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A REVIEW ON THE FUNCTIONALITY AND POTENTIAL APPLICATIONS OF BITTER YAM STARCH

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Abstract
Starches are important ingredient in the food industry. Currently, corn, potato and tapioca are the main sources of starch for various industrial applications. However, there is a growing demand for starch by the industry, due to the pressure on the conventional sources of starch for other non-food uses. Underutilised crops such as bitter yam may play a role as alternative source of starch to the commercial sources. Bitter yam belongs to the Dioscorea specie and it is rich in starch, which may be potentially used in food and non-food applications. This paper presents a review of literature on the functionality and potential applications of bitter yam starch. Majority of the studies in the literature focused on pharmaceutical applications. Bitter yam starch has remarkably small sized granules which may be employed as fat replacers for better mouth feel in foods such as mayonnaise and salad creams. Future studies are needed to fully characterize the starch extracted from bitter yam starch using Fourier Infrared Spectroscopy, Transmission Electron Microscopy, Rheometer and other high technologies previously used for conventional starch sources. The chain length distribution of the amylopectin components of bitter yam starch should also be investigated. Furthermore, effort should be made to modify the native starches for improved functionality for both food and non-food applications.

Keywords: Bitter yam; Starch; Functionality; Underutilised

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1. INTRODUCTION

Starch is a versatile ingredient with both food and non-food applications. Currently, starch extracted from corn, wheat potato and cassava are the major sources of starch for the industry. Among these sources, corn appears to be the largest source of starch for the industry. Due to the pressure on corn for uses other than starch e.g. as biofuels, there is a growing demand for alternative sources of starch by the industry. Many researchers are now focusing on underutilised crops as possible alternatives to the conventional cereal and tuber sources. These crops have shown novel properties that could be explored for various industrial applications. Underutilised crops such as bitter yam (*Dioscorea dumetorum*) are promising starch source which could be used for food and non-food applications. Yam has starch as its major component, which could be up to 85% of the tuber weight (Huang, Lin, & Wang, 2006). Although there are few studies on the characterization, modification and application of yam starches (Riley, Wheatley, Hassan, Ahmad, Morrison, & Asemota, 2004), studies on bitter yam starch is very limited (Adedokun & Itiola, 2010; Akinoso & Abiodun, 2013; Emiola & Delarosa, 1981; Ezeocha & Okafor, 2016; Falade & Ayetigbo, 2015). The limited research on bitter yam may be attributed to the bitter taste of the yam tubers caused by the presence of alkaloids (Okwu & Ndu, 2006). Nutritionally, bitter yam is richer than other yam varieties. For instance, the protein content (approx. 10%) of bitter yam is reportedly higher than water yam (approx. 8%) or white yam (approx. 7%) (Afoakwa & Sefa-Dedeh, 2001). Furthermore, bitter yam protein has been found to be balanced in the essential amino acids (with a slight deficiency of lysine) (Lape & Treche, 1994). Currently, bitter yam is simply boiled for consumption and eaten with oil, stew or alone. Focusing on the major component in the yam tuber e.g. starch will be important to propose new industrial ways to utilize the yam tuber for value addition. Hence, review summarizes the previous studies on bitter yam starch in terms of composition, morphology and functionality. Possible future studies and applications of the starch were also highlighted.

2. Starch yield, composition and purity

The yield of starch from bitter yam may vary between 10.96 and 88% (Akinoso & Abiodun, 2013; Emiola & Delarosa, 1981; Ezeocha & Okafor, 2016). Differences in starch yield may be attributed to source and variety of the tuber as well as extraction methods. White bitter yam starch reportedly showed higher starch yields (7.14-12.07%) than their yellow counterparts (5.09-8.52%) (Akinoso & Abiodun, 2013). The starch yield (5.09-12.07%) reported by Akinoso and Abiodun (2013) was very low compared to values (10.96 and 20.48%) reported for starches from 14 bitter yam landraces (Ezeocha & Okafor, 2016) and up to 88% reported by other authors (Emiola & Delarosa, 1981). The substantially higher yield reported by Emiola and Delarosa (1981), could be due to the use of potassium hydroxide required to solubilize proteins and the centrifugation step needed to separate other non-starch components. The period of harvest as well as storage of tuber may also influence the starch yield. For example, the starch yield from white and yellow bitter yam increased with increasing harvest period till 9 months and thereafter declined (Akinoso & Abiodun, 2013).

Starch granules are composed mainly of amylose and amylopectin, which represents about 98-99% of starch (dry weight) (Tester, Karkalas, & Qi, 2004). The amounts of these two starch components may vary with the origin and tuber variety. Previous studies found some variations in the amylose contents (approx. 11-28%) of bitter yam starch (Adedokun & Itiola, 2010; Akinoso & Abiodun, 2013; Amani, Buléon, Kamenan, & Colonna, 2004; Ezeocha & Okafor, 2016; Otegbayo, Oguniyan, & Akinwumi, 2014; Riley et al., 2004 ; Ukom, Ojimelukwe, & Emetole, 2015). Inherent genetic differences may also contribute to variation in the amylose content of starches. In general the amylose content of bitter yam starch is relatively low when compared to other yam varieties (Amani et al., 2004; Otegbayo et al., 2014; Zhu, 2015). Other factors such as the method of amylose determination and the physiological state of the yam tuber may also influence the amylose content of the extracted starch.

Starch may show the presence of lipids, proteins, and ash, which are present in minute quantities. Low contents of ash (0.02-0.09%), lipid (0.04-0.08%) and proteins (0.08-0.68%) in extracted bitter yam starch has been used as index of starch purity (Amani et al., 2004; Emiola & Delarosa, 1981). Low ash contents of starches are associated with the absence of hydrated fine fibers found in the cell wall enclosing the starch granules, while low nitrogen content indicates the absence lipids associated with endosperm proteins (Zhou, Hoover, & Liu, 2004). Although endogeneous lipids in starches such as in cereal starch may impact starch functionality, yam starches generally contain little or no endogenous lipids.

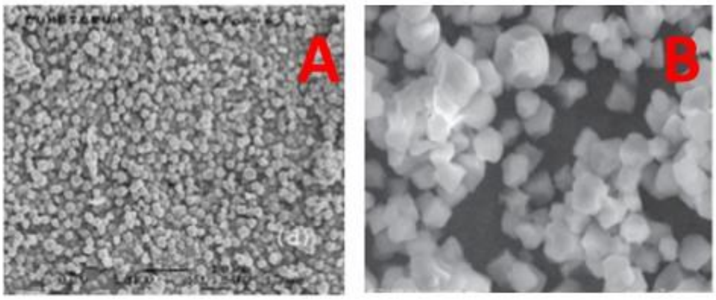

Fig. 1: Micrographs of bitter yam starch
A: (Amani et al., 2004),
B: (Odeku & Picker-Freye, 2009)

3. Granule Morphology

Bitter yam starch granules size and shape may vary with the source and cultivar of the tuber (Adedokun & Itiola, 2010). The absence of fissures on the surface of starch granules as observed under scanning electron microscopy is also frequently used to assess starch purity after extraction (Piecyk, Drużyńska, Worobiej, Wołosiak, & Ostrowska-Ligęza, 2013). However, yam starch granules may show small fissures on the surface. This could also be linked with extraction efficiency. According to previous studies, bitter yam starch has remarkably smaller granules (3-5 µm) (Farhat, Oguntona, & Neale, 1999)compared to granules from other yam species (> 21 µm) (Amani et al., 2004), which may explain their lower amylose contents (Zhu, 2015). It has been suggested that amylose component of starch is mostly formed when granules grow larger in yam, with larger granules exhibiting higher amylose contents than smaller ones (Jane, Ao, Duvick, Wiklund, Yoo, Wong, & Gardner, 2003; Zhu, 2015). In terms of shape, bitter yam starch was found to be polygonal (Amani et al., 2004; Otegbayo et al., 2014) compared to other yam varieties which showed oval, round and or triangular shape (Otegbayo et al., 2014). Differences in size and shape of starch granules could be atributed to varietal differences, source and possibly growing conditions. Small sized starch graunles has been suggested as possible lipid substitute in food systems due to their better mouth feel (Daniel & Whistler, 1990). Bitter yam starch may therefore find application as fat replacers in certain applications in the food industry such as stabilizers in baking powder and as laundry-stiffening agents since they can penetrate fabric and give high gloss and stiffness in textile industries (Otegbayo et al., 2014).

4. Crystallinity pattern

X-ray diffraction study revealed that the crystalline lamellae of amylopectin in starch has three distinct crystalline patterns (Jenkins & Donald, 1995). These patterns link the crystalline structure and the length of the amylopectin chains forming the clusters. Short A-chains are associated with A-type crystallinity, longer A-chains display B-type crystallinity, while intermediate-length A-chains show C-type crystallinity (Jenkins & Donald, 1995). The A and B crystalline patterns are differentiated based on the packing arrangement of double helices within amylopectin and their level of hydration (Imberty & Perez, 1988). The A-type is closely packed and are less hydrated, while the B-type has a more hydrated helical core (Cheetham & Tao, 1998; Imberty & Perez, 1988). Most cereal starches display A-type crystallinity pattern, tuber starches such as potato starch, mostly exhibit the B-type pattern, while pulse starches consists of mixtures of A and B polymorphic forms, and are categorized as C starches (Oates, 1997). Starch may show the V-type diffraction pattern in starches when the amylose fraction complexes with lipids (Figure 2). X-ray diffraction studies on bitter yam starch generally reported the A-type pattern (Amani et al., 2004; Farhat et al., 1999). Although some authors reported the C-type diffraction type for bitter yam starch (Odeku & Picker-Freye, 2009), both the A and C-type pattern are very unusual for tuber starches. Other reports on yam cultivars such as *Dioscorea alata* also observed differences in the crystallinity pattern of the extracted starches (Amani et al., 2004; Farhat et al., 1999; Riley et al., 2004). Differences in the crystalline pattern of starches have been attributed to differences in growth conditions, growth locations, and inherent genetic differences among plant species (Agama-Acevedo, Nuñez-Santiago, Alvarez-Ramirez, & Bello-Pérez, 2015; Bello-Perez, Roger, Baud, & Colonna, 1998; Kaptso, Njintang, Nguemtchouin, Scher, Hounhouigan, & Mbofung, 2014; Oyeyinka, Singh, Adebola, Gerrano, & Amonsou, 2015; Oyeyinka, Singh, & Amonsou, 2016; Waliszewski, Aparicio, Bello, & Monroy, 2003).

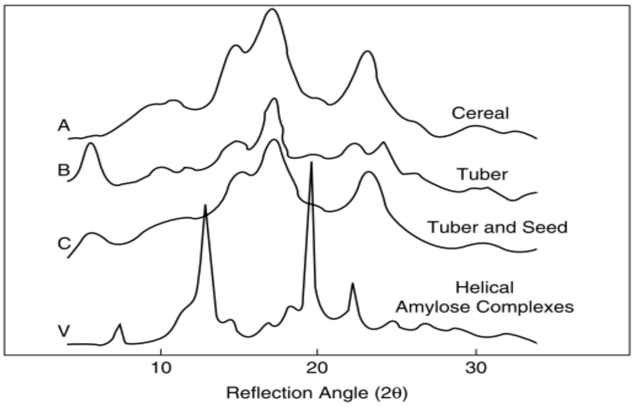

Fig. 2 X-ray diffraction patterns for different starches A, B, C and V amylose (Cui, 2005)

5. Functional properties

5.1 Gelatinisation

Starch gelatinisation involves a phase change of starch granules from an ordered state to a disordered state (Hermansson & Svegmark, 1996; Hoover, Hughes, Chung, & Liu, 2010). The phase transition occurs in the presence of excess water and over a temperature range specific for starch from different origin. Starch gelatinisation takes place in the amorphous region of starch and it is accompanied by subsequent swelling of starch granules. Other changes include loss of birefringence and crystalline order as well as dissociation of double helices and leaching of amylose into the surrounding medium (Hoover et al., 2010). Gelatinisation properties of starch have been studied using several methods, including the use of a differential scanning calorimeter. These starch properties (T_o: onset gelatinisation temperature, T_p: peak gelatinisation temperature T_c: conclusion gelatinisation temperature and the enthalpy of gelatinisation) are influenced by amylose content, botanical origin and the structure of amylopectin. Depending on source and the ratio of starch to water, the gelatinisation temperature of bitter yam starch may vary between 68 and 83°C (Amani et al., 2004; Emiola & Delarosa, 1981; Farhat et al., 1999; Ukom et al., 2015). Bitter yam starch seem to exhibit higher gelatinisation temperatures than starches from other yam cultivars (Amani et al., 2004; Farhat et al., 1999; Zhu, 2015). The higher gelatinisation temperature of bitter yam starch suggest better thermal stability than other yam cultivars which could be associated with the small sized granules and low amylose content. Previous studies reported that starch with low amylose content is generally associated with high gelatinisation temperature (Kaptso et al., 2014; Kaptso, Njintang, Nguemtchouin, Amungwa, Scher, Hounhouigan, & Mbofung, 2016; Naidoo, Amonsou, & Oyeyinka, 2015; Stevens & Elton, 1971). Emiola and Delarosa (1981) studied the physicochemical characteristics of starches extracted from four yam cultivars with varying amylose contents (21.6-25.4%). *Dioscorea cayenensis* with the lowest amylose content (21.6%) displayed the highest gelatinisation temperature of 72°C (Emiola & Delarosa, 1981). However, some studies on legumes and tuber starches found that low amylose starch did not show high gelatinisation temperature (Chung, Liu, Pauls, Fan, & Yada, 2008; Joshi, Aldred, McKnight, Panozzo, Kasapis, Adhikari, & Adhikari, 2013; Kaptso et al., 2016; Kaur, Sandhu, & Lim, 2010; Li & Yeh, 2001). Joshi et al. (2013) investigated the functional properties of starches with different amylose contents (lentil: 32.52%, corn: 24.78% and potato: 14.93%). Potato starch with the lowest amylose content displayed the lowest peak gelatinisation temperature of 65.65°C, while corn starch showed the highest value (73.80°C). Lentil starch reportedly showed peak gelatinisation temperature (68.32°C) which is intermediate to those of potato and corn starches. The high peak gelatinisation temperature of corn starch was associated with the more compact granular structure and the presence of lipids which may form an inclusion complex with amylose (Singh, Singh, Kaur, Sodhi, & Gill, 2003). Nevertheless, Noda, Takahata, Sato, Ikoma, and Mochida (1996), working with sweet potato and wheat starches found that the T_o, T_p, T_c and the enthalpy of gelatinisation (ΔH) are significantly influenced by the structure of amylopectin rather than amylose content. In general, starches with higher proportion of long amylopectin chains would display high T_o, T_p, T_c and ΔH, while those with abundant short amylopectin chains would exhibit low T_o, T_p, T_c and ΔH (Noda et al., 1996). Huang, Schols, van Soest, Jin, Sulmann, and Voragen (2007) associated high gelatinisation temperature in cowpea starch with the presence of higher amounts of long amylopectin chains. Therefore, future studies needs to be done to assess the influence of amylopectin structure on the gelatinisation properties of bitter yam starch.

5.2 Pasting

Pasting is a process that follows gelatinisation (BeMiller, 2011). During starch pasting, considerable granule swelling and leaching of amylose occurs, which contributes to the increased viscosity of starch after cooling. The pasting properties of starch is a reflection of its botanical origin as well as the composition of its major component (amylose and amylopectin). Pasting temperature of yam starches are generally high (>78°C) depending on the source and cultivar (Amani et al., 2004; Ezeocha & Okafor, 2016; Otegbayo et al., 2014; Zhu, 2015). Amani et al. (2004) found that bitter yam starch showed the highest pasting temperature (87°C) compared to other yam cultivars. The fairly high pasting temperature of bitter yam starch could be due to the small size of the starch granules. Smaller starch granules have been reported to be resistant to rupture and loss of molecular order (Dreher & Berry, 1983). Pasting temperature is a useful indicator of the ease of cooking these starches which provide an indication of the minimum temperature required for sample cooking. Other authors working with bitter yam harvested at different periods found substantially lower pasting temperature (approx. 50°C) for the extracted starch (Akinoso & Abiodun, 2013).

The peak viscosity of bitter yam starch may vary between 200 and 461 RVU (Akinoso & Abiodun, 2013; Ezeocha & Okafor, 2016; Otegbayo et al., 2014). Otegbayo et al. (2014) working with 43 varieties of yam cultivars found that bitter yam had the highest peak viscosity, which could be associated with its low amylose content. The peak viscosity, also referred to as “swelling peak” may be influenced by starch composition, structure and the presence of other minor components of starch such as lipids (Tester & Morrison, 1990). Starches with high amylose contents would show low peak viscosity due to restricted swelling of starch granules (Huang, Shang, Man, Liu, Zhu, & Wei, 2015). Peak viscosity indicates the ease with which the starch granules are disintegrated (Otegbayo et al., 2014). However, there are instances where high amylose starch did not show low peak viscosity (Ezeocha & Okafor, 2016). Other factors which could influence the pasting properties of yam starches include the presence of non-starch components such as mucilage as well as strong interaction between amylose–amylose and/or amylose–amylopectin chains and the molecular structure of amylose and amylopectin (Hoover et al., 2010). Huang et al. (2007), found that cowpea starch exhibited a higher peak and final viscosities than starches from chickpea and yellow pea due to its higher amount of long amylopectin chains. Previous studies similarly reported that the amylose contents and the distributions of amylopectin chain length of starches from different botanical origin predominantly affected their pasting properties (Jane, Chen, Lee, McPherson, Wong, Radosavljevic, & Kasemsuwan, 1999). Furthermore, the tuber maturity and harvesting period may also influence the pasting properties of bitter yam starch. Akinoso and Abiodun (2013) studied the effect of harvesting periods on morphology and physicochemical properties of bitter yam starch. The peak viscosity of bitter yam starch significantly decreased with increasing harvesting period from 7 to 11 months (Akinoso & Abiodun, 2013). The decrease in peak viscosities of the starches was associated with reduced starch contents, which could result from the activities of the enzyme amylase that breaks down the starch into (Afoakwa & Sefa-Dedeh, 2002).

5.3 Swelling power and solubility

Starch swelling involves interaction between the crystalline and amorphous regions of starch (Hoover, 2001; Singh et al., 2003). Swelling properties of bitter yam starch have been described using different methods such as swelling power, which measures the amount of swollen granules when heated at specified temperature or swelling index, which measures the increase in volume of starch granules after allowing to stand for specified time. Some authors reported the swelling power of bitter yam starch at varying temperatures (50-95°C) (Akinoso & Abiodun, 2013; Emiola & Delarosa, 1981; Odeku & Picker-Freyer, 2007), others reported the swelling power at a single temperature of 20°C (Odeku, Schmid, & Picker-Freyer, 2008), 25°C (Okunlola & Odeku, 2011) 50°C (Amani et al., 2004), 85°C

(Odeku et al., 2008; Sanful & Engmann, 2016) or 90°C (Adedokun & Itiola, 2010; Amani et al., 2004). In general swelling power of bitter yam starch increased with increasing temperature, which has been associated with the degree of macromolecular disorganization and also to variations in the degradation of starch during thermal treatment (Singh et al., 2003). Variation in the swelling ability of bitter yam starches may be attributed to the different experimental conditions (Table 1) such as starch concentration (starch to water ratio), heating temperature used in various studies as well as the cultivar differences. For example, Akinoso and Abiodun (2013) reported significant variations in the swelling power of starch extracted from white and yellow variety of bitter yam . The differences possibly may be linked with the variation in amylose contents and granule size. This seems plausible since the yellow bitter yam starch granules was reportedly smaller than the starch granules from the white variety (Akinoso & Abiodun, 2013). Beside the amylose contents and granule size, the molecular structure of amylopectin and the magnitude of interaction within the amorphous and crystalline region may influence the swelling behaviour of starches (Naidoo et al., 2015; Singh et al., 2003).

Table 1: Swelling power of bitter yam starches

Yam type	Starch concentration	Swelling power (g/g)	Temperature	References
Not specified	4%	13.7	90°C	[a](Amani et al., 2004)
Not specified	4%	15.1	50°C	[b](Amani et al., 2004)
White variety	1%	1.8-12	50-90°C	(Akinoso & Abiodun, 2013)
Yellow variety	1%	1.8-13	50-90°C	(Akinoso & Abiodun, 2013)
Not specified	1%	1.00-1.16	Not specified	[c](Ezeocha & Okafor, 2016)
White variety	1%	4.51	Not specified	(Adedokun & Itiola, 2010)
Yellow variety	1%	5.28	Not specified	(Adedokun & Itiola, 2010)
Not specified	1%	7.38-18.65	60-95°C	(Emiola & Delarosa, 1981)
Not specified	5%	0.8	25°C	(Okunlola & Odeku, 2011)

[a]Swelling power was determined at 90°C for 12 min, [a]Swelling power was determined at 50°C for 23 min [c]Reported as swelling index

6. Modification

Native starches are generally unsuitable for most industrial applications. Hence, they are modified to improve functionality and to enhance certain industrial applications. Modification of starch increases resistance towards extreme processing conditions such as high temperature and shear and may also slow down the extent and rate of starch retrogradation (D'Silva, Taylor, & Emmambux, 2011). Over the last decades, various starch modification processes such as physical, genetic, enzymatic, chemical have been studied (Kaur, Ariffin, Bhat, & Karim, 2012). Physical modification processes such as annealing and heat-moisture treatment can be safely used in starch modification, as it does not pose any major risk with regard to food safety (Kaur et al., 2012; Zavareze & Dias, 2011). Other physical methods employed in modification of starch as reviewed by Kaur et al. (2012) include osmotic pressure treatment, microwave radiation, pulsed electric filed treatment, multiple deep freezing and thawing. Genetic modification of starch involves traditional plant breeding or the application of biotechnology to produce starch with desirable properties (Kaur et al., 2012). It involves manipulating the enzyme system of the starch biosynthetic pathway to alter the ratios of amylose and amylopectin (Hui, 2006). The technology involved can produce novel starches, which may reduce the use of hazardous chemicals in starch modification (Kaur et al., 2012).

Chemical modification can be achieved by crosslinking, etherification, oxidation, esterification and grafting of starch molecules (Gao, Li, Bi, Mao, & Adhikari, 2014; Kaur et al., 2012; Kittipongpatana & Kittipongpatana, 2013; Wongsagonsup, Pujchakarn, Jitrakbumrung, Chaiwat, Fuongfuchat, Varavinit, Dangtip, & Suphantharika, 2014). However, certain chemicals such as epichlorohydrin used in starch modification is reported to be unsafe in food applications (Li, Wang, Li, Chiu, Zhang, Shi, Chen, & Mao, 2009). More recently, the use of naturally occurring compounds such as amino acids (Cui, Fang, Zhou, & Yang, 2014), ionic gums (Pramodrao & Riar, 2014), fatty acids (Kawai, Takato, Sasaki, & Kajiwara, 2012; Zhang, Huang, Luo, & Fu, 2012) and lysophospholipids (Ahmadi-Abhari, Woortman, Oudhuis, Hamer, & Loos, 2013; Cui & Oates, 1999; Siswoyo & Morita, 2003) are finding application in starch modification.

6.1 Oxidation

Oxidation of starch involves the conversion of the hydroxyl groups in starch, first to carbonyl group and then to carboxyl groups. Starches are oxidized mainly by treating starch with sodium hypochlorite. Oxidized starch may also be prepared using other chemicals such as ozone and hydrogen peroxide. Oxidized starch has wide applications in the industry, particularly where film formation and adhesion properties are required such as in the paper industry (Li & Vasanthan, 2003; Sangseethong, Termvejsayanon, & Sriroth, 2010). They could also be used in food products where low viscosity is desired such as in mayonnaise and salad cream (Li & Vasanthan, 2003). Although oxidation of bitter yam starch has not been reported, other researchers have investigated the effect of oxidation on some yam cultivars such as Chinese yam (*D. opposita*) (Xia, Wenyuan, Qianqian, Yanli, Xinhua, & Luqi, 2011; Zhang, Liu, Wang, & Gao, 2011), yellow yam (*D. cayenensis*) and white yam (*D. rotundata*) (Oladebeye, Oshodi, Amoo, & Karim, 2013). Oxidation of white and yellow yam starches using ozone was found to significantly increase their water solubility, which was associated with depolymerization and structural weakening of the starch granules (Oladebeye et al., 2013). The gel strength and tendency to retrograde as measured by setback viscosity similarly decreased after oxidation (Oladebeye et al., 2013). Setback is associated with the extent of starch retrogradation and firming tendency of starch gels. A higher rate of retrogradation is expected to occur when amylose is free to associate into crystallites (Liang, King, & Shih, 2002). The conformational reordering and rearrangement in oxidized starches through the introduction of carboxyl groups, prevents or slows down such re-associations of starch molecules. Furthermore, the introduction of carboxyl groups to replace hydroxyl groups during oxidation inhibits the formation of such binding forces (Oladebeye et al., 2013). Oxidation of Chinese yam reportedly reduced swelling and increased solubility (Xia et al., 2011). X-ray diffraction studies further revealed a change of polymorphic form from the C-type to the A-polymorph (Xia et al., 2011). The degree of oxidation as well as the starch structure in terms of organization may vary with the starch source and could influence the changes in functional properties of oxidized starch. Bitter yam has relatively small-sized starch granules which may play a role in controlling the efficiency of oxidation process due to increased surface area of small granules. Therefore, oxidation of bitter yam starch may be required to further increase the utilisation of this yam cultivar in food and non-food applications.

6.2 Annealing

Annealing (ANN) refers to treatment of starch in excess water (<65%, w/w) or at intermediate water levels of about 40 to 50% (w/w) at temperatures below the onset temperature of gelatinisation (Hoover et al., 2010). Studies on effect of ANN on physicochemical properties of starches extracted from *D. alata* (Falade & Ayetigbo, 2015; Jayakody, Hoover, Liu, & Donner, 2009; Vamadevan, Bertoft, Soldatov, & Seetharaman, 2013), *D. esculenta* (Jayakody et al., 2009; Vamadevan et al., 2013) *D. cayenesis and D. rotundata* (Falade & Ayetigbo, 2015) have been reported. However, only limited report exit on the functionality of annealed bitter yam starch (Falade & Ayetigbo, 2015). Falade and Ayetigbo (2015) reported slight reductions in the water absorption capacity of annealed bitter yam starch, but a substantial reductions in starch foaming capacity and stability after ANN. Furthermore, native or annealed bitter yam starch exhibited excellent compressibility than water, white and yellow yam starches (Falade & Ayetigbo, 2015). This could be related with its smaller granule size has previously stated. In general, ANN has been shown to reduce granular swelling, amylose leaching and susceptibility to hydrolysis (Jayakody et al., 2009; Vamadevan et al., 2013). These changes were associated with crystalline perfection and increased interaction between amylose-amylose and amylose-amylopectin chains (Chung, Liu, & Hoover, 2009; Hoover et al., 2010). According to Zavareze and Dias (2011), both crystalline perfection and starch molecule interactions decreased the amorphous region of starch resulting in a decrease in granular swelling. Studies on bitter yam starch did not focus on functional and physicochemical properties of annealed starch and its potential application in food systems. Hence further studies are needed to establish the effect of ANN on this yam cultivar, especially for both the yellow and white type.

6.3 Pre-gelatinisation

Starches are pre-gelatinized to make them cold-water soluble with improved flowability. Pregelatinisation of white and yellow bitter yam starches reportedly increased swelling and solubility by more than 2-folds (Adedokun & Itiola, 2010). According to these authors, starch molecules are disrupted during pregelatinisation resulting in the partial release of amylopectin which is responsible for starch swelling. However, the amylose contents, peak, setback, trough and break down viscosities decreased significantly (Adedokun & Itiola, 2010). Reduction in amylose contents could be attributed to leaching of amylose during the pregelatinisation process. The effect of pregelatinisation on other functional properties such as digestibility, microstructure, thermal and dynamic rheology of bitter yam starches may require further investigation. Additional research may also be required to establish the impact of variety on the modified starches.

7. Digestibility

The digestibility properties of bitter yam starch is very scarce in the literature. Riley et al. (2004), studied the in-vitro digestibility of raw starches extracted from bitter yam starch in comparison with other yam cultivars grown in Jamaica. Bitter yam starch was found to be more readily digested by α-amylase than other yam cultivars due to its small granule size which allowed for greater contact of enzyme with the starch granule interior. Digestibility of starches have been reported to be influenced by many factors such as the botanical origin (Ring, Gee, Whittam, Orford, & Johnson, 1988), amylose/amylopectin ratio (Kaur et al., 2010), degree of crystallinity (Hoover & Sosulski, 1985; Sandhu & Lim, 2008), granule size (Snow & O'Dea, 1981), molecular structure of amylopectin (Naidoo et al., 2015; Srichuwong & Jane, 2007). According to the rate of glucose release and absorption in the gastrointestinal tract, starch can be classified into rapidly digestible starch (RDS), slowly digestible starch (SDS) and resistant starch (RS) (Englyst, Kingman, & Cummings, 1992). RDS is the portion of starch that causes a rapid rise in the blood glucose level after ingestion, SDS, is the fraction of starch that is digested slowly when compared to RDS, but completely in the small intestine. RS is the starch fraction that is not digested in the small intestine but is fermented in the large intestine into small chain fatty acids and other nutrients with physiological benefits. No study has reported the nutritional classification of bitter yam starch into RDS, SDS and RS and the only study done is on a single cultivar. Consequently, it would be difficult to generalize the result reported in the literature for bitter yam starches. As previously noted, molecular structure of starch may also influence starch digestibility, hence future studies on bitter yam starch may be needed to understand the influence of cultivar, and molecular structure of amylose and amylopectin on the nutritional starch fractions of the starch component.

8. Potential utilisation

Currently, bitter yam starch is not available in the market. This could be associated with the very limited research done on the starch component of bitter yam. The remarkably small size of bitter yam starch granules suggest its potential applications as fat replacers for better mouth feel in foods such as mayonnaise and salad creams. Bitter yam starch also are characterised with relatively low amylose content suggesting that they may have low retrogradation tendencies when explored in food applications. Due to the growing demand of starch by the industry, bitter yam starch could play important role as alternative starch source for micro, small and medium scale industry. Hence, intensive research is needed to establish data on the physicochemical properties of bitter yam starch in order to determine their specific applications in the industry.

9. Conclusions and future research

Bitter yam is a good source of starch that is promising as a potential starch source for the industry. However, the current level of research on bitter yam starch is very limited. Full characterization of bitter yam starch such as the use of scanning electron microscopy, atomic force microscopy, thermal and rheological properties should be assessed. Furthermore, since most reported studies on bitter yam starch focused primarily on pharmaceutical applications, future studies on bitter yam starch should focus more on food applications including modification of the starch using existing methods such as annealing, heat moisture treatment, lipid modification, or a combination of these methods. Bitter yam starch could also be modified using non-thermal processing technologies such as irradiation, high pressure treatment and pulsed electric field. The effect of modification processes on digestibility of bitter yam starch should also be investigated. Future studies should also compare the physicochemical properties of bitter yam starch with conventional starch sources such as corn, potato and tapioca starches.

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