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Effect of heat moisture treatment and partial acid hydrolysis on the morphological, functional and pasting properties of sweet potato starch

G.J. Fadimu[1*], M.K. Adenekan[2], O. Akinlua[2], F. Al Juhaimi[1], K. Ghafoor[1] and E.E. Babiker[1]

[1]Department of Food Science and Nutrition, College of Food and Agricultural Sciences, King Saud University, P.O. Box 2460, Riyadh, Saudi Arabia; [2]Department of Food Technology, School of Pure and Applied Sciences, Moshood Abiola Polytechnic, Abeokuta, P.M.B. 2210, Ogun State, Nigeria; fadimugbemisola@gmail.com

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RESEARCH ARTICLE

Abstract

Sweet potato starch was modified by partial acid hydrolysis (PAH) and heat-moisture treatments (HMT) at different moisture content and temperature (HMT_1: 20% moisture, 90 °C; HMT_2: 20% moisture, 110 °C; HMT_3: 30% moisture, 90 °C temperature; HMT_4: 30% moisture, 110 °C). Modification was also done by combination of HMT and PAH (HMT-PAH_1: 20% moisture, 90 °C; HMT-PAH_2: 20% moisture, 110 °C; HMT-PAH_3: 30% moisture, 90 °C; HMT-PAH_4: 30% moisture, 110 °C). Pasting, functional, morphological and chemical properties of native and modified sweet potato starches were evaluated. Starch granules of native, single PAH, combined HMT-PAH_2, HMT-PAH_3-treated starches had identical granular sizes and smooth surfaces while other modified starches showed a rough surface with visible cracks. PAH promoted aggregation while combination of HMT and PAH treatments increased unevenness and rough surface on the starch granules. The peak and setback viscosities decreased in all modified starches while modification increased pasting temperature and pasting time. Functional properties of HMT treated samples were significantly (P<0.05) affected by different temperatures. Combination of HMT and PAH at 110 °C with 30% moisture content improved the water absorption, oil absorption while solubility index and swelling power of all modified starches were lower than native starch. Generally, starch modified using HMT may be more useful in food systems where high final and peak viscosities are desirable, while PAH and combination of HMT and PAH may find application in processing operations requiring rigid gels such as in hard candies.

Keywords: morphology, functional properties, heat-moisture treatment, modified starch, partial acid hydrolysis, pasting properties

1. Introduction

Starch is the main form in which carbohydrates are stored in plants. Starch is an important raw material in food industries. It can be used as a thickening agent, an adhesive, a binder, gelling agent and texturiser and may also find applications in non-food sector (Kaur *et al.*, 2011). Conventionally, starch may be prepared from maize, rice, wheat, tapioca and potato (Pinto *et al.*, 2015). Sweet potato is one of the principal agricultural crops that help prevent food insecurity in developing countries. It is one of the world's most important food crops in terms of human consumption. Sweet potato supplies more nutrients per hectare than other food crops in the world (Anonymous, 2012). Starch and sugar are the major forms of carbohydrate in sweet potato and these account for approximately 90% dry matter in the crop. Sweet potato also contains pectin, cellulose and hemi-cellulose to a lesser extent.

Starch is used industrially as a starting material or as processing aid such as an additive. However, starches in their native form irrespective of the source are undesirable for many industrial applications due to their inability to withstand processing conditions such as temperature, disperse pH, and high shear rate (Awolu and Olofinlae, 2016) and food processing operations require starches that can resist intense conditions associated with food processing (Zubala *et al.*, 2016). Modified starch is a better alternative to native starch in food processing. The purpose of starch modification is to transform the physico-chemical characteristics of native starch to enhance the functional, pasting, structural and morphological properties and to also increase their application in food industry. Starch can be modified using various methods such as physical, chemical, enzymatic and biological modification. Chemical modification such as oxidation, acid hydrolysis, acetylation, esterification, etherification and cross-linking have been used with some success.

Partial acid modification is a chemical type of modification which changes the physico-chemical properties of starch while maintaining its granular structure (Sun *et al.*, 2015). Effect of acid modification on corn, pea, cynanchum auriculatum and starch/xanthan starches have been reported (Jiang *et al.*, 2018; Lin *et al.*, 2015; Shi *et al.*, 2016; Wang *et al.*, 2017). Acid hydrolysis decreased the swelling power, solubility index and water binding capacity of starches from different botanical sources (Kaur *et al.*, 2011). In addition, Wang and Wang (2001) reported a change in viscoelastic properties of starches after acid modification.

Heat moisture treatment (HMT) is a physical modification that involves treatment of starch granules at low moisture (below 35%) level during a certain period of time and at a particular temperature above the glass transition temperature but below gelatinisation temperature (Gunarantne and Hoover, 2002). Various studies have been conducted on the effects of HMT in starches from different sources, including pinhao (Pinto *et al.*, 2015), plantain (Alimi *et al.*, 2016), wheat (Sun *et al.*, 2014), corn (Ratnayake and Jackson, 2006), potato (Varatharajan *et al.*, 2011) and cassava (Gunaratne and Hoover, 2002).

Modification of starch using dual HMT and partial acid hydrolysis (PAH) is now commonly used. Sun *et al.* (2015) used HMT and PAH to modify corn starch. The author reported a decrease in the swelling power, peak viscosity, trough viscosity and breakdown viscosity after modification, while solubility and pasting temperature increased. However, information on the effect of heat moisture treatment combined with acid hydrolysis (HMT-PAH) on the characteristics of sweet potato starch is not available in literature. Thus, this present study was aimed at evaluating the single effect of HMT, PAH and combined HMT and PAH modifications on the chemical, morphological, functional and pasting properties of sweet potato starch with the view to providing information on its industrial use.

2. Material and methods

Materials

Sweet potato (*Ipomoea batatas*) (yellow skin variety) were purchased from Kuto market in Abeokuta, Nigeria. The sweet potatoes were immediately transported to the laboratory for starch extraction. All chemicals used for the modification were of analytical grade. The sweet potato starch was isolated using water as solvent.

Extraction of starch from sweet potato

Starch extraction was done using the method described by Alimi *et al.* (2016) with some modifications. The potatoes were weighed, peeled and slurred. The slurry obtained was filtered using muslin cloth. The filtrate starch was allowed to settle and the supernatant was decanted. Water from the settled starch was drained out using muslin cloth. Then, the starch was spread on a tray and oven dried at 40 °C. The dried sweet potato starch was then milled using Phillips blender (model HR-1702, Tokyo, Japan) into powder and sieved using 100-mesh sieve size. The sample was kept in the Ziploc bag for further use.

Modification of starch

Heat-moisture treatment

Heat moisture treatment of sweet potato starch was carried out according to the method described by Senanayake *et al.* (2013) with slight modifications. Moisture content of 250 g sweet potato starch was adjusted to 20 and 30% moisture levels, placed in Duran bottles, sealed and equilibrated at room temperature for 12 h. The Duran bottles were labelled according to the percentage of moisture content and temperature to be used i.e. (HMT_1: 20% moisture at 90 °C; HMT_2: 30% moisture at 90 °C; HMT_3: 20% moisture at 110 °C and HMT_4: 30% moisture at 110 °C). The Duran bottles were thereafter placed in oven at 90 °C and 110 °C respectively for 6 h. After modification, the starch samples were cooled to room temperature and dried at 40 °C to a constant moisture content of 10% and equilibrated at room temperature for 2 days.

Partial-acid hydrolysis

The method described by Kaur *et al.* (2011) was used for acid hydrolysis. 250 g of native sweet potato starch was slurried in 1 l HCL solution having 0.1 N. The mixture was stirred magnetically for 6 h at temperature of 50 °C. The starch was then filtered and the residue obtained was washed six times with distilled water. It was then dried using a hot air oven at 40 °C to less than 10% moisture content. The dried starch was milled using the Phillips blender to achieve a finer texture, sieved using 100-mesh sieve size and packed in Ziploc bag for further analysis.

Combination of heat-moisture treatments and partial acid hydrolysis

100 g of the previously heat moisture treated starches were subjected to partial acid hydrolysis as described in section above and the samples were labelled as HMT-PAH_1, HMT-PAH_2, HMT-PAH_3 and HMT-PAH_4.

Determination of percentage yield

Percentage yield of sweet potato (*Ipomea batatas*) starch was calculated from the weight of potatoes used. The initial weight was denoted W_0, while the final weight of starch was denoted W_1. Percentage yield (X) was calculated using Equation 1:

$$X = \frac{W_1}{W_0} \times 100 \quad (1)$$

Where:
W_0=Initial weight of the tuber
W_1=Weight of the extracted starch

Swelling power and solubility index

Determination of swelling power and solubility index of starches was done according to the method of Leach *et al.* (1959). Swelling power was expressed in g/g and solubility index in %.

Water absorption capacity

Water absorption capacity (WAC) was determined using the method described by Abbey and Ibeh (1988). WAC was expressed as gram of water per gram of starch (g/g).

Oil absorption capacity

Oil absorption capacity (OAC) of the native and modified sweet potato starches were determined following the method described by Abbey and Ibeh (1988). Oil absorption capacity was expressed as gram of oil per gram of starch (g/g).

Determination of pasting properties

The pasting properties of the native and modified starches were determined using Rapid Visco Analyzer (RVA Techmaster, Newport Scientific Pty Limited, Warriewood, Australia). 3 g of the sample was slurried by adding 25 ml distilled water inside RVA test canister and the canister was then lowered into the RVA system (Newport Scientific, 1998). The slurry was heated from 50 to 95 °C and then cooled rapidly to 50 °C within 12 min, rotating the can at a speed of 160 rpm with continuous stirring of the content with a plastic paddle. Parameters estimated were peak viscosity, trough viscosity, breakdown viscosity, setback viscosity, final viscosity, pasting temperature and pasting time.

Determination of morphological properties

Scanning electron microscopy (SEM) of the starches (native and modified) were measured using SEM (Model 6390, Joel, Tokyo, Japan). This was done by sprinkling the starch sample on an adhesive tape, attached to specimen studs, and coated with gold JFC-1500 (Jeol, Tokyo, Japan). Photomicrographs were taken at 2,000×magnification using SEM apparatus at an accelerating voltage of 15 kV.

Determination of chemical composition

The chemical composition of the sweet potato starches were determined using standard AOAC 2003 methods (AOAC, 2003).

Statistical Analysis

The functional and pasting properties results were analysed using analysis of variance analysis (JMP version 9.0, SAS Institute, Cary, NC, USA) and differences between mean values were evaluated at $P<0.05$ using Duncan's multiple range test.

3. Results and discussion

Chemical properties

Percentage yield of sweet potato starch in this present study was 91% and this is similar to recovery yield reported for sweet potato starch by Babu *et al.* (2015). Native sweet potato starch contained 0.46% ash, 0.46% fat and 0.47% protein, thus giving 98.61% pure starch (Figure 1). The low percentage of ash, fat and protein in the native starch is an indication of purity of the extracted potato starch (Olatunde *et al.*, 2017). The moisture content of the starch was 10.68% and moisture plays an important role in the flow and other mechanical properties of starch (Zubala *et al.*, 2016). The amylose content of the starch was 16.53% and amylose content of the starch is important as it affects pasting, gelatinisation, retrogradation, swelling power and enzymatic vulnerability of starches to digestion (You and Izydorcyk, 2002).

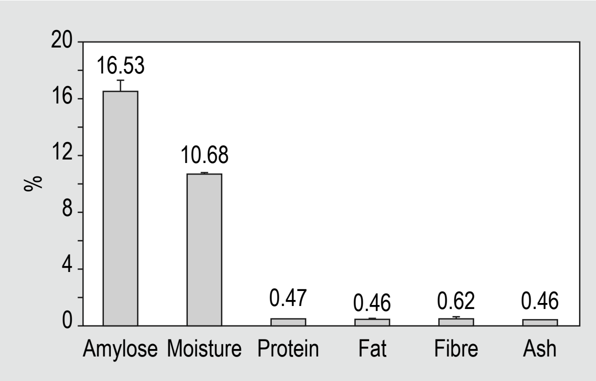

Figure 1. Chemical composition of native sweet potato starch.

Morphological properties

Figure 2 shows the scanning electron microscopy of native, HMT, PAH and combined HMT and PAH modified sweet potato starches. From the figures, it can be observed that starch granules of native starch had oval shapes, even surfaces and identical sizes. In addition, starch granules of HMT_1, HMT_3, HMT-PAH_2, HMT-PAH_3, HMT-PAH_4 and PAH treated starches had oval shapes, while the granules of HMT-PAH_2, HMT-PAH_3, HMT-PAH_4 and PAH had even surfaces and identical sizes, with only broken granules in HMT-PAH_2, HMT-PAH_3 and rough surfaces was observed in starch granules of other samples. However, there was an increase in granular sizes of HMT_1, HMT_2, HMT_3, HMT_4, HMT-PAH_4 and PAH modified starches and this is contrary to the observation of Kaur *et al.* (2011) who reported a decrease in granular size of sweet potato starch after acid modification. In addition, it can observed from Figure 2 that single HMT modification did not promote aggregation of starch granules and this is comparable to the results of Pinto *et al.* (2015) who reported that starch aggregation was not promoted when pinhao starch was modified using HMT with 22% moisture and 100 °C. Compared to single HMT treated starches which had high levels of surface erosion, PAH starch had smooth and aggregated starch granules and this implies that PAH promoted aggregation.

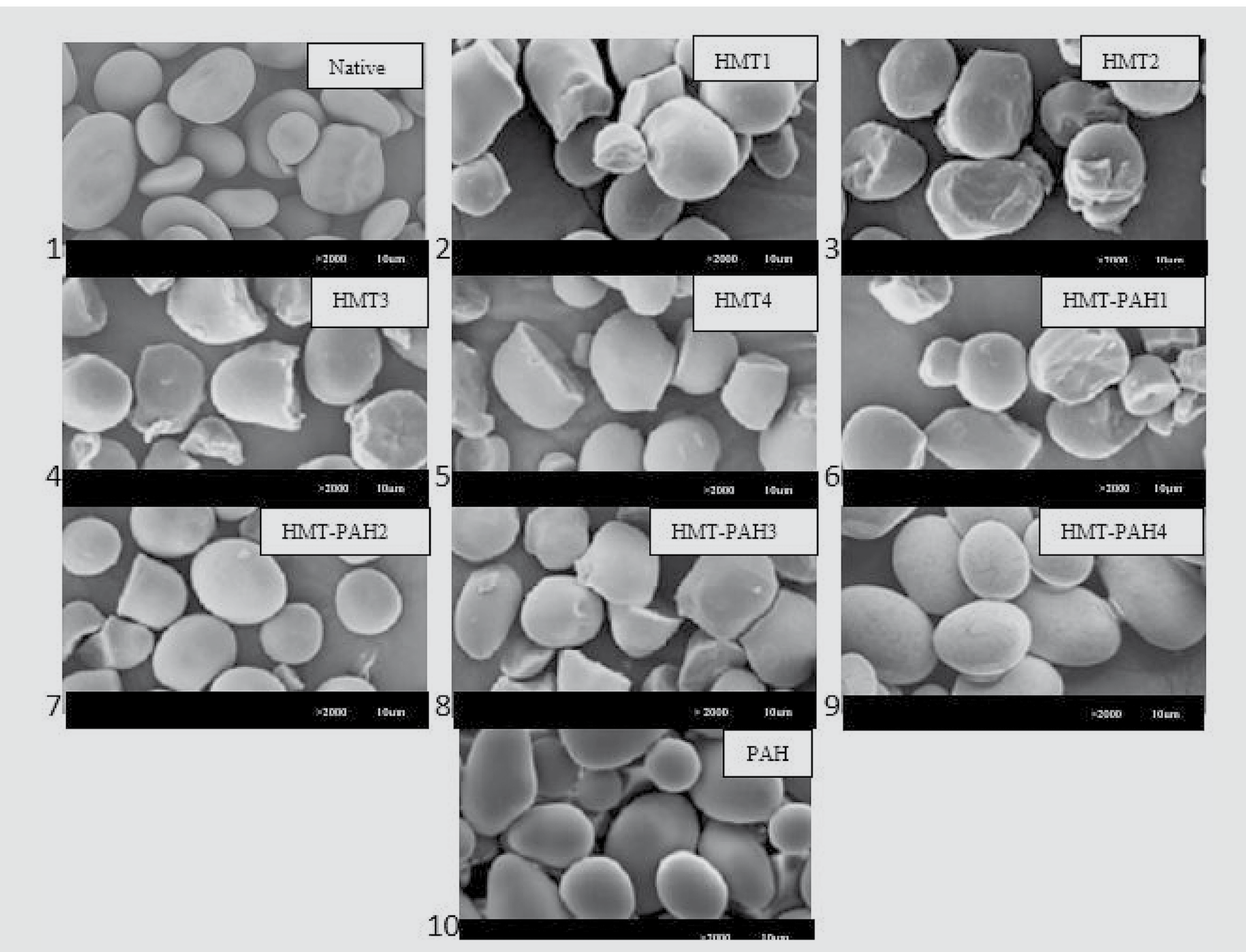

Figure 2.Scanning electron microscopy of native and modified sweet potato starches: native: native starch; HMT1: (20%, 90 °C); HMT2: (20%, 110 °C); HMT3: (30%, 90 °C); HMT4: (30%, 110 °C); HMT-PAH1: (20%, 90 °C); HMT-PAH2: (20%, 110 °C); HMT-PAH3: (30%, 90 °C), HMT-PAH4: (30%, 110˚C); PAH: acid hydrolysis.

Combination of HMT and PAH modifications increased unevenness and visible racks on the surface of the sweet potato starch granules. Double treatments caused changes on the surfaces of starch granule from HMT-PAH$_1$, HMT-PAH$_2$ and HMT-PAH$_3$ treatments. However, surface roughness was not observed in HMT-PAH$_4$ modified starch. Pinto *et al.* (2015) observed a similar trend in HMT-Annealing modified pinhao starch. Additionally, starch granules subjected to HMT-PAH at temperature of 90 °C (HMT-PAH$_1$ and HMT-PAH$_3$) had more surface erosions than those modified at 110 °C (HMT-PAH$_2$ and HMT-PAH$_4$). This may be attributed to the dual effect of heat and acid, which could have caused various interactions within the starch granules and resulted in changing the microstructure of the starch granules. The result of scanning electron micrographs obtained in this present study revealed that single HMT treatment had negative effects on morphological properties of sweet potato starch in comparison to dual HMT and PAH modifications.

Water and oil absorption capacity

WAC and OAC of native and modified sweet potato starches are presented in Table 1. Single HMT (HMT$_1$, HMT$_2$, HMT$_3$, HMT$_4$) treated samples had significantly (P<0.05) higher WAC and OAC than native starch. However, no significant difference was observed in WAC of single HMT treated samples and PAH decreased WAC of starch (Table 1). This implies that acid modification reduced the hydrophilic and hydrophobic capacities of the native starch. This reduction may be attributed to increase in crystalline region and reduction in amorphous region in starch granules which decreased the number of binding sites. Babu *et al.* (2015) and Awolu and Olofinlae (2016) reported a similar result for acid treated sweet potato and water yam starches respectively. Interestingly, the WAC of combined HMT-PAH (HMT-PAH$_1$, HMT-PAH$_2$, HMT-PAH$_3$, HMT-PAH$_4$) treated starches significantly (P>0.05) different from each other. Generally, HMT-PAH combination produced starch having higher WAC than native and single HMT (HMT$_1$, HMT$_2$, HMT$_3$, HMT$_4$) and PAH treatments. In our present study, it can be observed that PAH decreased the hydrophilic tendency of modified sweet potato starch, while HMT modification increased hydrophilicity of the modified starches which resulted in improved WAC. OAC of the modified starches were significant (P<0.05) higher than native starch. This indicates that lipophilic tendency of sweet potato starch increased after modification. Similar findings have been reported for modified pearl millet starch by Sharma *et al.* (2015). Considering the oil absorption result, it can be said that HMT in succession with PAH may be applied to enhance the OAC of sweet potato starch.

Swelling and solubility

Swelling power and solubility index of native and modified sweet potato starches are shown in Table 1. Single HMT (HMT$_1$, HMT$_2$, HMT$_3$, HMT$_4$) modified starches showed comparable swelling power and lower solubility index in comparison to native and combined HMT-PAH (HMT-PAH$_1$, HMT-PAH$_2$, HMT-PAH$_3$, HMT-PAH$_4$) modified starches. Also, single HMT modified starches regardless of the moisture content and temperature had significantly (P<0.05) lower swelling power and solubility index than native potato starch. Lowest swelling power was recorded with HMT$_3$ (30% moisture, 90 °C) and PAH starches while HMT$_4$ (30% moisture, 110 °C) had significantly (P<0.05) higher swelling power than other modified starches. Additionally, the solubility index of single HMT and PAH treatment were significantly (P<0.05) lower in

Table 1. Effect of heat-moisture treatments (HMT) and partial acid hydrolysis (PAH) on the functional properties of native and modified sweet potato starches.[1]

Sample[2]	Water absorption capacity (g/g)	Oil absorption capacity (g/g)	Solubility index (%)	Swelling power (g/g)
Native	122.50±0.89^d	107.90±0.35^e	9.48±0.27^a	18.04±0.56^a
HMT$_1$	148.90±1.02^{bc}	118.00±0.89^c	2.63±0.59^c	15.10±0.75^c
HMT$_2$	151.50±2.02^b	110.00±0.92^d	2.58±1.00^c	11.36±0.29^d
HMT$_3$	147.20±1.05^{bc}	116.60±0.53^c	2.85±0.47^c	10.73±0.72^{de}
HMT$_4$	154.90±0.79^b	123.10±0.75^{ab}	2.80±0.76^c	16.72±0.59^b
HMT-PAH$_1$	189.90±2.79^a	127.80±0.29^a	4.99±0.27^b	15.72±0.48^c
HMT-PAH$_2$	188.30±0.57^a	125.60±0.48^a	4.84±0.37^b	15.02±0.68^c
HMT-PAH$_3$	190.30±0.25^a	123.10±0.16^{ab}	4.83±0.81^b	15.20±0.49^c
HMT-PAH$_4$	194.50±1.49^a	128.00±0.79^a	5.13±0.74^b	15.11±0.71^c
PAH	115.50±0.97^e	109.40±1.07^d	2.86±0.72^c	10.14±0.86^e

[1] Means within a column with the same superscript are not significantly (P<0.05) different. All measurements are means values±SD of triplicate determinations.
[2] Native starch; HMT$_1$ (20%, 90 °C); HMT$_2$ (20%, 110 °C); HMT$_3$ (30%, 90 °C); HMT$_4$ (30%, 110 °C); HMT-PAH$_1$ (20%, 90 °C); HMT-PAH$_2$ (20%, 110 °C); HMT-PAH$_3$ (30%, 90 °C); HMT-PAH$_4$ (30%, 110 °C); PAH (acid hydrolysis).

comparison to values reported for native and combined HMT-PAH treatments. Also, combination of HMT and PAH at different moisture content and temperatures increased the swelling power in some of the starch samples compared to single HMT and PAH treatments. However, no significant (P>0.05) difference was observed in swelling power of combined HMT-PAH (HMT-PAH$_1$, HMT-PAH$_2$, HMT-PAH$_3$, HMT-PAH$_4$) treated samples. This is in agreement with the findings of Senanayake *et al.* (2013), who reported no significant difference in swelling and solubility index of sweet potato starch modified using different moisture-temperature combinations. Generally, modification reduced the swelling power and solubility index of starches. According to Liu *et al.* (2017), decrease in swelling power of HMT-modified starches may be due to increased crystallinity, amylose-amylose interaction and/or amylose-amylopectin chain interaction. In addition, decrease in swelling power of acid hydrolysed starches has been attributed to increase in high proportion of soluble dextrins of both small and medium chain lengths in starch granules (Kaur *et al.*, 2011). Therefore, the decrease in swelling power and solubility index of modified starches in this study in comparison to native starch may be reasonably attributed to increase in proportion of soluble dextrins in starch granules caused by acid hydrolysis and increase in crystallinity and amylose-amylopectin interaction as a result of HMT treatment.

Pasting properties

Table 2 and Supplementary Figure S1(A-F) shows the pasting properties of native and modified sweet potato starches. Variation in pasting properties as a result of HMT treatments have been attributed to a reduction in the granular swelling, amylose leaching and increase in interaction between starch chains and granular rigidity (Liu *et al.*, 2017). Also, effect of acid hydrolysis on starch viscosity reduction may be associated with removal of amorphous regions of starch granules (Kaur *et al.*, 2011). While single HMT (HMT$_1$, HMT$_2$, HMT$_3$, HMT$_4$) decreased the peak viscosity, breakdown, setback and increased the pasting temperature of sweet potato starch, the values obtained were still significantly (P<0.05) higher than those reported for single PAH and combine HMT-PAH (HMT-PAH$_1$, HMT-PAH$_2$, HMT-PAH$_3$, HMT-PAH$_4$) treatments. However, HMT$_1$ (20% moisture, 90 °C) increased the final viscosity of the starch. Generally, the peak viscosity of all modified starches decreased with increase in HMT temperature and reduced further when single PAH and HMT-PAH combinations were used compared to native starch (Table 2). Highest peak viscosity was reported in HMT$_1$ while lowest value was recorded in PAH treated starch. The reduction in peak viscosity as affected by combined HMT-PAH was also observed by Pinto *et al.* (2015) in HMT-Annealed pinhao starch. The breakdown viscosity which is a measure of susceptibility of the starch granules to shear stress and thermal agitation decreased for all the starches subjected to modification. The decrease in breakdown viscosities is an indication of high stability of the modified starches when subjected to heating and mechanical agitation. Pinto *et al.* (2012) and Klein *et al.* (2013) reported a similar result for pinhao starch. The stability may be attributed to the rearrangement of molecules within the starch granules (Sun *et al.*, 2014) which toughen the connection between amylose and amylopectin side chains (Zavareze *et al.*, 2011).

Setback value indicates short-term retrogradation (Qinjie *et al.*, 2013) and is affected by amylose leaching, amylose

Table 2. Effect of heat-moisture treatments (HMT) and partial acid hydrolysis (PAH) on the pasting properties of native and modified sweet potato starches.[1]

Sample[2]	Peak viscosity (cP)	Breakdown viscosity (cP)	Final viscosity (cP)	Setback viscosity (cP)	Pasting time (min)	Pasting temperature (°C)
Native	4,000±0.59^a	1,028±0.78^a	4,000±1.08^b	1,028±0.75^a	4.90±0.59^b	74.80±0.48^d
HMT$_1$	3,568±0.26^b	485±0.48^b	4,360±0.78^a	922±0.76^b	5.33±0.48^a	91.60±0.57^a
HMT$_2$	1,898±0.37^e	276±0.59^c	2,205±0.48^e	583±0.47^e	5.53±0.79^a	92.55±0.68^a
HMT$_3$	2,094±0.58^c	277±0.89^c	2,490±0.48^c	673±0.26^c	5.47±0.59^a	92.05±0.57^a
HMT$_4$	1,949±1.01^d	202±0.25^d	2,389±0.79^d	642±0.90^d	5.58±0.28^b	91.45±0.51^a
HMT-PAH$_1$	445±0.02^f	157±0.48^e	448±0.79^f	160±0.47^f	5.07±0.72^a	89.55±0.37^b
HMT-PAH$_2$	288±0.75^h	270±0.24^h	311±0.47^h	100±0.29^i	5.33±0.27^a	88.13±0.58^b
HMT-PAH$_3$	299±0.27^j	101±0.78^f	323±0.35^h	135±0.57^g	5.20±0.79^a	92.55±0.20^a
HMT-PAH$_4$	294±0.58^g	139±0.35^g	375±0.48^g	120±0.78^h	5.27±0.12^a	85.30±0.54^{bc}
PAH	230±0.49^i	112±0.27^i	244±0.38^i	322±0.75^j	5.47±0.47^a	82.80±0.37^{bc}

[1] Mean within a column with the same superscript are not significantly (P<0.05) different. All measurements are means values±SD of triplicate determinations.
[2] Native starch; HMT$_1$ (20%, 90 °C); HMT$_2$ (20%, 110 °C); HMT$_3$ (30%, 90 °C); HMT$_4$ (30%, 110 °C); HMT-PAH$_1$ (20%, 90 °C); HMT-PAH$_2$ (20%, 110 °C); HMT-PAH$_3$ (30%, 90 °C); HMT-PAH$_4$ (30%, 110 °C); PAH (acid hydrolysis).

content, granular size and presence of non-fragmented swollen granules (Lan *et al.*, 2008). Native sweet potato starch had significantly (P<0.05) higher setback value than modified starches. As setback value is influenced by amylose leaching, the lower setback values recorded in modified starches may be linked to the possible leaching of amylose during modification process. Modification brought about decrease in setback value of the modified starches, hence, brought about appreciable positive impact on the starches. Relative stability of starch granules is evaluated by final viscosity and shows the ability of starch to form a paste or gel after cooking (Shimels *et al.*, 2006). HMT_1 had highest final viscosity, followed by native starch; however, even with a lower final viscosity of native starch in comparison to HMT_1, the native starch still exhibited significantly (P<0.05) higher final viscosity than the remaining starches from single HMT and combined HMT-PAH treatments. However, PAH treated starch showed a significantly (P>0.05) lower final viscosity than other single HMT treatments and combined HMT-PAH treatments.

Pasting temperature is the measurement of lowest temperature needed to gelatinise a given starchy food (Sandhu and Singh, 2007). The pasting temperature is one of the pasting properties which provide an indication of the minimum temperature required for cooking starchy food to form gel, energy cost and other component stability. Modification brought about increase in the pasting temperature modified sweet potato starches. Increase in pasting temperature of modified starch implies that other components in foods may be affected and also indicate higher energy cost (Liu *et al.*, 2017).

4. Conclusions

Combination of HMT and PAH at different moisture content and temperature increased unevenness and cracking on the surface of starch granules. The swelling power and solubility index decreased in starches subjected to single PAH and HMT regardless of moisture content and temperature compared to control. Solubility index of single HMT starches were different from HMT-PAH combination modified starches. However, combination HMT-PAH at different moisture content and temperatures caused a significant increase in swelling power and solubility index of potato starch compared to single HMT and PAH treatments, except HMT_1 swelling power. Modification increased the WAC and OAC of sweet potato starch. Combination of HMT and PAH had stronger effect on WAC and OAC than single HMT and PAH treatments. HMT-treated starches had higher final viscosity while PAH treated starches had lowest; which indicates greater thickening of HMT modified starches during cooling. Generally, single HMT regardless of moisture content and temperature had less effect on the peak and final viscosities of sweet potato starch than PAH or combined HMT-PAH. Industrial application of these starches may vary depending on the required properties. Single HMT-treated starches may be more applicable in food systems requiring high final and peak viscosities, while PAH and combination of HMT-PAH may be more useful in processing operations requiring rigid gels such as in hard candies.

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Supplementary material

Supplementary material can be found online at https://doi.org/10.3920/QAS2018.1352.

Figure S1. Pasting properties of native and modified sweet potato starches. 3A: native starch; 3B: HMT1 (20%, 90 °C); 3C: HMT2 (20%, 110 °C); 3D: HMT-PAH1 (20%, 90 °C); 3E: HMT-PAH3 (30%, 90 °C); 3F: Rapid Visco Analyzer of partial acid hydrolysis.

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