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Research Article

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Physicochemical and Functional Properties of Modified Starches of White Yam, Trifoliate Yam and Sweet Potato

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Abstract

Starches from white yam, trifoliate yam and sweet potato were modified through heat moisture treatment (HMT) and acetylation before investigating their physicochemical and functional properties for applicable utilizations. CWYS (acetylated white yam starch) significantly ($p<0.05$) gave highest values in: blue value index (49.00%), amylose (33.65%), syneresis (16.25%); and lowest values in: oil absorption capacity (54.33%), solubility (16.40%), amylopectin (66.38%) and gelation concentration (7.00%). PSPS (heat moisture treated sweet potato starch) significantly ($p<0.05$) yielded the highest values in: water absorption capacity (167.00%), solubility (24.15%) and lowest value in swelling power (5.43%) while CSPS (acetylated sweet potato starch) significantly ($p<0.05$) scored highest value in viscosity (2.25 Kpa). NTYS (native trifoliate yam starch) significantly ($p<0.05$) had the highest in oil absorption capacity (104.67%), swelling power (75.50%) and amylopectin (73.60%) but significantly ($p<0.05$) toddled in blue value index (35.68%), gelation concentration (7.00%) and amylose (26.40%). PWYS (heat moisture treated white yam starch) significantly ($p<0.05$) scored highest values in gelation concentration (9.00%); while PTYS (heat moisture treated trifoliate yam starch) significantly ($p<0.05$) was highest in amylopectin (73.60%) and significantly ($p<0.05$) had lowest values in amylose (26.40%) and syneresis (11.90%). NWYS (native starch of white yam) significantly ($p<0.05$) had lowest value in viscosity (1.25 Kpa). NSPS (native starch of sweet potato) was significantly ($p<0.05$) lowest in water absorption capacity (62.50%) while CTYS (acetylated trifoliate yam starch) significantly ($p<0.05$) yielded lowest values in gelation concentration (7.00%). These results highlighted the potentials of these starches in the manufacture of food additives, condiments, beverages, and bakery products.

Keywords

Native and modified starches, Roots and tubers, White yam, Trifoliate yam, Sweet potato, Acetylation, Heat moisture treatment, Functional properties, Starch utilizations

Abbreviations

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; **WAC**: Water absorption capacity; **OAC**: Oil absorption capacity

Introduction

Starch, the most important source of carbohydrates in human diet remains a renewable and vast resource for various industries. As an agro-sourced polymer, its growing popularity is traceable to beneficial characteristics such as wide availability, low cost and compost-ability without toxic residue [1]. Also, starch constitutes 65-85% of grain based flour and thus plays key functional and nutritional roles in all flour based products [2, 3]. Thus, demands and applications of starch in both food and non-food systems are on the increase.

Pure starch is a soft, white, odourless and tasteless powder that is insoluble in solvents such as water and alcohol. Starch is essentially composed of two types of α-glucose polymers- the linear amylose (20-30%) and branched amylopectin (70-80%); and they play key role in determination of physicochemical properties of starch [4, 5]. Starch is contained in such staple foods as cassava, potatoes, cocoyam, wheat, maize, sweet potatoes, rice and yam [6]. Though, roots and tubers are second in importance to cereals as global sources of carbohydrates [7], processing starch from them is more cost-effective. Besides, extraction of starches from freshly harvested roots and tubers is a feasible way to control postharvest food losses owing to their poor storage-stability. Presently, Nigeria is the leading world yam producer [8] and the second leading producer of sweet potato globally [9] but yet yams and sweet potatoes are not fully utilized domestically and industrially. At least expanded utilizations of yams and sweet potatoes through industrial exploitations will: curb postharvest food losses threatening food security; create job opportunities and accelerate economic growth. Of course, there is burning desire in Nigeria to transform these selected roots and tubers from mainly domestic food crops into key industrial crops.

Physicochemical and functional properties of starches are key factors driving their commercial value and applicable utilizations. Amylose/amylopectin ratio, degree of polymerization, granule size/structure, interaction between starch molecules and other molecular properties determine the physicochemical and functional properties of starch [10]. More so, starches of different origins vary in compositional and structural properties and this variance affects properties of the end products. Surprisingly, the properties that define sweet potato and yam starches of Nigerian origin are not well detailed compared with the current market starches from cassava, maize and wheat. By detailing the physicochemical and functional properties of these starches (i.e., both native and modified), they can be differentiated and assigned specialized roles.

Starch can be classified into two types: native and modified [11]. Native starches, obtained by separation of occurring starches from their natural sources, can be used directly to produce certain foods but has limited usage in food industry. This is due to their lack of certain desired functional properties such as solubility in cold water, strong viscosity and thickening power after cooking, high shear resistance, thermal resistance, low tendency towards retrogradation, stability to low and high pH [6]. These shortcomings of native starches can be overcome through starch modifications [12].

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 [13]. The different ways of modifying native starch include altering one or more of the following properties: paste temperature, solids/viscosity ratio, starch paste viscosity, heat and or mechanical agitation (shear), retrogradation tendencies, ionic and hydrophilic nature [1]. Starch modification stabilizes starch granules during processing and expands its spectrum of applications. The modified starch is the choice of food processors because of their improved behavioural characteristics than those provided by native starches.

Techniques employed for starch modifications are broadly classified into four categories: physical, chemical, enzymatic and genetic modifications; and they have been used to produce such diverse products as food, paper, textiles, adhesives, beverages, pharmaceuticals and building materials [11, 14, 15]. However, starch modifications are mostly achieved by physical and chemical means [10, 16]. Physical modification methods include treatments such as superheating, dry heating, osmotic pressure treatment, multiple deep freezing and thawing, vacuum ball milling, pulsed electric fields treatment, etc. [10, 13]. They are simple, cheap and safe because they require no chemical and biological agents [1, 11], and are given more preference in food industry. They involve physical treatments that do not result in modification of the D-glucopyranosyl units of the starch polymer molecules [11]. Generally, they produce changes only in the packing arrangements of starch polymer molecules within granules and the overall structures of starch granules, but such changes can have significant impacts on the properties of the starch, the attributes of its pastes and gels, and even its digestibility.

Food grade starches are chemically modified mainly to increase paste consistency, smoothness and clarity, impart freeze-thaw and cold storage stabilities, improve adhesion and film formation, improve emulsion stability, modify cooking characteristics, decrease gelling tendencies and retrogradation [1]. Chemical modification is generally achieved through derivatizations, such as acetylation, cationization, oxidation, acid hydrolysis and cross-linking, with each treatment providing products of distinct functionality. It involves the introduction of functional groups into the native starch molecules thereby resulting in markedly altered physicochemical properties [1, 17]. According to Haq et al. [17] the hydroxyl group(s) of starch molecules is replaced by functional groups like carboxyl, acetyl etc. Such modification of native granular starches affects their proximate compositions, gelatinization, retrogradation, and pasting properties [18]. Chemical modification stabilizes intra- and inter-molecular bonds at random locations in the starch granule. The functional properties achieved by modified starches depend, inter alia, on starch source, reaction conditions, type of substituent, degree of substitution (DS), and the distribution of the substituents in the starch molecule [17, 19].

Thus, in view of this, modification of starches from selected roots and tubers (white yam, trifoliate yam and sweet potato) using physically and chemically methods through heat moisture treatment (HMT) and acetylation respectively in order to investigate their physicochemical and functional properties for applicable utilizations in a variety of industries, was the focus of this study.

Materials and Methods

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.

Methods

Starch production

The method of Kaur et al. [20] with slight modification was used in production of starches as shown in figure 1. Two kilograms, each of hand-peeled white yam tuber/trifoliate yam tuber/sweet potato root were washed thoroughly, chopped into approximately 1.0 cm cubes and grated for 10 min using double barrel grater (Stainless Steel Model). The resultant pulp was suspended in ten times its volume with distilled water, stirred for 5 min and subsequently sieved through a 0.075 mm mesh screen. The filtrate (starch slurry) was allowed to stand for 8 h and the supernatant decanted off after sedimentation in order to remove impurities. The starch slurry (sediment) was re-suspended in distilled water and stirred for 5 min. Filtration was repeated as before and the filtrate was allowed to sediment for 8 h before decanting off the supernatant. The starch (i.e., sediment) obtained from each selected root/tuber was oven dried in a cabinet dryer (RXH-5-C model) at 55 ± 2 ^{0}C for 1 h. The oven dried starches were cooled, packaged in polyethylene bags and stored in airy clean dry place at room temperature (27 ^{0}C) prior to analyses.

Modification of the starches

The 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.

Heat moisture treatment (HMT)

The method of Lim et al. [21] was used. Distilled water was sprayed onto 200 g 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^{o}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^{o}C. The starch sample was ground and sieved through a 0.075 mm mesh screen into plastic bags and stored at room temperature (27 ^{0}C) prior to analyses.

Acetylation

The method of Sathe and Salunkhe [22] 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 ^{0}C for 48 h. The acetylated starch was packaged in a polyethylene bag and stored at room temperature (27 ^{0}C) for further analyses.

Determination of the amylose and amylopectin contents of the starch samples

Amylose content

The amylose content of the native/ modified starch sample was determined using the method of Williams et al. [23]. The starch sample (0.1 g) was weighed into a 100 mL volumetric flask. Then 1 mL of 99.7-100% (v/v) ethanol and 9 mL 1 N sodium hydroxide were carefully added. The mouth of the flask was covered with parafilm, and the contents were properly mixed. The sample was heated for 10 min in a boiling water bath to gelatinize the starch (the timing started when boiling began). The sample was removed from the water bath and allowed to cool, then made up to the mark with distilled water and shaken thoroughly. Then 5 mL were pipetted into another 100 mL volumetric flask and 1.0 mL of 1 N acetic acid and 2.0 mL of iodine solution were added. The flask was topped up to the mark with distilled water. Absorbance (A) was read using a spectrophotometer at 620 nm wavelength. The blank contained I mL of ethanol and 9 mL of sodium hydroxide, boiled and topped up to the mark with distilled water. Finally, 5 mL were pipetted into a 100 mL volumetric flask; 1 mL of 1 N acetic acid and 2 mL of iodine solution were added and then topped up to the mark. This was used to standardize the spectrophotometer at 620 nm. The amylose content was calculated as:

$$Amylose\ content\ (\%) = (3.06 \times absorbance \times 20)$$

Amylopectin content

Amylopectin content was calculated using the below equation as explained by Huang et al. [24] and reported by Ekanayake et al. [25].

$$Amylopectin\ content\ (\%) = (100 - amylose\ content)$$

Functional properties of the starch samples

Swelling power

Swelling index of starch samples were determined using the method described by Ukpabi and Ndume [26].

Water Absorption Capacity

The method of Onwuka [27]. was used to determine the water absorption capacity of the starch samples.

Oil Absorption Capacity

It was determined by the method of Onwuka [27].

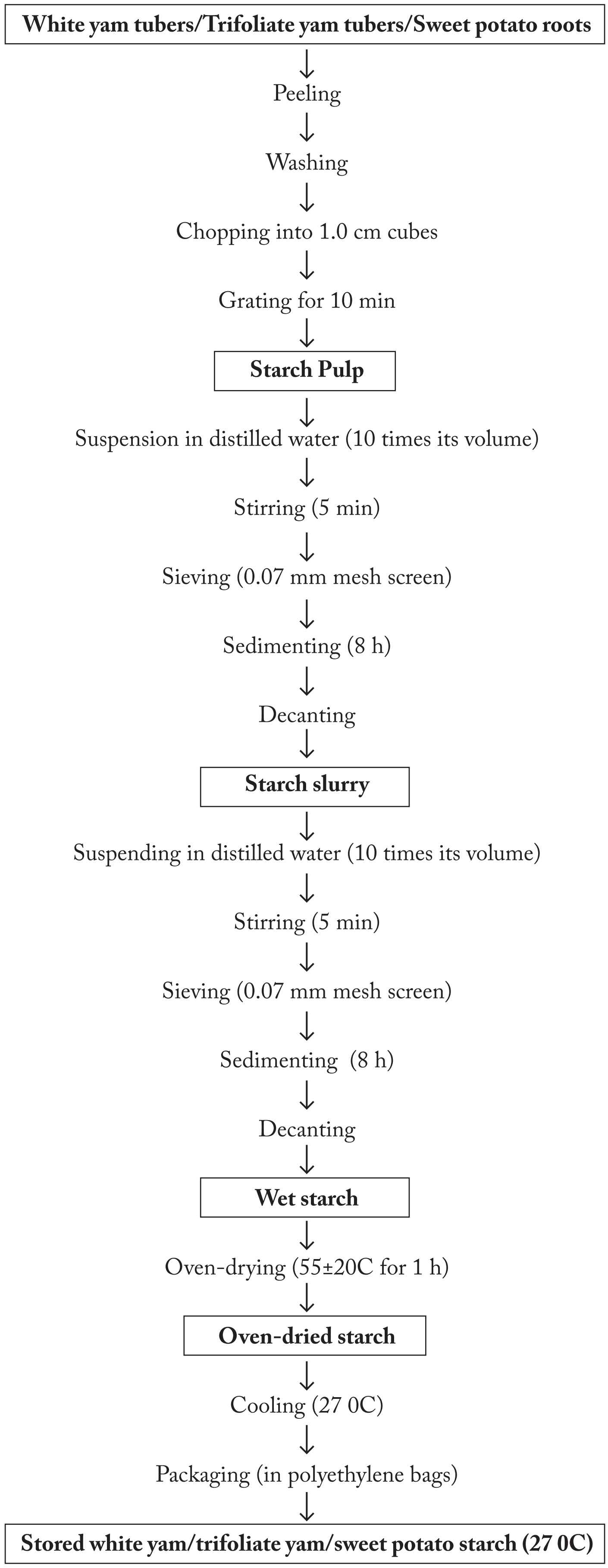

Figure 1: Flow chart for production of white yam/trifoliate/sweet potato starch.
Source: Modified Kaur et al. [20].

Blue Value Index

The blue value index (BVI) was determined using the method described by Nwokocha and Ogunmola [28].

Solubility

The cold-water extraction as described by Udensi and Onuora [29] was employed.

Gelation Capacity

It was determined according to the method of Coffman and Garcia [30].

Viscosity Test

The method of Onwuka [27] was employed in determination of the viscosities of the starches.

Syneresis

Syneresis was determined according to the method described by Ribotta et al. [31].

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 chemical and functional properties of the native and modified starches, yielding a total of twenty-seven (27) samples/experiment analyzed.

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.

Results and Discussion

Effects of root/tuber starch sources and modification methods on the physicochemical and functional properties of native and modified starches of white yam, trifoliate yam and sweet potato

The results of the physicochemical and functional properties of native, physically modified (HMT) and chemically modified (acetylated) starches of white yam, trifoliate yam and sweet potato are presented in the table 1.

The water absorption capacity (WAC) of the starches significantly ($P<0.05$) ranged from 62.50% (lowest value) in sample NSPS to 167.00% (highest value) in sample PSPS. Water absorption capacity (WAC) measures the ability of flour to absorb water and swell for improved consistency in food [32, 33]. From the results, the physical modification (HMT) method significantly ($p<0.05$) improved the water absorption capacity of all the native starches more than the chemical modification method (acetylation) irrespective of the starch source. Similarly, Awolu et al. [34] reported that physical modification (HMT) of native starch of tigernut significantly improved its water absorption capacity. The results show that hydrophilic tendencies of the starches improved significantly ($p<0.05$) after both physical (HMT) and chemical (acetylation) modification treatments. This result is in line with the results of Lawal [35], Ibikunle et al. [36] and Okereke et al. [15] that observed significant improvements in the water absorption 5 capacities of cocoyam (from 57.00 to 80.00%), African star apple kernel starch (from 0.52% to 1.49%) and cassava starches (from 51.00% to 67.00%) respectively after being acetylated; but contradicts the findings of Yusuf et al. [37] that observed decreased water absorption capacities of Jack bean starches (from 3.11% to 2.81%) after acetylation. Among the three selected starch sources, native starch of white yam had the highest water absorption capacity of 85.0% while native starch of sweet potato had the lowest value of 62.50%. This could be attributed to the differences in amylose/amylopectin ratio, degree of polymerization, granule size/structure as well as to the difference in chain length distributions among the different starch sources [38, 39]. Water absorption capacity is important in bulking and consistency of products as well as in baking applications [15, 33, 40] that require hydration to improve handling quality as well as emulsion, foaming, gelation and viscosity [15]. This imbibition of water is an important functional trait in foods such as ketchups, sausages, custards and doughs [39, 41, 42].

The oil absorption capacity (OAC) was observed to be significantly ($p<0.05$) highest (104.67%) in starch sample NTYS and lowest (54.33%) in starch sample CWYS. The results revealed that the oil absorption capacity of the native starch of white yam significantly ($p<0.05$) increased from 55.67% to 85.33% after physical modification (HMT) treatment, but significantly ($p<0.05$) reduced from 55.67% to 54.33% after chemical modification (acetylation) treatment. For the native starch of trifoliate yam, both chemical (acetylation) and physical (HMT) modification treatments reduced significantly ($p<0.05$). While for the native starch of sweet potato, physical modification (HMT) significantly ($p<0.05$) increased the oil absorption capacity from 74.67% to 80.00% and the chemical modification (acetylation) treatment significantly ($p<0.05$) reduced it from 74.67% to 69.00%. These results are in agreement with the report of Bolade et al. [43] in which acetylation decreased the oil absorption capacity of sweet potato starch (99.00% to 58.00%) and water yam starch (88.00% to 58.00%); but surprisingly, are in conflict with the results of Lawal [35], Uzoma and Ibe [40], Okereke et al. [15] and Ibikunle et al. [36] that reported significant appreciation of oil absorption capacities of the acetylated starches of new cocoyam (92% to 98%), three cassava varieties (46.3% to 53.72%), five improved cassava species (75.73% to 85.60%) and African star apple kernel starch (by 2.00%) respectively. Then, comparing among the three starch sources (i.e white yam, trifoliate yam and sweet potato), native starch of trifoliate yam had the highest value of 104.67% while the native starch of white yam had lowest value of 55.67%. Oil absorption capacity (OAC) is useful in structure interaction in food especially in flavor retention, mouth-feel, improved palatability and extension of shelf life particularly in soups, bakery or meat products [15, 33]. The formation of amylose-lipid complexes promotes oil absorption [40]. Hence, the binding of lipid is somewhat dependent on the molecular availability of solubility of starch polymers, especially amylose [44]. The results show that starch sample

Table 1: Physicochemical and functional properties of native, physically modified (HMT) and chemically modified (acetylated) starches of white yam, trifoliate yam and sweet potato.

Starch Sample	Water Absorption Capacity (%)	Oil Absorption Capacity (%)	Swelling Power (%)	Solubility (%)	Viscosity (Kpa)	Blue Value Index (%)	Amylose (%)	Amylo-pectin (%)	Gelation Conc. (%)	Syneresis (%)
NWYS	85.00 ± 0.00[f]	55.67 ± 0.00[h]	19.15 ± 0.14[h]	21.40 ± 0.00[e]	1.25 ± 0.07[b]	45.20 ± 0.07[c]	27.20 ± 0.14[e]	72.80 ± 0.14[c]	8.00 ± 0.00[bc]	14.40 ± 0.14[c]
NTYS	75.00 ± 0.42[g]	104.67 ± 0.15[a]	75.50 ± 0.00[a]	22.90 ± 0.00[c]	1.41 ± 0.00[b]	35.68 ± 0.11[i]	26.40 ± 0.00[g]	73.60 ± 0.00[a]	7.00 ± 0.00[d]	12.50 ± 0.00[f]
NSPS	62.50 ± 0.00[h]	74.67 ± 0.00[f]	62.25 ± 0.35[b]	23.30 ± 0.07[b]	1.54 ± 0.00[b]	44.23 ± 0.14[d]	28.60 ± 0.00[c]	71.40 ± 0.00[e]	8.00 ± 0.00[bc]	13.90 ± 0.00[d]
PWYS	101.10 ± 0.14[d]	85.33 ± 0.14[c]	29.03 ± 0.00[g]	23.25 ± 0.21[b]	1.50 ± 0.02[b]	47.00 ± 0.00[b]	31.32 ± 0.42[b]	68.68 ± 0.04[f]	9.00 ± 0.00[a]	15.13 ± 0.04[b]
PTYS	118.00 ± 0.14[c]	78.00 ± 0.00[e]	60.00 ± 0.07[d]	22.65 ± 0.07[d]	1.57 ± 0.00[b]	37.00 ± 0.07[g]	26.40 ± 0.00g	73.60 ± 0.00[a]	8.00 ± 0.00[bc]	11.90 ± 0.00[h]
PSPS	167.00 ± 0.28[a]	80.00 ± 0.07[d]	5.43 ± 0.25[i]	24.15 ± 0.00[a]	1.63 ± 0.03[b]	39.00 ± 0.00[f]	26.98 ± 0.11[ef]	73.03 ± 0.11[b]	8.50 ± 0.00[ab]	12.60 ± 0.07[f]
CWYS	91.50 ± 0.71[e]	54.33 ± 0.00[i]	54.33 ± 0.00[e]	16.40 ± 0.14[g]	1.72 ± 0.14[ab]	49.00 ± 0.14[a]	33.65 ± 0.08[a]	66.36 ± 0.08[g]	7.00 ± 0.00[d]	16.25 ± 0.07[a]
CTYS	117.50 ± 0.71[c]	94.67 ± 0.14[b]	39.24 ± 0.14[f]	20.00 ± 0.00[f]	1.54 ± 0.71[b]	36.10 ± 0.14[h]	26.55 ± 0.14[g]	73.45 ± 0.14[a]	7.00 ± 0.00[d]	12.30 ± 0.00[g]
CSPS	125.00 ± 0.71[b]	69.00 ± 0.00[g]	60.98 ± 0.00[c]	22.80 ± 0.07[cd]	2.25 ± 0.01[a]	42.05 ± 0.07[e]	27.50 ± 0.00[d]	72.50 ± 0.00[d]	7.50 ± 0.71[cd]	13.55 ± 0.07[e]

Values are mean ± standard deviation of triplicate determinations; Values with different superscripts within the same column are significantly different at (P<0.05).

KEY: WAC= Water absorption capacity; OAC = Oil absorption capacity ; 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

NTYS with the highest value in oil absorption capacity than other starches will have a higher degree of flavor retention and mouth feel than the other starches [33].

The swelling power of the starches was recorded highest (75.50%) in sample NTYS and lowest (5.43%) in sample PSPS. Physical modification (HMT) significantly ($p<0.05$) improved the swelling power of the native starch of white yam from 19.15% to 29.03%; depreciated ($p<0.05$) significantly the swelling power of the native starch of trifoliate yam from 75.50% to 60.00% and that of the sweet potato from 62.25% to 5.4%. Chemical modification (acetylation) treatment improved significantly ($p<0.05$) the swelling power of native starch of white yam (i.e., from 19.15 – 54.33%); but depreciated significantly ($p<0.05$) the swelling powers of the native starches of trifoliate yam (from 75.50 – 39.24%) and sweet potato (from 62.25 – 60.98%). The result of the effect of acetylation on native starch of white yam agrees with the earlier reports on acetylated starches [15, 35, 41]. According to Lawal [35], acetylation reduces intermolecular association in the starch granules and this reduces structural limitations against swelling. Among the three starch sources, native starch of trifoliate yam had the highest value of 75.50% while native starch of white yam had the lowest value of 19.15%. This is in agreement with the report of [45] that swelling behavior is the property of its amylopectin and amylose contents where amylose acts as a diluent and inhibitor of swelling. This also agrees with other reports which stated that the packing of amylose and amylopectin within the granules vary among starches from different botanical sources [15, 40, 41]. These differences in swelling power values of various starches are largely attributed to different intensities of molecular associative forces inside the granules and these factors are governed by factors which include amylose and amylopectin contents and ratio, molecular weight, conformation, polymerization degree of both fractions, degree of branching of amylopectin and the effect of different modification treatments on the structure of the starch [46, 47]. In some instances, the amylose chain contributes effectively to maintaining the granule integrity by complexing with lipids and facilitating the linkage among amylopectin chains [23, 42]. The amylose content of the starch granules varies with the botanical source of the starch and is affected by the climatic conditions and soil type during growth [15, 40, 48]. From the results obtained, starches of NTYS, NSPS, PTYS, CSPS, CWYS and CTYS are preferred in food systems where high swelling ability would be needed to control volume or size [15, 40]. Swelling power is an indication of the water absorption index of the granules during heating [47]. It reflects the extent of the associative forces within the granule.

Significant differences exist among the solubility values of the different starch samples. The values for the solubility of the starches ranged from 16.40% (lowest) in CWYS to 24.15% (highest) in PSPS. Physical modification through heat moisture treatment significantly ($p<0.05$) increased the solubility values of the native starches of white yam (i.e NWYS < PWYS or from 21.40 to 23.25%) and sweet potato (NSPS < PSPS or from 23.30 to 24.15%), but decreased that of the native starch of trifoliate yam (i.e NTYS > PTYS or from 22.90 to 22.65%). Then, chemical modification through acetylation significantly ($p<0.05$) decreased the solubility values of all the native starches- white yam (i.e from 21.40 to 16.40%), trifoliate yam (from 22.90 to 20.00%) and sweet potato (from 23.30 to 22.80%); this result agrees with the reports of Lawal [35], Uzomah and Ibe [40] and Okereke et al. [15] on solubility values of acetylated starches of various botanical sources. Comparing among the native starches of the three starch sources, native starch of sweet potato had the highest value of 23.30% against 22.90% of trifoliate yam and 21.40% of white yam. Solubility provides evidence of the interaction between starch chains of amorphous and crystalline domains and thus indicates the degree of dispersion of granules after cooking [4, 45]. The solubility could therefore imply the amount of amylose leached out when swollen [15] and the higher the amount of amylose leached out, the higher the solubility [42]. Decrease in solubility values of some of the starches could be as a result of their low amylose contents. Factors such as origin, granule size and other components of the starch influence the solubility of starches. Solubility has been shown to positively correlate with swelling. Srichuwong et al. [49] indicated that solubilization occurred along with granular swelling. Solubility is an important characteristic for production of thickeners, binders and bakery products [12, 50].

Viscosities of the starches were observed to be significantly ($p<0.05$) highest (2.25 KPa) in sample CSPS and lowest (1.25 KPa) in sample NWYS. Viscosity is the internal friction of a fluid or its tendency to resist flow [51]. It is an important functional property that affects mouthfeel and textural quality of fluid foods such as beverages and batters and the design of processing line. Fluid flow through pipes, pumps, extruders, heat exchangers and spray dryers are a function of viscosity of material being processed [52]. Even the role of starch as a thickener in food industries is dependent on this property. The viscosities of all the native starches were significantly ($p<0.05$) improved by both physical and chemical modification treatments through heat moisture treatment and acetylation respectively. Native starches of white yam and sweet potato had their viscosities significantly ($p<0.05$) improved most by chemical modification (acetylation) while native starch of trifoliate yam had its viscosity improved most by physical modification through heat moisture treatment. The results are in line with the results of Lawal [35] and Okereke [41] on acetylated starches of new cocoyam and cassava respectively. The increase in viscosity of acetylated starch was because of disruption of inter and intra-molecular hydrogen bonds of the starch chains by the ester groups [35]. This weakened the granular structure of starch, leading to an increase in motional freedom of starch chains in amorphous regions [15]. Ester groups are efficient in preventing amylose retrogradation [35, 53]. Acetylation prevents gelling, weeping (syneresis) and maintains good textural appearance. Wide applications of acetylated starches of high viscosities are in foods as texturizing agents and they provide good freeze-thaw stability [53] that is utilized in the making of frozen sauces in vegetables, appetizers and pastries [10]. In paper industry, starch acetate can provide extremely good viscosity stability. Reddy and Bhotmange [54] reported that in the manufacture of the food aimed at supplying a substantial amount of nutrient such as weaning and supplementary foods, it is desirable to include materials that do not form highly viscous pastes at low solids concentrations. Comparing the three native starch sources, sweet potato (NSPS) had highest viscosity value of 1.54 KPa while white yam had the lowest value of 1.25 KPa. These results project sweet potato roots as good sources of starch for making texturizing agents [15, 55] whereas samples NWYS and NTYS, with lower viscosity values permit higher concentrations to be used for forming rigid gels in gums, pastries and jellies. Viscosity is an important quality parameter for liquid and semi liquid pastes or pureed products whose measurement and control are essential in determining the quality of the pasting products [56].

The blue value index was significantly ($p<0.05$) highest (49.00%) in sample CWYS and lowest (35.68%) in sample NTYS. Blue value index indicates the extent of the breakdown of the starch molecules in the native starches [15, 41, 57]. Thus, starches with high blue value index due to more damaged starch granules, showed that solubilization of amylose molecules seems to be more pronounced in in them [15, 35]. From the results, both physical modification (HMT) and chemical modification (acetylation) processes significantly ($p<0.05$) increased the blue value index of the three native starches. For native starches of white yam and sweet potato, highest improvements of 49.00% and 42.05% respectively were obtained after chemical modification (acetylation) processes while native starch of trifoliate yam was best improved through physical modification (HMT) processes. Then, among the three native starch sources, white yam starch significantly ($p<0.05$) had the highest blue value index of 45.20% while trifoliate yam had significantly ($p<0.05$) lowest value of 35.68%. Starches with low blue value index than other starch samples may be attributed to less damaged starch granules in them [57].

The amylose content varied significantly ($p<0.05$) from 26.40% (lowest) in NTYS and PTYS to 33.65% (highest) in CWYS. Amylose content is an important factor affecting starch pasting and retrogradation behaviors. Amylose tends to retrograde and is considered primarily responsible for retrogradation of starch. It provides surface and textural regularity, elasticity and sticky characteristics to starch based products [57]. Physical modification through heat moisture treatment led to significant (p<0.05) increase in amylose content of native starches of white yam (i.e., 27.20% to 31.32%) and decrease in that of native starches of sweet potato (28.60% to 26.98%), but never affected that of the native starch of trifoliate yam. Then, chemical modification through acetylation induced significant (p<0.05) increase in the amylose contents of native starches of white yam (7.20% to 26.55%) and trifoliate yam (6.40% to 26.55%) but declined that of sweet potato starch (i.e., 28.60% to 27.50%). Comparing among the three native starch sources, highest amylose content was recorded highest by sweet potato (28.60%), followed by white yam (27.20%) and trifoliate yam (26.40%). The amylose contents recorded were higher than that of cassava starch (17.00%), but similar to those of trifoliate yam starches (11.689-28.060%) and corn starches of 24.00-26.00% [58, 59]. Amylose influences the packing of amylopectin into crystallites and the organization of the crystalline lamella within starch granules, thereby affecting properties related to water uptake such as swelling and gelatinization [4, 60]. Variations of amylose contents in starches of the same botanical source affect the granule size distribution, molecular characteristics of amylose and amylopectin; and functional properties such as paste temperature and viscosity [4, 15]. Starches with higher amylose content are more exothermic and can form a more stable amylose-lipid complex that affects the thermal properties and gel formation [41, 60]. Increase in amylose concentration, leads to reduction in gel stickiness but increases in gel firmness.

Amylopectin contents of the starch samples ranged significantly (p<0.05) from 66.38% in CWYS to 73.60% in NTYS and PTYS. Physical modification (HMT) significantly (p<0.05) increased the amylopectin content of native starch of sweet potato from 71.40% to 73.03% but reduced that of native starch of white yam from 72.80% to 68.38% and did not affect that of the native starch of trifoliate yam. Chemical modification (acetylation) of the starches led to decrease in amylopectin contents of the native starches of white yam significantly (p<0.05) from 72.80% to 66.36% and insignificantly (p<0.05) from 73.60% to 73.45% for trifoliate yam; but significantly (p<0.05) increased that of native starch of sweet potato from 71.40% to 72.50%. Among the three starch sources, native starch of trifoliate yam (NTYS) had the highest value of 73.60% while native starch of sweet potato (NSPS) had the lowest value of 71.40%. The results obtained agree with the results of Amoo et al. [61] that reported amylopectin contents of four yam varieties ranging from 68.45-72.00%; and Ezeocha and Okafor [59] who reported values ranging from 71.940 - 88.311% for starches extracted from fourteen trifoliate yam landraces. According to Beech et al. [62] amylose/amylopectin ratio influences flours' behaviors in food systems. Amylopectin chain length distribution is an important factor that determines certain starch properties [60] and it varies with botanical source [6]. Low molecular weight amylopectin with long branched chains facilitates the formation of amylose-lipid helicoidal complex [30, 41].

The gelation concentration (an index of gelation capacity) significantly (p<0.05) varied from 7.00% in samples NTYS, CWYS and CTYS to 9.00% in sample PWYS. The Least Gelation Capacity (LGC) is defined as the lowest concentration required for the formation of a self-supporting gel [42]. Samples with lower gelation concentrations have greater gelling capacities [15, 42, 63]. Physical modifications (HMT) of the native starches led to significant (p<0.05) increase of the gelation concentrations of all the starch samples: white yam increased from 8.00 to 9.00%, trifoliate yam increased from 7.00 to 8.00% and sweet potato increased from 8.00% to 8.50%. This shows that gelation capacities of native starches of white yam, trifoliate yam and sweet potato are not improved through heat moisture treatments (physical modification). Chemical modification (acetylation) of the native starches resulted in significant (p<0.05) decreases in the gelation concentrations of samples of white yam from 8.00% to 7.00% and sweet potato from 8.00% to 7.50% but did not have any effect on the trifoliate yam. The result has shown that chemical modification of native starches of white yam and sweet potato through acetylation significantly (p<0.05) improved their gelation capacities but did not have effect on the trifoliate yam starch. The observations are in conflict with the results of Lawal [35] and Okereke et al. [15] that reported significant increase in gelation concentrations of native starches of new cocoyam (from 8.00 to 10.00%) and improved cassava species (from 8.00 to 11.20%) respectively through acetylation treatments. Among the three starch sources, native starches of white yam and sweet potato had the highest gelation concentration value of 8.00% while that of trifoliate yam had lowest value of 7.00%. The result is evidence that native starch of trifoliate yam is a better gelating food additive amongst roots and tuber crops investigated in this study. Variations in gelling properties have been associated with the relative ratio of different constituents such as proteins, lipids and carbohydrates [15, 41]. The results showed starch samples NTYS, CWYS and CTYS as much better gelating agents than all the others.

The values of the syneresis of the starch samples significantly (p<0.05) ranged from 11.90% in PTYS to 16.25% in CWYS. Physical modification through heat moisture treatment significantly (p<0.05) increased the values of syneresis from 14.40 – 15.13% for white yam and significantly (p<0.05) decreased those of trifoliate yam starch (12.50 – 11.90%) and sweet potato starch (13.90 – 12.60%). Chemical modification of the native starches through acetylation took same trend but impacted higher values. In this study, it was observed that white yam starch increased from 14.40% to 16.25%, trifoliate yam starch decreased from 12.50% to 12.30% and sweet potato starch decreased from 13.90% to 13.55%. Then comparing among the three starch sources, native starch of white yam (NWYS) recorded the highest value of 14.40% while native starch of trifoliate yam had the lowest value of 12.50%. Syneresis (expulsion of soluble phase from the starch gel) negatively affects the functional and sensory properties of foods [64, 65]. It is a phenomenon that expresses gel retrogradation and involves re-organization of the disaggregated amylose and amylopectin molecules into ordered structure [66]. Syneresis of starch correlates with starch propensity or tendency to retrograde [67]. Syneresis of starches are affected by factors such as storage time and condition, amylose content, granule morphology, structural arrangements of starch chains within the amorphous and crystalline regions of ungelatinized granules, and presence of other components in the starch [67, 68]. The differences in the syneresis values of the starches observed may have resulted from varying amylose contents among the different starch sources and types, with starches of lower amylose contents exhibiting weaker tendencies to retrogradation and vice versa. For example, starch sample PTYS with relatively lowest amylose content (26.40%) exhibited the strongest resistance (weakest tendency) to retrogradation with lowest syneresis value of 11.90% while sample CWYS with relatively highest amylose content (33.65%) exhibited weakest resistance (strongest tendency) to retrogradation with highest syneresis value of 16.25%. From the results, starches of low syneresis values such as PTYS (11.90%), CTYS (12.30%), NTYS (12.50%) and PSPS (12.60%) are recommendable for commercial purposes because of their high resistances to retrogradation [66]. Starch retrogradation can cause undesirable effects as observed in the staling of bread and other starchy foods [9, 70]. This in turn can reduce shelf-life and consumer acceptance of products leading to significant waste. However, starch retrogradation is desirable in some applications, such as in the production of breakfast cereals, parboiled rice, dehydrated mashed potatoes, and Chinese rice vermicelli, due to modification of the structural, mechanical, and sensory properties [70, 71]. Starch retrogradation is also desirable in terms of nutritional significance, due to the slower enzymatic digestion of retrograded starch and moderated release of glucose into the blood stream [70, 72]. Therefore, the starches of high syneresis values like CWYS (16.25%), PWYS (15.13%) and NWYS (14.40%) are also applicable in the above-mentioned areas.

Conclusion

Native, physically modified (HMT) and chemically modified (acetylated) starches from white yam, trifoliate yam and sweet potato were developed, evaluated physico-chemically and functionally. These developed starches of varying sources and modification treatments exhibited various physicochemical and functional properties that differentiated them into specialized roles for applicable utilizations in the manufacture of confectioneries, thickeners, stabilizers, binders, fillers, flavoring agents, cheese, gravies, sauces, coating system, dairy products, drugs, beverage and brewery products. The development of these starches from these roots and tubers for various utilizations will tremendously curtail the huge post-harvest food losses that threaten food security; reduce depletion of foreign exchange reserve traceable to huge importation of wheat flour, and promote the commercial and industrial exploitations of these local roots and tubers, as well as create employment opportunities and contribute meaningfully to the economy of Nigeria.

Conflict of Interest

Authors have declared that no competing interests exist. Also, the research was not funded by the producing company rather it was funded by personal efforts of the authors.

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