantly ($p<0.050$ ranged from 266.22 RVU in sample PWYS to 277.02 RVU in sample NWYS. Setback viscosity indicates the retrogradation tendency of cooked starch during cooling and this correlates with texture of various starch-based products [46, 58]. Physical modification (HMT) decreased significantly ($p<0.05$) the setback viscosity value of white yam starch (from 277.02 to 266.22 RVU) and insignificantly ($p<0.05$) that of sweet potato from 274.77 to 273.07 RVU, but insignificantly ($p<0.05$) increased that of trifoliate yam starch from 269.21 to 270.14 RVU. Chemical modification (acetylation) led to insignificant ($p<0.05$) decrease in starch of white yam (from 277.02 to 274.99 RVU) but increases in starches of trifoliate yam (from 269.21 to 272.08 RVU) and sweet potato (from 274.77 to 276.85 RVU). Among the three starch sources, native starch of white yam had highest setback viscosity value of 277.02 RVU while native starch of trifoliate yam toddled with a value of 269.21 RVU. Setback measures the degree of re-aggregation of starch molecular chains [58, 61]. Starches with high setback viscosity values, such as NWYS (277.02 RVU), CSPS (276.85 RVU), CWYS (274.99 RVU), NSPS (274.77 RVU), PSPS (273.07 RVU) and CTYS (272.08 RVU) will have lower potentials for retrogradation in food products made with them. These starches also will have lesser ability to form gels after

cooling [50, 56] and form gels of high rigidity when utilized in food products (High setback is associated with a high degree of affinity among starch molecules caused by hydrogen bonding [69]. They could be utilized in the production of pounded yam that requires high cohesive pastes. Starches that exhibited low setback viscosity values include PWYS (266.22 RVU) and NTYS (269.21 RVU), and thus had high retrogradation tendencies. They have higher abilities to form gels after cooking and cooling. Their applications are products like weaning foods which require low viscosity and paste stability at low temperature [58, 70].

Pasting temperature varied significantly ($p<0.05$) from 59.79°C (lowest) in sample NWYS to 63.08°C (highest) in sample CWYS. Pasting temperature is the minimum temperature required to cook a given starch or food sample [55, 64]. Hence, starches with higher pasting temperatures may not be recommended for certain products due to high cost of energy in their preparations. Physical modification (HMT) significantly ($p<0.05$) induced increase in pasting temperature of the native starch of white yam from 59.79°C to 60.27°C, insignificantly ($p<0.05$) decreased that of native starch of trifoliate yam from 61.75°C to 61.66°C but did not have any effect on that of native starch of sweet potato. Chemical modification (acetylation) significantly ($p<0.05$) caused increase in the pasting temperature of the native starch of white yam (from 59.79 to 63.08°C), trifoliate yam (from 61.75 to 62.98°C) and sweet potato (from 60.50 to 62.09°C). Then, comparing among the starch sources, native starch of trifoliate yam recorded the highest pasting temperature (61.75°C), followed by native starch of sweet potato (60.50°C) while native starch of white yam had the lowest value of 59.79°C. Pasting temperature indicates the strength of the associative forces within the starch granules and it is also related to paste stability and water binding capacity [43, 71, 72]. The results reveal lower gelatinization temperatures of starch samples NWYS, PWYS, NSPS, and PSPS which translate into shorter cooking times and lower paste stabilities as opposed to the other starch samples with high pasting temperatures such as CWYS, CTYS, CSPS, NTYS and PTYS [71, 72]. However, all the starches had pasting temperatures that are lower than the boiling temperature of water, hence they can form pastes in hot water below boiling point. This implies that there will be huge energy savings at commercial scale utilizations of these starches. Also, pasting temperature correlates with water binding capacity, and a higher pasting temperature translates higher water binding capacity property of starch due to high degree of association between starch granules [65]. These results obtained from this study are lower in pasting temperature values than the results reported by Iwe et al [43] and Tortoe et al [65] which ranged from 74.35 – 94.45°C for high quality cassava-wheat flour blends and 84.00 - 87.27°C for plantain- *poundo* yam flours respectively.

Pasting or Peak time which is a measure of the cooking time for the starch or products, was significantly ($p<0.05$) highest (6.98 min.) in sample CWYS and lowest (6.10 min.) in sample NWYS. Physical modification through heat moisture treatment increased significantly ($p<0.05$) the pasting time of native starch of white yam from 6.10 – 6.33 min., insignificantly native starch of sweet potato from 6.38 – 6.44 min., but decreased insignificantly ($p<0.05$) that of native starch of trifoliate yam. Chemical modification through acetylation significantly ($p<0.05$) increased the pasting time of all the three native starches- white yam was from 6.10 – 6.98 minutes, trifoliate yam was from 6.46 – 6.79 minutes while sweet potato was from 6.30 – 6.44 minutes. Among the three starch sources, native starch of white yam had significantly ($p<0.05$) the shortest pasting time of 6.10 minutes while native starch of trifoliate yam significantly ($p<0.05$) had the longest pasting time of 6.46 minutes. From the results, there was correlation of pasting time with the pasting temperature, as the lower the pasting temperature of the starch, the shorter the pasting time of the starch. This relationship translates to energy and time savings on commercial scales. Therefore starch sample NWYS with the shortest pasting time and of course lowest pasting temperature will generate to more gains in time and energy than other starches when utilized in food preparations.

4. Conclusion

Proximate composition and pasting properties of native, physically modified (HMT) and chemically modified (acetylated) starches of white yam, trifoliate yam and sweet potato developed, were investigated. These developed starches exhibited various proximate composition and pasting properties that differentiated them into specialized roles for applicable utilizations in the manufacture of confectioneries, thickeners, stabilizers, binders, fillers, flavouring agents, texturizers, cheese, gravies, sauces, coating system, weaning foods, geling agents, composite flours, energy-giving foods, bakery foods, dairy products, drugs, beverage and brewery products. The results of the investigation have further revealed the potentials of such starch sources and modification treatments in: industrial time and energy savings, cutting-down the huge post-harvest food losses (a threat to food security); reduce depletion of foreign exchange reserve traceable to huge importation of wheat flour, and also promote the commercial and industrial exploitations of these local roots and tubers, as well as provide employment opportunities and strengthen the nation's economy.

5. Recommendations

The spectrum of researches should be extended to other local sources of starch in Nigeria and the entire Africa to: save some lesser known crops from going into extinctions, optimize utilizations of local food crops and encourage local agriculture and exploitation of their industrial potentials. Both modification methods (HMT and acetylation) used added functionalities to the starches. Thus, research beam should be extended to other forms and methods of starch modifications that will yield positivity in terms of value addition, food safety and resource-friendliness. These will

expand and enrich the research and economic base of Nigeria and even Africa.

Conflict of Interest Statement

The authors declare that they have no competing interests.

References

[1] Peter, R. S and Sandra, J. H (2015). The Contribution of Wheat To Human Diet and Health. *Food and Energy Security*, 4 (3): 178-202.

[2] Ryan, R. and Ms, R. D. (2017). 19 Foods That Are High in Starch. *Nutrition News Letter.*

[3] Xie, W. Q., Gong, Y. X. and Yu, K. X. (2017). Qualitative Analysis of Total Starch Content in Wheat Flour by Reaction Headspace Gas Chromograph. Anal Bioanalytical Chemistry. 409 (22): 5195-5200.

[4] Okereke, G. O., Igbabul, B. D. and Ikya, J. K. (2021). Evaluation of breads made from wheat flour, modified white yam/trifoliate yam/sweet potato starches and *Moringa oleifera* seed flour blends. International Journal of Food Science and Nutrition, 6 (2): 107-119.

[5] Khali, A., Mansour, E. and Dawodu, F. M. (1999). Influence of malt on rheological and baking properties of wheat-cassava composite flours. Dept. of Food Science and Technology, Faculty of Agriculture, Menosiya University, Shibin El-kom, Egypt.

[6] Iwe, M. O., Okereke, G. O. and Agiriga, A. N. (2014). Production and Evaluation of bread made from modified cassava starch and wheat flour blends. *Agrotechnology*. 4: 133.

[7] Eke-Ejiofor, J. (2015). Physico-chemical and pasting properties of starches from cassava, sweet potato and three leaf yam and their application in salad cream production. International Journal of Biotechnology and Food Science, 3 (2): 23-30.

[8] Barbara, P. and Samuel, CZ (2016) Formation of starch in plant cells. Cellular and Mollecular Life Sciences.

[9] Zia-Ud-Din, Xiong, H. and Fei, P. (2017). Physical and chemical modification of starches: A review. *Critical Reviews in food Science and Nutrition*. 57: (12).

[10] Boudries, N., Bensemra, N. A., Boubekum, M (2009) Physicochemical and functional properties of starches from sorghum cultivated in the Sahara of Algeria. Carbohydrate polymers 78 (3): 475-480.

[11] Slattery, C. J., Kavakli, I. H. and Okita, T. W. (2000). Engineering starch for increased quantity and quality. *Trends in Plant Science*, 5 (7), 291-298.

[12] Bawa, N. M., Agbenorhevi, J. K., Kpodo, F. M. and Sampson, G. O. (2000). Pasting properties of starch-okra pectin mixed system. CYTA-Journal of Food, 18 (1): 742-746.

[13] Wang, S., Li, C., Copeland, L., Niu, Q. and Wang, S. (2015). Starch Retrogradation: A Comprehensive Review. *Comprehensive Reviews in Food Science and Food Safety*, 14: (5): 568-585.

[14] Hoover, R., Hughes, T., Chung, H., & Liu, Q. (2010). Composition, molecular structure, properties, and modification of pulse starches: A review. Food Research International, 43 (2), 399–413.

[15] Eriksson, E. (2013) Flour from three local varieties of cassava (*Manihot Esculenta Crantz*): physicochemical properties, bread making quality and sensory evaluation. Swedish Univ. Agric. Sci. 371: 1-41.

[16] Aidoo, R., Oduro, I. N., Agbeworhevi, J. K., Ellis, W. O. and Pepra-Ameyaw, N. B. (2022). Physicochemical and pasting properties of flour and starch from new cassava accessions. International Journal of Food Properties, 25 (1).

[17] Fan, X., Zhu, J., Dong, W., Sun, Y., Lv, C., Guo, B. and Xu, R. (2019) Comparison of pasting properties measured from the wheat grain flour and extracted starch in barley (*Hordeum vulgare L.*). *PLoS ONE*, 14 (5): e0216978.

[18] Ocheme, O. B., Adedeji, O. E., Chinma, C. E., Yakubu, C. M. and Ajibo, C. H. (2018) Proximate composition, functional, and pasting properties of wheat and groundnut protein concentrate flour blends. Food Science and Nutrition, 6 (5): 1173-1178.

[19] Liu, L., Yang, T., Yang, J., Zhou, Q., Wang, X., Cai, J., Huang, M., Tingbo, D., Cao, W. and Jiang, D. (2022). Relationship of starch pasting properties and dough rheology, and the role of starch in determining quality of short biscuit. *Frontiers in Plant Science*, 13: 829229. doi: 10.3389/fpls.2022.829229.

[20] Zhou, Q., Li, X., Yang, J., Zhou, L., Cai, J., Wang, X., Dai. T., Cao, W. and Jiang, D. (2018). Spatial distribution patterns of protein and starch in wheat grain affect baking quality of bread and biscuit. J. Cereal Sci. 79, 362-369.

[21] Yang, T., Wang, P., Wang, F., Zhou, Q., Wang, X., Cai, J., Huang, M. and Jiang, D. (2022). Influence of starch physicochemical properties on biscuit-making quality of wheat lines with high-molecular-weight glutenin subunit (HMW-GS) absence. *LWT* 158: 113166. doi: 10.1016/j.lwt.2022.113166.

[22] Iwe, M. O., Wolters, I., Gort, G., Stolp, W. and vanZuilichem, D. J. (1999) Behaviour of gelatinization and viscosity in Soy-sweet potato mixtures by single-screw extrusion: A Response Surface Analysis.

[23] Ikegwu, O. J., Nwobasi, V. N., Odoh, M. O. and Oledinma, N. U. (2009) Evaluation of the Pasting and Some Functional Properties of Starch Isolated from Some Improved Cassava Varieties in Nigeria. African Journal of Biotechnology, 8, 2310-2315.

[24] Kavlani, N., Sharma, V. and Singh, L. (2012). Various techniques for the modification of starch and the applications of its derivatives. Research Journal of Pharmacy. 2230-8407.

[25] BeMiller, J. N. and Huber, K. C. (2015). Physical Modification of Food Starch Functionalities. Annual Review of Food Science and Technology, 6: 19-69.

[26] Adebowale, K. O., and Lawal, O. S. (2002). Effect of annealing and heat moisture conditioning on the physicochemical characteristics of Bambarra groundnut (*Voandzeia subterranea*) starch. *Die Nahrung*, 46 (5): 311-316.

[27] Miyazaki, M., Hong, P. V., Maeda, T. and Monta, N. (2006). Recent Advances in Application of Modified starch. Trends in Food Science and Technology, 17 (11): 591-599.

[28] Hirsch, J. B. and Kokini, J. L. (2002). Physico-chemical properties of wheat. Cereal Chemistry, 79: 102-107.

[29] Wang, Y. J. and Wang, L. (2002). Characterization of acetylated waxy maize starches prepared under catalysis by different alkali and alkaline-earth hydroxides. Starch/Starke, 54 (1), 25-30.

[30] Haq, F., Yu, H., Wang, L., Teng, L., Haroon, M., Khan, R. U., Mehmood, S., Amin, B-U., Ullallah, R. S., Khan, A. and Nazir, A. (2019). Advances in chemical modifications of starches and their applications. Carbohydrate Research, 476: 12-35.

[31] Cai, C and Wei, C. (2013). In situ observation of crystallinity disruption patterns during starch gelatinization. Carbohydr Polym., 92: 469-78.

[32] Sameh, A. K., Kamal-Alahmad, Sobio, N., Al-Farga, A., Farah, Z. and Tao, Z. (2016). Chemically Modified Starch and Utilization in Food Stuffs. International Journal of Nutrition and Food Science. 5 (4): 264-272.

[33] Adebowale, K. O., Afolabi, T. A. and Lawal, O. S. (2002). Isolation, chemical modification and physicochemical characterisation of bambarra groundnut (*Voandzeia subterranean*) starch and flour.. Food Chem. 78: 305-311.

[34] IITA (2005). Cassava Starch production. Integrated cassava project, International Institute of Tropical Agriculture (IITA), Ibadan.

[35] Onabolu, A., Abbas, A. and Bokanga, M. A. (2003). New Food Product from Cassava. *International Institute of Tropical Agriculture*, Ibadan, pp. 8-40.

[36] Kaur, K., Ahluwalia, P. and Singh, H. (2016). Cassava: Extraction of starch and utilization of flour in bakery products. International Journal of Food and Fermentation Technology, 6 (2): 351-355.

[37] Lim, S. T., Chang, E. H. and Chung, H. J. (2001). Thermal transition characteristics of heat-moisture treated corn and potato starches. Carbohydrate Polymers. 46: 107-115.

[38] Sathe, S. K. and Salunkhe, D. K. (1981). Isolation, partial characterization and modification of the Northern Bean (Phasous Vulgarris L) starch. Journal of Food Science. 46: 617-621.

[39] AOAC (2005). Official Methods of Analysis, 18th edn. Association of Official Analytical Chemists (A. O. A. C) Arlington, V. A, pp. 806-842.

[40] Ihekoronye, A. I. and Ngoddy, P. O. (1985). *Integrated Food Science and Technology for the Tropics*. Macmillian Publishers Ltd, London, pp. 10-22, 270-288.

[41] Kent, N. L. and Evers, A. D. (1994). Technology of cereals- an introduction for students of food science and agriculture. Pergamon, Elsevier Publications, Fourth Editions, Oxford.

[42] Igbabul, B. D., Num, G. and Amove, J. (2014). Quality Evaluation of Composite Bread Produced from Wheat, Maize and Orange Fleshed Sweet Potato Flours. American Journal of Food Science and Technology. 2 (4): 109-115.

[43] Iwe, M. O., Michael, N., Madu, N. E., Obasi, N. E., Onwuka, G. I., Nwabueze, T. U. and Onuh, J. O. (2017). Physicochemical and Pasting Properties High Quality Cassava Flour (HQCF) and Wheat Flour Blends. Agrotechnology, 6 (2): 167.

[44] Arkroyed, W. R. and Doughty, J. (1994). Legumes in Human Nutrition. Food and Agricultural Nutrition Studies Publication. Lima Bean (Phaseolus Lunatus). 1: 349.

[45] Hayma J. (2003). The storage of tropical agricultural products. Agromisa Foundation: Wageningen, Netherlands; P. 84.

[46] Ojo, M. O., Ariahu, C. C. and Chinma, E. C. (2017). Proximate, functional and pasting properties of cassava starch and mushroom (Plenrotus pulmonarius) flour blends. American Journal of Food Science and Technology. 5 (1): 11-18.

[47] Oko, A. O., Famurewa, A. C. and Nwaza, J. O. (2015). Proximate Composition, Mineral Elements and Starch Characteristics: Study of Eight (8) Unripe Plantain Cultivars in Nigeria. British Journal of Applied Science & Technology, 6 (3): 285-294.

[48] Abass, A. B., Onabolu, A. O. and Bokanga, M. (1998). Impact of the high-quality cassava flour technology in Nigeria. In: Root crops in the 21st century. Compiled by Akoroda, M. O. and Ngeve, J. M. Proceedings of the 7th Triennial Symposium of the International Society for Tropical Root Crops- Africa Branch (ISTRC-AB). Centre International des Conferences, Cotonou, Benin.

[49] Luzia, D. M. and Jorge, N. (2014). Study of antioxidant activity of non-conventional Brazilian fruits. *J. Food Sci. Technol*., 51 (6): 1167-1172.

[50] Tsakama, M., Mwangwela, A. M., Manani, T. A. and Mahungu, N. M. (2010). Physicochemical and pasting properties of starch extracted from eleven sweet potato varieties. African Journal of Food Science and Technology, 1: 90-98.

[51] Otegbayo, B., Yam, D. O. and Akinwumi, O. (2014). Physico-chemical and functional characterization of yam starch for potential industrial applications. Starch-stake. 66: 235-250.

[52] Zhu, F. (2015b). Impact of ultrasound on structure, physicochemical properties, modification and applications of starch. Trends in Food Science and Technology.

[53] Chen, Z., Schols, H. A. and Voragen, A. G. J. (2003). Physicochemical properties of starches obtained from three different varieties of Chinese sweet potatoes. Journal of Food Science, 68: 431-437.

[54] Maziya-Dixon, B., Dixon, A. G. O and Adebowale A. A (2004). Targeting different and users of cassava; genotype variations for cyanogenic potentials and pasting properties. A paper presented at ISTRC AB symposium 31st Oct, - 5th Nov. 2004. Whitesand Hotel, Mombasu, Keyan.

[55] Kiin-Kabari, D. B. (2015). Physico-Chemical and Sensory Properties of Bread Prepared from Wheat and Unripe Plantain Composite Flours Fortified with Bambara Groundnut Protein Concentrate. International Journal of Nutrition and Food Sciences. 4 (5): 594-599.

[56] Shimelis, E., Meaza, M. and Rakshit, S. (2006). Physicochemcial characteristics of flour and starches from improved bean (Phaseous vulgaris L.) varieties grown in East Africa. Electronic Journal of Agriculture and Engineering International, 8: 1-18.

[57] Sanni, A. I., Asiedu, M., and Ayernor, G. S. (2001). Influence of processing conditions on the nutritive value of ogi-baba, a Nigerian fermented sorghum gruel. Plant Foods for Human Nutrition, 56 (3): 217–223.

[58] Ezeocha, C. V. and Okafor, J. C (2016). Evaluation of the chemical, functional and pasting properties of starch from trifoliate yam (*Dioscorea dumentorum*) landraces. *European* Journal of Advanced Research in Biological and Life Sciences, 4 (2): 53-62.

[59] Arisa, N. N, Adelakan, A. O., Alamu, A. E and Ogunfowora, E. J (2013). The effect of pretreatmentof plantain (Musa paradisiaca) flour on the pasting and sensory characteristics of Biscuit. International Journal of Food and Nutrition Science, 2 (1) 10-23.

[60] Addy, R. N. A., Wireko-Manu, F. D. and Oduro, I. (2014). Physicochemical and Pasting Properties of Starch Extracted from Four Yam Varieties. Journal of Food and Nutrition Sciences, 2 (6): 262-269.

[61] Jimoh, K. O., Olurin, T. O. and Aina, J. O. (2009) Effect of drying methods on the rheological characteristics and colour of yam flours. African Journal of Biotechnology, 8: 2325-2328.

[62] Uzoma, A. and Ibe, C. (2011). The Functional properties, pasting and baking behavior of chemically modified sour cassava starches. African Journal of Food Science. 5 (12): 686 – 694.

[63] Adebowale, K. O., Olawumi, E. K. and Lawal, O. S. (2005). Functional properties of native, physically and chemically modified breadfruit (*Artocarpus artilis*) starch. *Industrial Corps and Products,* 21: 343-351.

[64] Rosida, R., Harijono, E. T. and Sriwahyuni, E. (2017). Functional and pasting characteristics of modified water yam flour (*Diocorea alata*). International Food Research Journal, 24 (5): 1880-1888.

[65] Tortoe, C., Aknor, P. T. and Ofori, J. (2019). Starches of two water yam (*Dioscorea alata*) varieties used as congeals in yogurt production. Food Science and Nutrition, 7 (3): 1053-1062.

[66] Venema, K., Minekus, M., and Havennar, R. (2004). Advance in vitro models of the gastrointestinal tract – Novel tools to study functionality of dietary fibres. In J. W. van der Kamp, N.-G. Asp, J. Miller Jones, & G. Schaafsma (Eds.), Dietary fibre: bio-active carbohydrates for food and feed (P. 108). The Netherlands: Wageningen Academic Press.

[67] Okafor, C. C and Ugwu, E. E (2013). Comparative study of pasting properties of High fibre plantain based flour intended for Diabetic food (fufu). Work Academy of Science, Engineering and Technology, 79, 193-197.

[68] Ikegwu, O. J., Okechukwu, P. E. and Ekumankama, E. O. (2010). Physicochemical and pasting characteristics of flour and starch from Achi (Brachystegia eurcoma). Seed. Journal of Food Science, 8: 58-66.

[69] Sefa-Dedeh, S. and Sackey, E. K. (2002). Starch structure and some properties of cocoyam (*Xanthosoma sagittifolium* and *Colocasia esculenta*) starch and raphides. Food Chemistry, 79 (4): 435-444.

[70] Oduro, I., Ellis, W. O., Nyarko, L., Koomson, G. and Otoo, J. A. (2001). Physicochemical and pasting properties of flour from four sweetpotato varieties in Ghana. Proceedings of the Eight Triennial Symposium of the International Society for Tropical Root Crops (ISTRC-AB), Ibadan, Nigeria. 2001, 12-16 November.

[71] Afoakwa, E. O. and Sefa-Dedeh, S. (2002). Viscoelastic properties and changes in pasting characteristics of trifoliate yam (*Dioscorea dumetorum*) starch after harvest. Food Chemistry, 77: 85-91.

[72] Iwe, M. O and Agiriga, A. N. (2015). Effect of Different Harvesting Regimes on the Pasting Properties of Selected Varieties of Banana – A Response Surface Study. Agrotechnol, 4: 132.