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INVESTIGATION OF THE EFFECT OF CHEMICAL MODIFICATION ON SOME QUALITY CHARACTERISTICS OF STARCH EXTRACTED FROM *ACHA* (*Digitaria exilis*) AND ITS NOODLES MAKING POTENTIAL

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Abstract: *Acha is rich in pentosan; a carbohydrate compound with good water absorption capacity properties that could be utilized in production of pasta products like noodles. This study investigated the effect of chemical modification (oxidation, acetylation, pre-gelatinization and dual) on proximate composition, functional, pasting, mineral, color and antioxidant properties of acha (Digitaria exilis) starch and its resultant noodles making potential. Starch was extracted from acha grains and then dried, milled and sieved through a 75-micron screen and the native and modified acha starch were substituted into wheat flour at 15% to produce noodles. Results showed that modified acha starches have significant influenced (p<0.05) in all the quality attributes evaluated. The modified acha starches showed least moisture content with an increase in protein and ash contents, while carbohydrates decreases when compared to the native starch. Modification increases and improved the functional characteristics of the acha starches. Pasting properties of native starch was significantly higher than modified starches. Some minerals element of native starch was most predominant than the modified starches. There was a slight reduction in phenolic and flavonoid compounds while colour of the acha sample was relatively higher due to modification. Conclusively, this study showed that starch modification improved the quality of acha and sensory scores revealed that the most preferred acha noodles are from pre-gelatinized acha starch. Thus, chemical modification could serve as alternative food grade starch additive for the possibility of new food applications.*

Keywords: *Acha*, starch modification, extraction, noodles, sensory evaluation

1. Introduction

Acha (*Digitaria exilis*) is a small annual forest seed/grain commonly found in West-African countries in large quantity. Nutritionists and researchers have neglected *acha* due to lack of interest despite its nutritional value [1, 2]. The crude protein content of the grain (7.7% protein) as reported by [3] is similar to that of maize and complementary to legumes in methionine and cysteine contents. *Acha* has been reported to possess the potential to act as a survival food and also complement for standard diets [4]. *Acha* seeds are known to contain high amount of amino acid such as methionine and cystine, which of great importance in human health. Omeira et al. [5] reported that *acha* flour could be replaced up to 20% level in wheat and soybean flour to produce noodles. Moreso, *acha* is rich in pentosan; a carbohydrate compound with good water absorption capacity properties that could be utilized in production of pasta products like noodles. Good thickening and gelling properties of starch makes it a good ingredient for the processing of various food products [6]. Though, native starches, notwithstanding their source are not desirable for many

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applications in the food industry, because they lack the ability to withstand some heating process conditions, hence, there is need to improve its desirable functional properties. Starches are modified either physically or chemically by degradation, substitution or cross-bonding to meet the demands of specific industries [7]. Starch modification is a process which may be used to alter the physicochemical properties of starches in order to meet various industrial specifications [8]. Several researchers have reported the various benefits of modifications which include improved water holding capacity, heat resistant behavior; reinforce starches binding ability, reduced syneresis of starch and improve thickening properties [9]. However, the understanding of the modification effects on starch structures is important in relation to their functional behavior during processing and enhanced the development of desired quality product in the food industry. Adebowale *et al.* [10] reported that importance of blending different starches either native or modified as gained widespread acceptance and resulted in improved desirable functional properties which reduce the limitation of native starches. Chemical modifications have been reported to confer several advantages over native starches such as improved functional characteristics, high viscosity, better thickening power, low gelatinization and retrogradation [11]. Noodles are fast becoming the most widely consumed food in the world due to the fact that they easy to cook with low cost relative to long shelf life, versatility, organoleptic appeal and satiety. Also, the nutritional composition of noodles varies widely which depend on factors such as noodle type and quality, and processing methods [12]. Market surveys have shown that the consumption of noodles is still expanding across the world as instant noodles have become the fastest growing sector of these products. Noodles are produced via frying and steaming process giving rise to a porous spongy structure which enhances quick serving when compared with other pastry products [13, 14]. Generally, the utilization of *acha* is limited in food processing with no visible industrial application. Therefore, the production and modification of starch from *acha* may bring about the expansion of their potential in industrial application. This study however, is focusing on the potential uses of *acha* starch in the production of noodles and the detailed knowledge of the *acha* starch characteristics will unravel the opportunities offered by the grains to facilitate the utilization of the starch.

2. Materials and Methods

Materials: *Acha* grains were purchased from Mile 2 market (7.5^{o}N longitude, 4.5^{o}E latitude) Lagos State, Nigeria. All chemicals used were of analytical grade.

Extraction of *Acha* starch

Starch was extracted from *acha* grains as shown in Fig. 1 using the modified methods as reported by [12]. *Acha* grains were sorted, cleaned and steeped in water for 72 h. Then, it was washed in portable water, wet milled and sieved to obtain wet starch slurry. The starch granule was oven dried at 50 ^{o}C for 6 h. The dried starch cake was milled, and sieved through a 75-micron screen. The sieved starch was stored in low density polyethylene bags till further use at ambient temperature.

Methods of starch modification

Oxidation of starch: The method of [13] was used for the oxidation of *acha* starch. Starch slurry (100 g) was dispersed in 500 ml of distilled water by adjusting the pH of the slurry to 9.5 with 2 M NaOH. About 10 g of Sodium Hypochlorate was added to the slurry for 30 min while maintaining the pH range at 9.0 to 9.5 with constant stirring at room temperature. This was allowed to proceed for another 10 min after the addition of NaCl and then pH was adjusted to 7.0 using 1 M H_2SO_4. The oxidized starch produced was then filtered, washed several times with distilled water and then oven-dried at 40 °C for 48 h.

Acetylation of starch: The method described by [13] was adopted for processing of acetylated starch with little modification. About 100 g of starch was dispersed in 500 ml of distilled water and stirred for 20 min while pH of the slurry was adjusted to 8.0 using 1M NaOH. About 10.2 g of acetic anhydride was added while maintaining a pH at 8.5. The reaction was allowed to proceed for 5 min after the addition of acetic anhydride. The pH was then adjusted to 4.5 using 0.5M HCl. It was then filtered and washed four times with distilled water and oven-dried at 40 °C for 48 h.

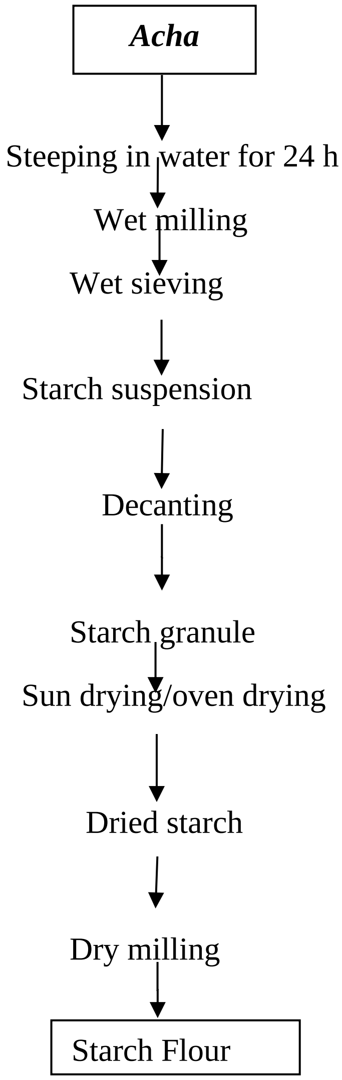

Fig. 1 Flow chart for the extraction of starch from freshly harvested *Acha*
Source: Lawal (2004)

Pre-gelatinization of starch: The method described by [13] was also adopted for producing pre-gelatinized starch. About 300 g of starch was dispensed in 1L of distilled water and heated to 80 °C for 15 min with slow mixing. The pre-gelatinized starch produced was then placed in a stainless-steel tray in a thin layer and then oven-dried at 40 ºC for 48 h. The dried starch was milled and sieved using a 100 mm mesh screen and stored at room temperature in polyethylene bag until further use.

Dual Modification: The modified method of [14] was used for dual modification of *acha* starch which involved acetylation-oxidation process. The *acha* starch was subjected to oxidization, followed by acetylation as reported earlier.

Chemical Analysis

Proximate composition: Moisture, total ash, crude fat and crude fibre contents were determined using the standard methods of Association of [15] Official Analytical Chemists (2005). The crude protein content was determined by the micro Kjeldahl nitrogen method and the nitrogen content was converted to protein using a 6.25 conversion factor. Carbohydrate content was determined by difference. This was carried out by adding the value of moisture, total ash, crude fat, crude fibre and protein in percentages, and subtracting from 100 %.

Functional Properties: Bulk density of the *acha* starch was evaluated by the method described by [16] while solubility index was evaluated by the method described by [17] with little modification. Foaming capacity was evaluated by the method reported by [18]. Water absorption and oil absorption capacities were determined as described by [19]. The method of Yasumatsu *et al*. [20] was adopted for the determination of emulsion and gelation capacity.

Pasting characteristics: Pasting characteristics were assessed according to the method described by AACC [21] using a rapid visco analyzer (RVA-4, Newport Scientific Pvt., Ltd., Australia). 3 g of the sample was weigh and 25ml of water was dispersed into a canister. Paddles were placed inside the canister and this centrally placed into the paddle coupling and insert into RVA machine. The measurement cycle was initiated by pressing the motor tower of the instrument. The profile was seen as it running on the monitor of a computer connected to the instrument.

The 12 minutes profile was used. The time temperature regime to be used was 50°C to 95°C in 3 minute. 45 seconds. The held at 95°C for 2 minutes, 30 seconds, the sample was subsequently cooked to 50°C over 30 minutes period followed by period of 2 minutes when the temperature is control at 50°C.

Colour evaluation: The colour characteristics of the starch samples was measured using a colorimeter (Model SN 3000421, Color TEC-PCM, USA) according to the method of [22] and the values expressed on the L*, a*, b*. Where L* represent lightness from 0 (black) to 100 (white); a* and b* represent redness (+a) to greenness (-a) and yellowness (+b) to blueness (-b), respectively. About 3 g of the starch samples was put in clean paper and the color meter was placed on the sample by allowing the sensor to touch the sample and the reading was taken directly.

Mineral composition: About 1 g samples were weighed into Teflon tubes (MARSXpress – High Throughput Vessels) and mixed with 10 mL concentrated nitric acid (HNO_3). Together with the blank (HNO3), they were all digested in a microwave digester (CEM One TouchTM Technology, CEM Technologies, USA). Temperature conditions of the microwave-digester were as follows; temperature program was 25–170 ºC for 10 min and 170 ºC–240 ºC for another 10 min at 1000 W, followed by immediate ventilation at room temperature for 20 min. The resulting solutions were cooled and made up to mark with Milli-Q water (Millipore, Bedford, MA) in a 50 mL volumetric flask before analysis and the mineral elements evaluated include iron, calcium, sodium, potassium and zin according to the modified method of official [15].

Antioxidant properties

The total phenolic content of the *acha* starch samples was determined by the method of [23] while total flavonoid content was determined using a colorimeter assay developed by [24].

Production of Noodles

The method described by Omeire *et al.* [5] with some modifications was used. Noodles were produced by mixing separately the samples (400 g) with about 140 mL water (40 ^oC) and 5% Carboxyl-methylcellulose (CMC). Both native and modified *acha* starches were substitute into wheat flour at 15% to produce noodles. About 400 g of each formulation from the native and modified starches were mixed with 140 mL of water with 4 g of common salt and CMC to produce homogenous dough which was allowed to stand for 15 min. Small portions of dough were subsequently passed through rolling mill rolls (Model: BE-8200, Bethel, Seoul, Korea), and the dough sheets were cut in the form of noodles with 100 mm long and 5 mm wide. The noodle strands were put in cleaned aluminum trays; steamed for 90secs in and then placed in a wire basket fitted with a lid and the basket was dipped in hot palm olein at 150 ^oC for 1 min and cooled to room temperature before packing.

Sensory evaluation

Ethical clearance was acknowledged by the research committee of Mountain Top University, Nigeria for the sensory acceptability test. Informed consent of member panelists (n=50) was sought and gotten prior to this evaluation. The panelists were consistence noodles consumers and were probed to assess each coded sample using 9-point hedonic scale where 1 - dislike very much and 9 - like extremely [25]. Each panelist was provided with clean water to rinse their mouth in between testing of the noodles to avoid carry over effect. The noodles sample was analyzed on the basis of color, aroma, taste, mouth feel and overall acceptability.

Statistical analysis

All analyses were done in triplicate and results represent the average of triplicate determinations, expressed as mean ± standard deviation (S.D). The data obtained were analyzed by analysis of variance (ANOVA) using SPSS Statistics 22 software (IBM, USA). Mean values and standard deviation were presented and values were compared using Duncan's multiple range test [26] at $p \leq 0.05$ level of significance.

3. Results and Discussion

Proximate composition of *acha* starch

The proximate composition of native and modified *acha* starch samples are presented in Table 1. The moisture content, total ash, fat and crude protein were used to evaluate the quality of the native starch as well as the effects of the chemical modifications. The native starch was compared with modified starches i.e., oxidation (ASO), acetylation (ASA), dual modified (ASD) and pre-gelatinized (ASP) and the results were shown in Table 1. Native *acha* starch has 9.99% moisture content which increases to 11.09% with oxidation. This may be attributed to the incorporation of carboxyl functional groups on the starch molecules which enhanced binding capacity more than the native starch [26]. Modified *acha* starch using (ASA) had the least moisture content of 8.30%, and this was as a result of the removal of water binding proteins during the alkali extraction stage. Furthermore, the low moisture content of this ASA suggests a prolong shelf stability during storage as a result of mold growth prevention and lowering moisture induced biochemical reactions.

The dual modified (ASD) and pre-gelatinized (ASP) *acha* starches have the moisture content of 12.53 and 12.19%, respectively. These were higher compared to the native starch due to the incubation of the starch granules in excess water during the modification processes. The increases in the moisture contents of the modified starches were in agreement with the reports on the physically modified bambara groundnut starch and Mucunna pruriens bean starch [27]. Several authors reported that moisture content of starch is a factor to consider during flow properties study; this however depends on factors such as method and extent of drying, and humidity of the environment [28, 29]. In addition, the moisture of native *acha* starch is lower than other chemically modified starches except acetylated *acha* starch which showed a significant decrease.

Table 1:

Proximate composition of native and modified *acha* starch

Samples	Moisture (%)	Protein (%)	Ash (%)	Fat (%)	Fiber (%)	Carbohydrate (%)
ASN	9.99±0.39^{b}	6.63±0.06^{c}	6.22±0.44^{c}	0.58±0.02^{bc}	0.18±0.04^{b}	74.44±0.84^{a}
ASO	11.09±0.06^{bc}	5.88±0.12^{a}	2.34±0.22^{ab}	0.48±0.03^{b}	0.11±0.01^{a}	80.10±0.36^{b}
ASA	8.30±1.33^{a}	7.02±0.13^{d}	6.48±0.07^{c}	0.53±0.02^{cd}	0.12±0.00^{a}	79.50±1.41^{a}
ASD	12.53±0.10^{c}	6.10±0.05^{ab}	2.25±0.17^{a}	0.62±0.01^{d}	0.09±0.01^{a}	78.42±0.01^{ab}
ASP	12.19±0.05^{c}	6.28±0.06^{b}	2.97±0.23^{b}	0.39±0.02^{a}	0.14±0.02^{ab}	78.04±0.18^{a}

Values with different superscript letters in the same column are significantly different ($p<0.05$).
ASN =Native Acha starch; ASO=Acha starch modified using oxidation; ASA=Acha starch modified by acetylation; ASD= Dual modified Acha starch ASP=Acha starch pre-gelatinized.

Pelissari *et al*. [27] reported a change in moisture content of *acha* starch which was as a result of different drying methods, temperature and time used. There was an increase in protein and ash contents of the modified starch compared to the native starch except for ASA which was recorded with lower values. The reduction of native starch could be attributed to extensive purification through alkaline solubilization and degradative effect in amylose fraction of starch granules after modification. The low protein content could be useful in the production of syrups with high glucose content compared to the native starch. Similar observations were reported by Adebowale and Lawal, (2004). For instance, a lower protein, fat and ash contents is an indication of high starch purity which may be associated with the method of starch extraction [30, 31]. The fat and fiber content of the native and modified *acha* starches ranged from 0.39 to 0.62%, 0.09 to 0.18%, respectively. Both the native and modified starches have lower fat and fiber contents which discouraged the development of rancidity during storage.

The lower value observed in native *acha* starches may be due to the fact that starch oil are not a good source of edible fat and major macro-nutrients in the *acha* grain. Native starch was relatively higher in carbohydrate and decreases slightly after modification. The higher carbohydrate contents (>80%) showed that the native starch is predominantly starchy food but reduces with modification. Aning [30] reported that high starch content of *acha* accorded the plant a unique functional property in food processing while Majzoobi *et al.* [31] and Butt Batool [32] also corroborates the uniqueness of *acha* in offering cold storage stabilities and preservation of organoleptic properties of foods.

Functional properties of *acha* starch

The functional properties of native and modified *Acha* starch are presented in Table 2.

Table 2:

Functional properties of native and modified *Acha* starch

Samples	LBD (g/ml)	TBD (g/ml)	WAC (g/g)	OAC (g/g)	Swelling (g/g)	LGC (%)	Emulsion (%)	Solubility (%)
ASA	0.41 ± 0.01^{c}	0.73 ± 0.02^{c}	1.04 ± 0.01^{b}	0.83 ± 0.01^{c}	4.32 ± 0.09^{b}	12.00 ± 0.00^{a}	15.54 ± 0.64^{b}	6.39 ± 0.12^{b}
ASP	0.46 ± 0.00^{b}	0.78 ± 0.01^{ab}	1.12 ± 0.01^{a}	0.93 ± 0.00^{b}	4.74 ± 0.15^{a}	12.00 ± 0.00^{a}	14.00 ± 0.00^{c}	6.22 ± 0.00^{b}
ASD	0.53 ± 0.00^{a}	0.80 ± 0.02^{a}	1.01 ± 0.02^{b}	0.97 ± 0.00^{a}	3.93 ± 0.02^{c}	8.00 ± 0.00^{b}	3.88 ± 0.16^{c}	6.44 ± 0.06^{b}
ASO	0.48 ± 0.02^{b}	0.78 ± 0.00^{b}	0.97 ± 0.00^{c}	0.95 ± 0.00^{ab}	4.02 ± 0.05^{c}	2.00 ± 0.00^{c}	9.71 ± 0.00^{d}	5.43 ± 0.12^{c}
ASN	0.41 ± 0.01^{c}	0.74 ± 0.00^{bc}	0.97 ± 0.01^{c}	0.86 ± 0.02^{c}	4.27 ± 0.02^{b}	8.00 ± 0.00^{b}	20.00 ± 0.00^{a}	7.10 ± 0.00^{a}

Values with similar letter with the same column are not significantly different ($p>0.05$) LBD – Loose bulk density; TBD – Tapped bulk density; WAC – Water absorption capacity, OAC– Oil absorption capacity; LGC–Least gelation capacity; ASA – Acetylated *Acha* starch; ASP–Pre-gelatinized *Acha* starch ASD- Dual *Acha* starch, ASO – Oxidized *Acha* starch, ASN – Native starch.

The functional parameters for all modified starch samples were significantly different at ($p<0.05$). ASD showed higher values for loose bulk density, trapped bulk density and oil absorption capacity while ASP had higher values from water absorption capacity, swelling capacity, least gelation capacity. ASN is relatively high in emulsion capacity and protein solubility. Generally, functional properties have shown to be an important factor which is very useful in the application and use of foods for various food products [32]. Bulk density has been reported to be useful in packaging requirement in food product which gives an indication of the behavior of product in dry mixes and can vary in relation to fineness of particles [33]. Samples with high bulk densities (> 0.5g/ml) are considered heavy. Hence, native and modification by acetylation, pre-gelatinization, and oxidation of the starch has lower bulk density values. The bulk densities for both native and modified starches were in the range of 0.41 to 0.53. Bulk density of native starch was 0.41 g/ml; whereas there was no significant difference ($p>0.05$) between native and acetylated starch. Pre-gelatinized *acha* starch was ranged from 0.41 to 0.46g/ml, oxidation *acha* starch was ranged between 0.41 and 0.48 g/ml and dual modified *acha* starch ranged from 0.41 to 0.58/ml, respectively. However, there were no significant differences in the bulk density between native and acetylated starches. Similar result was reported for Indian Horse Chestnut starch by [34]. Low bulk densities of starch are good physical attributes when determining transportation and storability [30]. These attributes could also be useful in complementary foods formulation for infants and children [32]. Swelling capacity is an important parameter which ultimately determines sample consistency which could either be solid, semi-solid, or liquid which may be affected by the nutritional composition of the sample [35]. The swelling capacity observed in this study compared to native *acha* starch showed that ASP *Acha* starch had the highest swelling capacity. This increase could be attributed to the interplay of increased crystalline perfection and decreased hydration. Adegunwa *et al.,* [36] reported that amylase-amylose and/or amylopectin-amylopectin interaction, increased intra-granular binding forces and reinforcement of the granules [37] and amylose-lipid complex formation [37]. The ASD *acha* starch recorded the least value, while ASA *Acha* starch increases. The increment is expected as a result of starch granules swell, the intra-granular bonds are weakened the more and the loosely held starch molecules mostly amylose leach out into the continuous medium [38]. When starch molecules are heated in excess water, the semi crystalline structure is disrupted and water molecules become linked by hydrogen bonding to the exposed hydroxyl groups of amylose and amylopectin which causes an increase in granule swelling and solubility in terms of modification of starch by dual and oxidation and the swelling reduces compared to native *acha* starch. Similar reductions in swelling power after acid thinning and oxidation have been reported by [38, 39]. During the process of acid thinning, the hydroxonium ion (H_3O^+) breaks down the glycosidic oxygen atoms and hydrolyses the glycosidic linkages. Acid gradually degrades the surface of the starch granule first before entering the inner region. It preferentially breaks down the amorphous region because the crystalline area is not freely accessible to the acid and this makes it remain intact. As a result of this development, relative crystallinity increases following acid thinning. Perhaps, increases in crystalline probably accounts for reduction in swelling capacity of the acid thinned starch since swelling is restricted by stiffness of entangled amylopectin network in the crystalline region of the starch [40]. According to Ahmedna *et al.,* [41], water absorption capacity (WAC) enables flour to absorb water and swell for improved consistency in food, which is desirable in food systems to improve yield and consistency of foods [41]. High WAC in starch samples could be attributed to the high protein content of flour [42]. The WAC in this study is 0.97 for native starch and increases as the starch is modified and this could be attributed to the electrostatic repulsions resulting from the interactions of the bulky functional groups on oxidized starch molecules facilitating percolation of water molecules within the starch granules. The increase in water absorption capacity following oxidation is a very important property especially in the application of pastry foods as well as drug carrier or disintegrant in tablets and capsule formulation. The oil absorption capacity of the modified starches is higher than the native starch. This was due to the functional groups incorporated into the starch molecule following chemical modification and this is thought to occur in the amorphous region of the starch molecules leading to increase in starch crystallinity. Oil absorption capacity attributed mainly to the physical entrapment of oils. It is an indicator of the rate at which the protein binds to fat in food formulation [43]. The oil absorption capacity of the starches was slightly lower than the values reported for Bambara starch and native starch by [44]. The low oil absorption capacity suggest that the starch could be fairly useful in bakery products, especially noodles where fat absorption or flavour retention are desired and in which structural interaction is involved during processing [45 Adebowale *et al.,* 2002)]. The least gelation varied significantly ($p<0.05$). Both the ASA and ASP *Acha* starches were higher while the least value was observed in ASD *Acha* starch. The modification of the starches influenced the emulsion capacity. The native starch was significantly different ($p<0.05$) from the modified starches where there is gradual reduction in the emulsion capacity. This was due to the activity of emulsifying agents in the formation of an emulsion and this is related to the ability of proteins to absorb to the interfacial area of oil and water in an emulsion [45]. Starches with high emulsifying capacity are good for salad dressing and soup, while low emulsion capacity can be found in bakery foods [41]. The modification processes decrease the solubility of the *acha* starch. Native starch was recorded with the higher solubility values compared to modified samples. The decrease in modified sample is probably due to introductions of bulky functional groups reducing the mobility of starch molecules. This pattern agreed with the results of [40]. Thus, modifications altered the functional properties of native *acha* starch.

Pasting properties of *acha* starch

The pasting properties of native and modified *acha* starch are presented in Table 3. The peak viscosity is regarded as the maximum viscosity which starch attained during gelatinization when heated in water. This is also an indication of the extent at which starch can bind with water. The peak viscosity of the starch samples in this study varied significantly ($p<0.05$) and the differences observed may be attributed to the modification methods adopted. All the starch samples showed a high value of peak viscosity and breakdown while both ASO and ASP *acha* starches showed lower values. However, the ASA starch recorded the highest value for peak viscosity and breakdown. These results are in similar trends with the findings of [29] where pre-gelatinized starch recorded the lowest peak and breakdown viscosity. Adeniji *et al*. [42] had earlier reported that the higher the breakdown viscosity, the lower the ability of the starch to withstand heat and shear stress during cooking. Therefore, this affirmed generally that pre-gelatinized starches demonstrated resistance to high temperatures and shear stress. Trough viscosity measures the ability of the paste or gel formed to withstand breakdown during cooling while final viscosity shows the resistance offered to shear by the starch paste during stirring, and the capacity of the starch to form a gel after cooking and cooling [46].

Table 3:

Pasting Properties of Native and Modified Acha Starch

Samples	Peak (RVU)	Trough (RVU)	Breakdown (RVU)	Final Viscosity (RVU)	Setback (RVU)	Pasting Time (min)	Pasting Temperature (°C)
ASA	5586.00±29.69[a]	2409.50±4.95[c]	3176.50±2.12[d]	466.00±2.82[d]	466.00±2.82[d]	4.40±0.00[c]	74.67±0.60[d]
ASP	3067.00±28.28[d]	2710.00±11.31[b]	327.00±39.59[d]	3902.00±11.31[b]	1162.00±22.62[b]	5.96±0.04[a]	79.87±0.10[a]
ASD	3173±16.97[c]	2636.00±22.62[c]	547.00±5.65[c]	3613.50±50.20[c]	977.50±27.57[b]	5.73±0.00[b]	78.27±0.03[c]
ASO	2950.50±6.36[c]	2482.00±5.65[d]	468.50±0.70[c]	3596.50±20.50[c]	1114.50±26.16[b]	5.66±0.00[c]	76.60±0.07[c]
ASN	4527.50±7.77[b]	3050.50±43.13[a]	14477.00±50.91[b]	4278.50±31.82[a]	1228.00±11.31[a]	5.06±0.00[d]	75.90±1.13[d]

Values with similar letter with the same column are not significantly different ($p<0.05$). **ASA** – Acetylated *Acha* **ASP**– Pre-gelatinized *Acha* starch; **ASD**- Dual *Acha* starch; **ASO**– Oxidized *Acha* starch; **ASN** – Native starch

The native starch had the highest value for trough and final viscosity while the ASA starch recorded the lowest value. This showed that all the native starch could readily form viscous paste or gel after cooking and cooling than the rest of the starch samples. Modification brought about decrease in the final viscosity as expected. It is an indication of whether the starch materials form a gel or a paste on cooling and also proved the strength of cooked paste [27, 45]. Higher final viscosity of starch is desirable in many food products (soups and sauces) where it is needed [35]. Setback viscosity prescribes gel stability and potential for retro-gradation [47, 48]. The setback values are significantly different ($p<0.05$) and the native starch value was higher compared to modified starches. Anonymous [48] reported that low setback may give rise to starch with retro-gradation at low rate or undergo freeze-thaw cycles during syneresis. Lower retro-gradation appears to be an important consideration in the production of soups, sauces, dessert and cake filling as well as refrigerated foods [46]. The estimated pasting time was within the range of 4.40 and 5.96 min for both native and modified *Acha* starches. This range shows similar trends with the report of [49]. It is of note that the shorter the pasting time, the higher the ease of cooking [27]. The pasting temperature is an indication of the minimum temperature required to cook the starch sample [49]. The pasting temperature of the modified starched was higher than the native starch. Swelling, gelatinization and subsequent gel formation during processing is ensured when the pasting temperature is attained [49, 50]. The higher values obtained in modified samples was due to its ability to strengthen the intermolecular network and increases in the crystallinity of the starch granules [51]. The rearrangement of amylose and amylopectin molecules in the starch granules may have also occurred during the modification processes [52, 27]. This probably led to the increase in the stability of the molecular interaction within the starch granules [51]. Thus, high energy was attained to overcome the intermolecular forces that bound the molecules together in the starch granules and hence, the higher pasting temperatures of the modified *acha* starches.

Mineral composition of *acha* starch

The mineral composition of native and modified *acha* starch samples are presented in Table 4. Result shows that the mineral content of native starch was most predominant in potassium, magnesium and zinc than in all the modified starches except ASP starch due to non-chemical modification process. Both native and modified starches contained good amount of magnesium, sodium, iron, zinc and potassium.

Table 4:

Mineral Composition of Native and Modified Acha Starch

Samples	**Na (mg/kg)**	**K(mg/kg)**	**Fe (mg/kg)**	**Mg (mg/kg)**	**Zn (mg/kg)**
ASN	285.23±14.77^{a}	836.11±14.05^{a}	1.22±0.39^{b}	83.76±0.17^{a}	6.81±2.77^{a}
ASO	105.86 ± 1.22^{c}	73.78±1.35^{e}	0.03±0.02^{c}	3.04±0.04^{c}	1.46±0.02^{c}
ASP	300.40± 2.04^{a}	690.78±7.14^{b}	2.54±0.01^{a}	79.22±0.04^{b}	6.02±0.02^{a}
ASA	136.53±0.00^{b}	184.68±1.02^{c}	1.03±0.01^{b}	29.94±0.00^{d}	3.37±0.00^{b}
ASD	102.57±0.07^{c}	95.81±0.27^{d}	0.37±0.42^{c}	32.77±0.31^{c}	2.37±0.34^{c}

*Values with different superscript letters in the same column are significantly different ($p\leq0.05$). **ASA**- Acetylated Acha starch; **ASP**-Pre-gelatinized Acha Starch; **ASD**- Dual Acha Starch; **ASO**- Oxidized Acha Starch; **ASN**- Native Starch*

High content of potassium in the body was reported to improve iron utilization as reported by [22, 24]. High presence of potassium may be useful in reduces heart related diseases since it helps to control blood pressure and possibly prevents stroke [43]. Potassium and sodium are important component in intracellular and extracellular digestion. Zinc is attributed to the normal functioning of the immune system while iron

(Fe) is an essential trace element for hemoglobin formation. *Acha* is a good source of minerals, containing significant quantities of sodium and potassium [24]. From the result obtained, ASN *acha* starch possessed the highest amount of potassium followed by ASP sample, while generally chemical modification reduces the potassium content in *acha* starch. Again, it was observed that iron content in ASP is relatively higher than other samples. Perhaps, this suggested that iron is quite resistant to heat and pre-gelatinization method.

Antioxidant properties of *acha* starch

The antioxidant properties of native and modified *acha* starch samples are presented in Table 5.

Table 5:

Total phenolic and flavonoid of native and modified *acha* starch

Samples	TPC (mg/100g garlic acid)	TFC (mg/100g Quercetin)
ASN	43.07±0.09[a]	68.70±0.20[a]
ASO	29.66±0.06[e]	52.20±0.04[d]
ASP	42.17±0.09[b]	54.67±0.31[c]
ASA	39.88±0.31[d]	57.53±0.31[b]
ASD	40.40±0.22[b]	54.41±0.01[c]

Values with different superscript letters in the same column are significantly different ($p < 0.05$);
***ASA** – Acetylated Acha starch; **ASP**– Pre-gelatinized Acha starch; **ASD**- Dual Acha starch;*
***ASO**–Oxidized Acha starch; **ASN** – Native starch; TPC - Total phenolic content, TFC - Total flavonoid content*

The phenolic and flavonoid contents reduce with modification. Phenolics have been reported by several authors as anti-nutrients due to the facts that they have the tendency to inhibit bioactive nutrients in the body of human being by forming large complexes with proteins and mineral element present in foods [50]. However, reports have shown that phenolic compounds possess health promoting properties such as lowering risk of cardiovascular diseases and prevention of degenerative disease [50]. This study observed reduction in total phenolic and flavonoid contents of the modified starch samples and this may be due to rearrangement of their structures as a result of acidic environment encountered during modification processes which leads to the decrease in the extractability and self - polymerization of the compounds.

Colour analysis of *acha* starch

The colour attributes of native and modified *acha* starch samples are presented in Table 6. Colour is an important attribute in foods that influence consumer acceptability. The colour of the modified starches is relatively higher compared to native starch. A high value of lightness is desired to meet consumers' preference [27]. Therefore, the ASO and ASD *acha* starches are desirable to meet consumer's preference. The values of redness are negative which indicate the absence of red or green colour. These factors are important in visual assessment of fruit ripening as reported. All the colour parameters *acha* starches exhibited lower values for lightness, redness, yellowness and energy values when compared with the work reported by [29,53]. Perhaps due to the modification methods, agronomic characteristics of *acha* and drying conditions process of *acha* starches.

Table 6:
Colour properties of native and modified *Acha* starch

Samples	L*	a*	b*	ΔL*	Δa*	Δb*	ΔE*
ASN	58.35±1.16^{b}	-4.74±0.13^{c}	7.30±0.17^{ab}	44.78±1.20^{ab}	-5.22±0.13^{c}	6.17±0.16^{ab}	45.82±1.16^{ab}
ASO	78.17±0.54^{d}	-6.66±0.22^{a}	8.61±0.26^{c}	63.26±2.46^{d}	-7.14±0.22^{a}	7.50±0.27^{c}	64.11±2.48^{d}
ASA	55.01±2.31^{a}	-4.60±0.22^{c}	6.90±0.34^{a}	41.77±2.31^{a}	-5.08±0.22^{c}	5.80±0.34^{a}	42.48±2.35^{a}
ASD	64.20±0.50^{c}	-5.48±0.21^{b}	7.28±0.30^{ab}	50.63±0.62^{c}	-5.96±0.21^{b}	6.18±0.30^{ab}	51.33±0.67^{c}
ASP	59.11±2.13^{b}	-4.91±0.21^{c}	7.51±0.33^{b}	45.88±2.13^{b}	-5.40±0.21^{c}	6.40±0.32^{b}	46.63±2.17^{b}

Values with different superscript letters in the same column are significantly different (P<0.05). L -Lightness; a* - redness; b* - yellowness; ΔL* - difference in lightness value; Δa* - difference in redness value; Δb* - difference in yellowness value; ΔE*- total colour difference value;* ***ASN*** *– Native Acha Starch;* ***ASO*** *– Acha Starch Modified using oxidation;* ***ASA*** *– Acha Starch Modified using acetylation;* ***ASD*** *- Acha Starch modified by dual method;* ***ASP*** *- Acha starch pregelatinized*

Sensory evaluation of noodles from *acha* starch

Sensory scores of native and modified *acha* noodles are presented in Fig. 2. There were significant differences (p<0.05) in all the sensory attributes i.e., colour, taste, aroma, mouth-feel and overall acceptability. The colour of noodles is in agreement with the report of Miyazaki *et al*. (2006) which state that modified *acha* starch was darker than the native due to excess sugar that caused the maillard reaction to occur between reducing sugar and protein. Significant effect (p<0.05) was observed in the taste and aroma of the *acha* starch noodles [54]. Similar trend was reported by [55, 56] for taste and aroma of noodles starch extracted from *acha*. In terms of mouth-feel, modification of *acha* starch caused a significant (p<0.05) increase in the score which was as a result of decrease in gritty like texture of the *acha* starch samples which resulted in the smoothness feel of the noodles [55,57]. There was significant difference (p<0.05) among the samples in terms of overall acceptability. Highest value was judged by the panelists that the most preferred *acha* noodles is from ASP flour sample, while ASO gave the least acceptability.

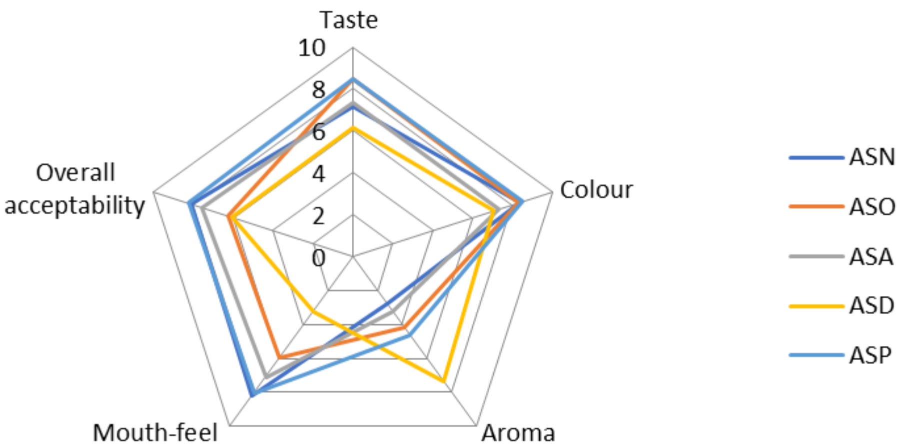

Fig. 2 Sensory scores of noodles from native and modified *acha* starch**, ASN** – Native *Acha* Starch**; ASO–***Acha* Starch Modified using oxidation; **ASA** – *Acha* Starch Modified using acetylation**; ASD** – Dual modified *Acha* Starch; **ASP** - *Acha* starch pregelatinized.

4. Conclusion

The studies affirmed that chemical modification (oxidation, acetylation, pregelatinization and dual) of *acha* starch have significant influenced ($p<0.05$) in all the quality attributes evaluated. The modified *acha* starches showed least moisture content with an increase in protein and ash contents of the modified starches, while carbohydrates decrease when compared to the native starch. Modification increases and improved the functional characteristics of the *acha* starches. Pasting properties of native starch revealed that trough, setback and final viscosity of native starch was significantly higher than modified starches. The mineral content of native starch was most predominant in potassium, magnesium and zinc than in all the modified starches. There was a slight reduction in phenolic and flavonoid compounds while colour of the *acha* sample was relatively higher due to modification. Sensory scores revealed that the most preferred *acha* noodles are from ASP flour sample, while ASO has least acceptability. Thus, chemical modification could be useful as alternative food grade starch additive for industrial purposes and for the possibility of new food applications.

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