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Review paper

Tuber Crop Starches Importance, Properties and Applications: Review

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ABSTRACT

The major carbohydrate of tuber and root crops is starch, which accounts for 16-24% of their total weight. In recent years, substantial process has been made in understanding the relationship between starch structure and physicochemical properties. However, these studies have been mainly on cereal starches. The present status of knowledge on the composition, structure, gelatinization, and rheology also reviewed. The tropical tuber crops contain starch as the major component and thus act as important source of starch. Except cassava and to a smaller extent sweet potato, starch from other tuber crops has not been exploited for industrial applications partly because of difficulty in the extraction of the pure starches and partly because of non-availability of information about the properties of these lesser known starches. This review attempts at collecting data available on the physicochemical and functional characteristics of the tropical tuber starches, highlighting their unique properties and potential field of applications. The physicochemical properties like granule shape and size, X-ray diffraction (XRD) patterns, amylose content, or content of non-starchy components, show considerable variation among the tuber starches. The starch granules of *Colocasia esculenta* and *Dioscorea esculenta* tubers are very small whereas those of *Canna edulis* are very large. DSC gelatinisation temperatures are low for cassava starch and high for the aroid starches. The functional characteristics like viscosity, swelling power and solubility also depend on a number of factors such as varietal variation, method of extraction, processing conditions and instruments used for analysis. Viscosity is high for cassava and *C. edulis* starches, but low for most aroid starches. Clarity is good for cassava and yam starches compared to the others. The diversity available in the tuber starches shows that some of the starches can be used in place of chemically modified starches available on the market. The realisation of their importance can help in value addition of these neglected crops and also provide starch with special properties for specific applications.

Keywords: Tuber and root crops starch, starch structure, physico-chemical properties of starches

Starch is the most abundant storage reserve carbohydrate in plants. It is found in many different plant organs, include seeds, fruits, tubers and roots, where it is used as a source of energy during period of dormancy and re- growth. Many of these starch-storing for example the grains of maize and rice or the tubers of cassava and potatoes are staple foodstuffs in the human diet. Starch is a versatile and useful polymer not only because it is a cheap, natural material but also because of the ease with which its physicochemical properties can be altered through

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chemical or enzyme modification and/or physical treatment (Steve, 2004). Starch is the major calorie source in a variety of diets of people worldwide. Thus, starches from various plant species, especially tubers, have received very extensive attention in food research. Cassava, potato and corn are the most common sources of starch for industries (Wickramasinghe *et al.* 2009). Starch is an important ingredient in various food systems as thickening, gelling and binding agents. It imparts texture to a great diversity of foodstuffs such as soups, potages, sauces, processed foods, etc. (Thebaudin *et al.* 1998).

Starch consists of two molecules, long essentially linear chains of α-(1→4)-linked glucopyranosyl residues (amylose), and a much larger, highly branched molecule (amylopectin) consisting of thousands of short α-(1→4)-linked glucan chains of degree of polymerisation (DP) 6 to >100 that are attached by α-(1→6)-linked branch points. Amylose and amylopectin are synthesised in the plastids, where they assemble into a semicrystalline granule. Amylopectin is the major component, making up 70–80% of starch in most species. Amylose is synthesised by granule-bound starch synthase (GBSS), whereas a large complex of enzymes is required to synthesise amylopectin. This complex consists of four soluble starch synthases (SSI, SSII, SSIII, SSIV) and two types of starch branching enzyme (SBEI, SBEII), with various debranching enzymes, kinases and other enzymes also involved (Zeeman *et al.* 2010).

Major starch sources are cereals (40 to 90%), roots (30 to 70%), tubers (65 to 85%), legumes (25 to 50%) and some immature fruits like bananas or mangos, which contain approximately 70% of starch by dry weight (Santana & Meireles, 2014). The accumulation pattern of starch granules in each plant tissue, shape, size, structure and composition is unique to each botanical species (Smith, 2001). Amylose and amylopectin are two macromolecular components of starch granules (Be Miller, 2007). Isolated starch is used in the food industry to impart functional properties, modify food texture, consistency and so on. Not only is the amount of starch important for the texture of a given product, but also the type of starch is critical (Biliaderis, 1991).

Tropical root and tuber crops are important food crops serving either as subsidiary or subsistence food in different parts of the tropical belt. They are rich sources of starch (Hoover R, 2001) besides many vitamins, minerals, etc. Although there has been some decline in their use as food, their industrial application, especially that of cassava, is making rapid advances. Cassava and to a small extent, sweet potato (*Ipomoea batatas* Lam.) are used for starch extraction in countries like India, Brazil, Thailand, Indonesia, Philippines and China. Studies at different laboratories have brought to light the wide diversity in the starch characteristics of tuber crops and the possibility of using these native starches instead of chemically modified starches (Whistler *et al.* 1984).

Cassava (*Manihot esculenta* Crantz) is a sturdy perennial crop grown in many parts of Asia, Africa and South America. The yield of the crop is normally around 20 t/ha and the starch yield forms nearly one quarter of the total yield. The starch has been studied in detail and finds use in a large range of industries (Moorthy, 2001).

Sweet potato (*Ipomoea batatas* Lam.) is an herbaceous perennial vine and is grown extensively in the tropics and also in some parts of the USA for its tubers. The tubers have different sizes, shapes and colour. The yield varies anywhere from 8±30 t/ha and it has been possible to have three crops in a year thus giving a very high annual starch yield. The starch content in the fresh tubers varies from 12±30% (Moorthy, 2001).

Taro (*Colocasia esculenta*) is a small herbaceous plant with large leaves found in most parts of the tropics and is very important in the pacific regions. The crop is harvested at 8±10 month stage and produces a number of cormels around a corm. The yield is 5±10 t/ha and starch content in the tubers is 12±20% (Moorthy, 2001).

Tannia (*Xanthosoma sagittifolium*) is a large herbaceous plant grown widely for its cormels which are much larger than taro cormels. The yield is around 10±25 t/ha and starch content in the tubers nearly 20% (Moorthy, 2001).

Elephant Foot Yam (*Amorphophallus paeoniifolius*) is grown extensively for its huge corms. It is a big perennial herb harvested after one year and the corms can weigh over 15 kg. The yield is over 20 t/ha and starch content in the tubers is approximately 20%. Yams comprise a large genus with over 600 species from which a few are more commonly cultivated. Most of them are trailers. The tubers are harvested at 8±12 months after planting (Moorthy, 2001).

African yam bean (*Sphenostylis stenocarpa*) belongs to Leguminosae. It is a vigorous herbaceous climbing vine reaching 1.5±2 m in height producing pods as well as small spindle shaped tubers about 5±8 cm long similar to sweet potato. The crop is found mainly in Africa yielding up to 4 t/ha. The tubers are rich in starch (25%) but there are no studies on this starch (Moorthy, 2001).

Arracacha, Peruvian carrot, (*Arracacia xanthorrhiza*) is a stout semi-caulescent herb, resembling celery grown in south America and parts of Africa mainly at high altitudes. The edible secondary tubers are usually 6±10 in number with a yield of 3±18 t/ha. The tubers which contain nearly 20% starch, are used as a source of edible starch (Moorthy, 2001).

Chinese water chestnut (*Eleocharis dulcis*) is a variable annual stout aquatic plant producing corms found in the Asian region. The yield is 20±40 t/ha and starch content is around 7%. In China the starch is extracted by rasping and settling (Moorthy, 2001).

East Indian arrowroot (*Tacca leontopetaloides*) is a perennial herb with a tuberous rhizome producing large/small sized tubers, found in tropical areas. The tubers are similar to potato are harvested after 8±10 months and can weigh up to 1 kg. The tubers are rich in starch (20±30%) and it is extracted and used widely (Moorthy, 2001).

Giant taro (*Alocasia macrorrhiza*) is a tall succulent herbaceous plant up to 4.5 metres in height producing big corms up to 18 kg. It is grown in Asia and South America and harvested 10±12 months after planting. The tubers contain 17±25% starch (Moorthy, 2001).

Coleus (*Plectranthes rotundifolius*) is a small herbaceous annual 15±30 cm high found in Africa and Asia. At maturity (6 months) they yield round to oval tubers that are very prized for their delicate flavour. The yield is 7±15 t/ha and the starch content is nearly 15% (Moorthy, 2001).

Kudzu (*Pueraria lobata*), known as arrowroot vine, is a small perennial twining herb or shrub with elongated tuberous roots often weighing up to 40 kg and yield of 5±7 t/ha. Roots are starchy, 30±60 cm long and used as a source of edible starch in place of arrowroot starch or gelatine in many foods. The starch content is over 20% and is extracted on a small scale in Japan but the starch has not been studied (Moorthy, 2001).

Lotus root (*Nelumbo nucifera*) is a perennial aquatic herb, rooting in mud found in South and South-east Asia, Africa and Australia. The white globulous rhizomes which are harvested at 6±9 months measure 60±120 cm in length. The root yield is 5 t/ha and starch content is nearly 18%. In China, a fine starch is isolated from the rhizomes (Moorthy, 2001).

Oca (*Oxalis tuberosa*) is a small compact annual tuberous herb 20±30 cm high. Oca is an ancient food plant of the Andes and found in many parts of South America. The rhizomatous tubers are harvested at eight months maturity and are similar to potato (5±8 cm in length). The tuber yield is 4±5 t/ha while the starch content is 12% (Moorthy, 2001).

Queensland arrowroot (*Canna* sp) is perennial herbaceous monocotyledon found in many parts of Asia, Africa and South America. The shape of the rhizomes varies from cylindrical to tapering and 5±9 cm in size. The tuber yield is 15±40 t/ha and the starch content varies from 24±30% (Moorthy, 2001).

Shoti (*Curcuma zedoaria*) known as Indian arrowroot, is a robust perennial with a fleshy branching rhizomes cultivated in Asia. The starchy finger shaped rhizomes are greyish in colour, grow to 15 cm in length and have a musky odour. The tuber yield is 8±12 t/ha and starch content is 12±15%. The starch is extracted by rasping the tubers, sieving and settling and serves as a source of easily digested starch (Moorthy, 2001).

Table 1 shows the various tuber crops sources, yield and its starch content.

Table 1: Tuber crop Sources, Yield and Starch content (Moorthy, 2001)

Sl. No.	Source Name	Yield (Tonne/ Ha)	Starch Content (%)
1	Cassava	20	25
2	Sweet potato	8-30	12-30
3	Taro	5-10	12-20
4	Tannia	10-25	20
5	Elephant Foot Yam	20	20
6	African yam bean	4	25
7	Arracacha, Peruvian carrot	3-18	20
8	Chinese water chestnut	20-40	7
9	East Indian arrowroot	10-30	20-30
10	Giant taro	10-20	17-25
11	Coleus	7-15	15
12	Kudzu	5-7	>20
13	Lotus root	5	18
14	Oca	4-5	12
15	Queensland arrowroot	15-40	24-30
16	Shoti	8-12	12-15
17	Swamp taro	7-10	28-30
18	Winged bean	2-6	20

Swamp taro (*Cyrtosperma chamiossonis*) is a giant herbaceous perennial 3±4 m in height with huge leaves. It is cultivated in many parts of Asia, Africa and the Pacific islands. The yield of corms is 7±10 t/ha and the starch content 28± 30% (Moorthy, 2001).

Winged bean (*Psophocarpus tetragonolobus*) is a leguminous, climbing perennial found in Asia and Africa. Tubers are obtained 5±8 months after planting with a yield of 2±6 t/ha. Root tubers are 5±12 cm in length and contain nearly 20% starch (Moorthy, 2001).

Starch synthesized by plant cells is formed by two types of polymers: amylopectin and amylose. Amylopectin consists of linear chains of glucose units linked by α-1,4 glycosidic bonds and is highly branched at the α-1,6 positions by small glucose chains at intervals of 10 nm along the molecule's axis; it constitutes between 70 to 85% of common starch (Durrani & Donald, 1995). Amylose is essentially a linear chain of α-1, 4 glucans with limited branching points at the α-1, 6 positions and constitutes between 15-30% of common starch. Starch's structural units, amylose and amylopectin, the polymodal distribution of α-glucans chains of different sizes and the grouping of branch points in the amylopectin molecule allow the formation of double helical chains. Amylose and amylopectin can be arranged in a semicrystalline structure forming a matrix of starch granules with alternating amorphous (amylose) and crystalline (amylopectin) material, which is known as the growth rings in superior plant starch (Jenkins *et al.* 1993).

Maize or corn starch makes more than 80% of the world market for starch and most of this is produced in USA. Europe is the major producer of wheat and potato starches, where cassava or tapioca starch is produced mainly in Asia. Other starches, such as those from rice and sweet potato, make up only a minor portion of the total (Steve, 2004). Root and tuber crops are grown worldwide and usually have low commercial value for direct consumption. Even though the information available on such underutilized crops is spare, it has been proved that the starch of such crops would be a good source for different food industries as mentioned by Amani *et al*.

Starch is important in bread making, as a meat binder in confectionary and as an additive in most food and beverages. This is in addition to its use in textiles, paper and plywood industries, as filler in biodegradable plastics and in the mining and construction industry. The use of starch in these applications depend on its physicochemical and functional properties which are determined by its structure that depends on its granule and crystalline properties (Nuwamanya *et al.* 2010b). These properties also depend on the amylose amylopectin ratio, chemical properties and molecular characteristics of amylose and amylopectin (Tetchi *et al.* 2007). However, the properties that define cassava, potato and sweet potato starches are not well detailed compared with the current market starches from maize and wheat. By detailing these properties, notably functional and solution properties, various starches can be differentiated and assigned specialised roles. With the onset of industrialisation in the East African region, the demand for starch especially in the dietary, textiles and paper industries has increased tremendously (Nuwamanya, 2010a). This demand has always relied on imported cereal starch which as expected is of a high cost in addition to the unreliable supply. The solution to this is to locally produce starch that can be used in its native form or modified to suit its applications. However, this cannot be possible without providing empirical evidence that these starches are of comparable value for the intended applications. Thus, the study of characteristics of starch from tuber and root crops that are mainly grown in East Africa provides a convincing entry point for commercialisation and, increased production of these crops. The properties of starch for cassava from selected Ugandan varieties have been studied (Nuwamanya *et al.* 2009; 2010a, b).

Characteristics and properties of Tuber Crop starches

1. Rheological Properties of Tuber Crop Starch

Among the vast sources of starch outlined above, only cassava and maize starches have been commercially exploited for some time and continue to be major sources of starch. The extraction of maize starch is slightly complicated because of the need for steeping the dried cobs for facilitating starch extraction and use of whitening agents. On the other hand, cassava starch is easily extractable since the tubers contain a very low quantity of proteins, fats, etc. Hence the extraction process is simple and the starch obtained is pure white in colour if the process is carried out properly. Since the lipid content in the starch is very little (<0.1%), the starch and its derivatives have a non-cereal taste very desirable in many food products. Cassava starch granules are mostly round (Moorthy, 2001) with a flat surface on one side containing a conical pit, which extends to a well-defined eccentric hilum. Under polarised light, a well-defined cross is observed. The granules exhibit wide variation in size range (5±40 μm) and variation in granular size distribution among varieties and during growth period during different seasons has been reported (Moorthy and Maini 1982; Moorthy 2002; Defloor, 1998). Thermal characteristics of cassava starch have been studied in detail using differential scanning calorimetry (DSC) which has become very important in the characterisation of starch gelatinization. DSC analysis of starch extracted from five varieties of cassava possessing different organoleptic quality showed that varietal differences manifest themselves in the DSC patterns. The characteristic peak shape could be traced to structural differences among the varieties. Table 2 shows the rheological properties of tuber crop starches.

Table 2: Rheological Properties of Tuber Crop Starch (Hoover, 2000)

Starch	Granule shape & size	Amylose content (%)	DSC Characteristics		Swelling Volume (ml/g)	Solubility (%)
			$T_{onset} – T_{end}$ °C	ΔH J/g		
Cassava	Round, 5-40	18-25	65-77	12-15	25-30	25-30
Sweet potato	Round, oval, 3-40	15-25	64-84	12.9	20-27	15-35
Arrowroot	Round, Polygonal, 10-18	16-28	68-85	14.4	23-28	—
Coleus	Round, 4-46	28-33	—	—	33	20
Kudzu	Polygonal, 3-23	15-25	—	—	—	—
Lotus	Round, 15-40	65-100	—	—	—	—
Arracacha	Round, oval, 5-7	<4	60.1	17.6	—	—
Oca	Oval, 20-55	18.4	55.9	14.6	—	—
Pacchrrhizus	Round, 35-64	17-25	63-76	13.65	25	—
Winged bean	Oval, 25-36	36	—	—	18	15
Curcuma zedoaria	Elliptical, 14-42	25-28	74-97	16	19-30	11-23
Swamp taro	Round, 4-17	—	—	—	—	—

The gelatinisation parameters of cassava starch extracted incorporated water were enhanced from 59.6 to 62.0°C for T_{onset} and 84.7 to 87.2°C for T_{end}. (Sriroth *et al.* 1998). The gelatinisation temperatures of cassava starch determined microscopically were ranged from 49±64 °C to 62±73 °C (Rickard, 1998). The values were quite close to DSC values of 66 and 78 °C for T_{onset} and T_{peak} respectively. The swelling power and solubility of starch provide evidence of non-covalent bonding between starch molecules. Factors like amylose-amylopectin ratio, chain length and molecular weight distribution, degree/length of branching and conformation decide the swelling and solubility. Cassava starch has medium swelling power compared to potato and cereal starches a property in conformity with its observed viscosity. The reported values for the swelling power of cassava starch vary considerably from 42±71 (Rickard, 1991) the swelling volume of different varieties of cassava varied from 25.5 to 41. 8 ml/g of starch. It was observed that during the growth period, starch of two varieties maintained their swelling volumes within small ranges while that for some varieties expressed wide variations which indicate that these varieties are very much susceptible to environmental influences (Moorthy and Ramanujam, 1986) and also point to possible relationships between cooking quality and swelling volumes. (Soni *et al.* 1985) have reported a two-stage swelling for cassava starch and attributed it to the two types of forces that require different energy input to cause relaxation of the starch molecules. (Asaoka *et al.* 1992) have determined the swelling volume of four varieties of cassava harvested during two seasons and observed that swelling power was higher in samples harvested in November compared to those harvested in August. Cassava starch has a higher solubility compared to the other tuber crop starches and the higher solubility can be attributed partly to the high swelling it undergoes during gelatinisation and the reported values ranged from 25 to 48% (Rickard, 1991). The solubility of starch of different cassava varieties varied from 17.2 to 27.2%. However, no direct correlation between swelling and solubility could be observed. The values for solubility of starch from different varieties during the growth period also indicated that starch of two varieties had good stability in their solubility, whereas the others had medium or poor stability. (Moorthy and Ramanujam, 1986).

Cassava starch having weaker associative forces compared to cereal starches has better clarity. During cooling and storage, the starch molecules associate leading to settling of the starch gel. This settling is not desirable in food products, especially those canned and subjected to freezing and thawing. In this respect cassava starch has fair sol stability compared to the cereal starches (Eliasson, 1996).

Sweet potato starch is also similar to cassava starch in its lipid and phosphorus content and hence its properties are quite similar to cassava starch. Sweet potato starch is polygonal or almost round in shape (Tian *et al.* 1991). Granule size of sweet potato is in the same range as that of cassava starch (5±40 μm). (Bowkamp, 1985) reported negative correlation between particle size and susceptibility to amylase and acid degradation in some sweet potato cultivars. (Noda *et al.* 1996) found no effect of fertilisation on starch granule size. The same authors found that the average granule size increased during the early stage of development and then remained steady in two varieties. Collado *et al.* have examined the DSC characteristics of sweet potato and obtained considerable variation in all the parameters. The mean T_{onset} was 64.6 °C and range 61.3±70 °C, mean T_{peak} 73.9 °C (range 70.2±77 °C) and mean T_{end} 84.6 °C, range being 80.7±88.5 °C. Garcia and Walter have examined sweet potatoes and found the range to be between 58±64 °C for T_{onset}, 63±74 °C for T_{peak} and 78±83 °C for T_{end}. The starch from fresh tubers and freeze-dried sweet potato tubers gave nearly equal values (67± 73 °C), but the small granules gelatinised between 75 and 88 °C. The pasting temperature of sweet potato starch varied between 66.0 and 86.3 °C by viscography while microscopic determination gave values of 57±70 to 70±90 °C. Sweet potato starch behaves similarly to cassava starch in its viscosity characteristics, viz., peak viscosity, viscosity breakdown and set back viscosity. Collado *et al.* found the solubility to be in the range 12 to 24%

(average 16.9%). It was presumed that the bonding forces might be tenuous but comparatively extensive, immobilising the starch within the granules even at high levels of swelling.

The extraction of starch from yams and aroids is difficult due to the presence of mucilage in the tubers. This is especially true for Colocasia which contains a large quantity of mucilage. However, use of dilute ammonia was found to facilitate extraction of starch from these tubers. The yield was enhanced and the quality of the resultant starch was equal or superior to the starch extracted using water. These starches also have low lipid content. However the yam starches have higher phosphorus content which contributes to their viscosity and gel properties. Yam starches have a large variability in shape, viz. round, triangular, oval and elliptical.

The arrowroot starch granules are round or polygonal in shape having size range of 5± 25 μm. The amylose content ranges from 16± 27%. The starch has a pasting temperature of 75±92 °C and the DSC values are for T_{onset}: 68.5 °C, T_{end}: 85 °C. The reported swelling volume for the starch is 23 ml/g. Arrowroot starch is easily digestible and therefore finds wide use in convalescent foods, baby foods and bakery items, especially biscuits. The Pacchyrrhizus starch granules are round, cupoliform or polyhedral with size range of 6±35 μm, amylose content of 17±25%, and gelatinisation temperature of 63±76 °C.

The Arracacha starch granules are similar to cassava starch granules, and spherical or ovoid in shape, with size range of 5±27 μm. The T_{peak} is 60.1 °C. The starch contains very little amylose and therefore is a source of high amylopectin starch. The starch is easily digestible and is important for food applications (Santacruz *et al.* 2003 & Moorthy, 2002).

Chinese water chestnuts starch grains being round or irregular have a size up to 27 μm. East Indian arrowroot starch extracted is pure white similar to cassava and arrowroot. Grains are polyhedrons or hemisphere and 8±40 μm in size. Giant taro starch grains are small, irregular and 1±5 μm in size. The amylose content is approximately 21%. Coleus starch granules are round or oval with a size range of 4±46 μm. The amylose content is higher compared to other tuber starches, viz., 33%. The intrinsic viscosity was 40 sec (Redwood) and swelling volume 37 ml. Lotus root starch grains are long and elongated and are rather big in size, 65±100 μm. Oca starch granules are oval in shape and have a size range of 20±55 μm. Amylose content is 18%. It has a T_{peak} of 55.9 °C. Queensland arrowroot starch is characterised by its high phosphorus content and hence possesses high viscosity. The granules are oval or polyhedral in shape and have size range of 5±44 μm. The amylose content is quite high (28%). The pasting temperature ranges from 65±95 °C and DSC values for T_{onset} and T_{end} are 65 and 85 °C respectively. The starch forms a strong gel even at 3% concentration and has excellent application as a food grade starch (Moorthy, 2002).

Physicochemical Properties of Tuber Crop Starches

1. Moisture content

Nuwamanya *et al.* (2010) stated that the moisture content (MC) varied among different botanical sources of starch with cassava displaying the highest MC (16.5%) compared with other starch among the root and tuber starches. They reported that moisture content of cassava, potato, sweet potato, maize, wheat, sorghum, and millet starch are 16.50%, 13.67%, 9.33%, 13.65%, 10.00 %, 9.20%, 9.30% respectively.

Omojola (2013) reported that Moisture content of Tacca starch is 9.15-10.0%. Ajala Lola (2012) reported that Moisture content of Cassava starch is 9.02%. Salwa Abo El-Fetoh (2010) reported that Moisture content of Corn, Tiger nut, Sweet Potato and Taro starch are 8.35%, 9.17%, 5.37% and 7.12%. Makhlouf Himeda *et al.* (2012) reported that Moisture content of Taro starch is 7.76 %. Table 3 shows the moisture content of various starches.

2. Ash Content

The ash content of a sample is the non-volatile inorganic matter of a compound which remains after subjecting it to a high decomposition temperature. During heating, the organic compounds are decomposed or released leaving behind the residue which consists mainly of other inorganic matters. Hence the ash content can be considered an indication of clean processing. Modification by cross-linking decreases the ash content of starch (Alejandro *et al.* 2008).

Table 3: Moisture content of various Starches

Sl. No.	Starch	Moisture content (%)	References
1	Cassava	16.50	Nuwamanya *et al.* (2010)
	Potato	13.67	
	Sweet potato	9.33	
	Maize	13.65	
	Wheat	10.00	
	Sorghum	9.20	
	Millet	9.30	
2	Tacca	9.15-10.00	Omojola, M.O. (2013)
3	Cassava	9.02	Ajala Lola, (2012)
4	Corn	8.35	Salwa M. Abo El-Fetoh, (2010)
	Tiger nut	9.17	
	Sweet Potato	5.37	
	Taro	7.12	
5	Taro	7.76	Makhlouf Himeda *et al.* (2012)

Ash is an indication of the mineral content in the sample, this reduction may be due to degradation of naturally occurring chemicals and loss due to spoilage. Ajala Lola (2012) stated that the ash content of Cassava starch is 0.25%. Abida Ali (2014) stated that the ash content of Rice and Corn starch are 0.16% and 0.20% respectively.

Nuwamanya *et al.* (2010) stated that ash contents is high among cereal starches than root and tuber starches. The Ash content of Cassava, Potato, Sweet Potato, Maize, wheat, Sorghum are 0.31%, 0.25%, 0.28%, 0.46%, 0.60 and 0.63 respectively. Salwa M. Abo El-Fetoh *et al.* (2010) reported that ash content of Corn, Tiger nut, Sweet Potato and Taro starch are 0.241%, 0.244%, 0.275% and 0.851% respectively. The ash content of Taro starch (0.851%) is higher than other tested starches; due to its higher phosphorus content (0.407) than others. Gunaratne and Hoover (2001) stated that ash content of Potato, True yam, Taro, New cocoyam and Cassava starch are 0.25%, 0.12%, 0.14%, 0.15% and 0.11% respectively. Table 4 represents the ash content of various starches.

Table 4: Ash content of various Starches

Sl. No.	Starch	Ash content (%)	References
1	Cassava	0.31	Nuwamanya *et al.* (2010)
	Potato	0.25	
	Sweet potato	0.28	
	Maize	0.46	
	Wheat	0.60	
	Sorghum	0.63	
2	Rice	0.16	Abida Ali, (2014)
	Corn	0.20	
3	Cassava	0.25	Ajala Lola (2012)
4	Corn	0.241	Salwa M. Abo El-Fetoh (2010)
	Tiger nut	0.244	
	Sweet Potato	0.275	
	Taro	0.850	
5	Potato	0.25	Gunaratne and Hoover (2001)
	True yam	0.12	
	Taro	0.14	
	New cocoyam	0.15	
	Cassava	0.11	

3. pH of Starch

The pH of a substance is the degree of acidity or alkalinity of that substance. Starch pastes from cross-linked starches have been reported to be less likely to break down with extended cooking times and possess increased acidity or severe shear (Langan, 1986). Nuwamanya *et al.* (2010) stated that the pH of Cassava, Potato, Sweet Potato, Maize, wheat, Sorghum Starches are 5.17, 8.74, 6.71, 2.35, 5.88 and 3.23 respectively.

Salwa Abo El-Fetoh *et al.* (2010) reported that pH of Corn, Tiger nut, Sweet Potato and Taro starches are 4.50, 6.25, 6.15 and 6.15 respectively. Omojola (2013) reported that pH of Tacca starch is 5.80. Akpa *et al.*, (2012) stated that pH of Five Cassava starch samples are 5.41, 7.05, 7.54, 5.66 and 7.13 respectively. Table 5 shows the pH of various starches.

Table 5: pH of various Starches

Sl. No.	Starch	pH	References
1	Cassava	5.17	Nuwamanya *et al.* (2010)
	Potato	8.74	
	Sweet potato	6.71	
	Maize	2.35	
	Wheat	5.88	
	Sorghum	3.23	
2	Tacca	0.25	Omojola, M.O. (2013)
3	Corn	4.50	Salwa M. Abo El-Fetoh (2010)
	Tiger nut	6.25	
	Sweet Potato	6.15	
	Taro	6.15	
4	Cassava		Akpa *et al.* (2012)
	Sample 1	5.41	
	Sample 2	7.05	
	Sample 3	7.54	
	Sample 4	5.66	
	Sample 5	7.13	

4. Gelatinization Temperature

The gelatinization temperature of starch is the temperature at which the starch forms a completely transparent gel. Gelatinization is a process that breaks down the intermolecular bonds of starch molecules in the presence of water and heat and allows the starch molecules to engage more water. This penetration of water increases randomness in the structure of the starch. As expected the stronger the bond between the starches molecules, the higher the amount of heat required to break the inter-molecular bond and therefore, the higher the gel temperature (Singh-Sodhi and Singh, 2005).

Akpa *et al.* (2012) stated that Gelatinization Temperature of Five Cassava starch samples are 69 ^{o}C, 75 ^{o}C, 79 ^{o}C, 74 ^{o}C and 77 ^{o}C respectively. The Gelatinization temperature of native starches followed the order: Taro>True Yam>New Cocoyam>Cassava> Potato. Gelatinization Temperature of Taro, True Yam, New Cocoyam, Cassava and Potato starches are 75.0 ^{o}C, 76.8 ^{o}C, 71.5 ^{o}C, 63.0 ^{o}C and 59.6 ^{o}C respectively. Gunaratne and Hoover (2001). Elevina E. Perez *et al.* (1998) stated that Gelatinization Temperature range of Sago, Arrowroot and Cassava starches are 73-95 ^{o}C, 79-92 ^{o}C and 73-90 ^{o}C respectively. Hoover (2000) stated Gelatinization Temperature range of Manihot Esculenta starch is 57.0-76.1 ^{o}C. Table 6 shows the gelatinization temperature of various starches.

Table 6: Gelatinization Temperature of various Starches

Sl. No.	Starch	Gela. Temp. (^{o}C)	References
1	Manihot Esculenta	57.0-76.1	Hoover (2000)
2	Sago	73-95	Elevina E. Perez *et al.* (1998)
	Arrowroot	79-92	
	Cassava	73-90	
3	Cassava		Akpa *et al.* (2012)
	Sample 1	69	
	Sample 2	75	
	Sample 3	79	
	Sample 4	74	
	Sample 5	77	
4	Potato	59.6	Gunaratne and Hoover (2001)
	True yam	75.3	
	Taro	76.8	
	New cocoyam	71.5	
	Cassava	63.5	

5. Bulk Density

The bulk density of a powder describes its packing behaviour during the various unit operations of tableting such as die filling, mixing, granulation and compression. Higher bulk density is advantageous in tableting due to reduction in the fill volume of the die. The ranking for the bulk density is DCP>Corn starch > GPGS > lactose > GNS > ENS > EPGS. The bulk densities of Efuru native starch (ENS), Efuru pregelatinized starch (EPGS), Gbongi native starch (GNS), Gbongi pregelatinized starch (GPGS), Corn starch (CS), Dicalcium phosphate (DCP), Lactose (LAC) are 0.4587, 0.3922, 0.4854, 0.5495, 0.6404, 0.5196 and 0.8151 g/cc (Bakre Lateef Gbenga *et al.* 2014).

Omojola, M.O. (2013) reported that bulk density of Tacca starch is 0.81 g/cc. Abida Ali (2014) Stated that the bulk densities of Rice and Corn starches are 0.48 g/cc and 0.55 g/cc. Marcel Tunkumgnen Bayor (2013) stated that the bulk properties describe the density, packing and flow of a powder mass. The sweet potato starch powders had higher bulk density (0.58 g/cc) compared to the commercial Corn starch (0.40 g/cc) as shown in Table 7.

Table 7: Bulk density of various Starches

Sl. No.	Starch	Bulk density (g/cc)	References
1	ENS	0.4587	Bakre Lateef Gbenga *et al.* (2014)
	EPGS	0.3922	
	GNS	0.4854	
	GPGS	0.5495	
	CS	0.6404	
	DCP	0.5196	
	LAC	0.8151	
2	Tacca	0.81	Omojola, M.O. (2013)
3	Rice	0.48	Abida Ali, (2014)
	Corn	0.55	
4	Sweet potato	0.58	Marcel Tunkumgnen Bayor, (2013)
	Corn	0.40	

APPLICATIONS OF STARCH

1. Starch applications in the food industry

Starch is one of the most versatile biomaterials in the food, textile, cosmetics, plastics, adhesives, paper and pharmaceutical industries. It is a renewable and almost unlimited resource material. About 54 % of the starches produced globally are utilized for food applications with 46 % for non-food applications. The diverse industrial usage of starch is premised on its availability at low cost, high caloric value, inherent excellence physicochemical properties and the ease of its modification to other derivatives. The industrial utilization of starch is determined by starch morphology and its physicochemical characteristics which are typical of its biological origin (Gebre-Mariam and Schmidt, 1996).

The biological function of starch in plants is as a reserve of carbon and energy. As food, starch is the most abundant and important digestible polysaccharide. The starches in food are commonly derived from grains or seeds (wheat, corn, rice, and barley), tubers (potato) and roots (cassava) (Buleon *et al.* 1998; Waterschoot *et al.* 2015a). Starch provides 70 - 80% of the calories consumed by humans worldwide. As food, starch functions as a structural agent because of the modifications introduced during manufacturing. Starch is used in the food industry mainly as a modifier of texture, viscosity, adhesion, moisture retention, gel formation and films (Waterschoot *et al.* 2015a).

An important utilization of starch in the food industry is in baking flour. Among the bakery products, cakes and breads are the most important due to their high consumption. In the formulations of the baking industry, starch is one of the components responsible for the structure and properties of the final products. Other industrial processes include starch in small quantities as a food additive or a thickening and gelling agent (Dhall, 2013).

Starch is often used in granular form and is thus is included in the confectionery industry as a moulding powder for the various forms of sweets, which can be reused many times. Starch is also used in the preparation of diverse types of pasta in the preparation of noodles and those intended for extrusion and in the formulation of instant foods and fried foods (Bourtoom, 2008).

In the food industry, edible films are barriers that prevent moisture transfer, gas exchange, oxidation and the movement of solutes, while maintaining their organoleptic properties. During manufacturing, films are incorporated as plasticizers, flavours, colours, sweeteners, antioxidants and antimicrobials. Edible films have received much attention due to their advantages over synthetic films. Edible films are produced from renewable materials; they can be consumed together with coated food and otherwise do not contribute to pollution because their degradation is faster than synthetic films. Their main disadvantage lies in their mechanical and permeable properties (Bourtoom, 2008). The basic materials used to produce edible films are cellulose, starch, gums and chitosan; the linear configuration of polymers can produce films with flexible, transparent and oil resistant properties. For these reasons, amylose is the most important fraction in starch granules. Typically, the starch granule is composed of 25% amylose and 75% amylopectin. Edible films require starches with a high amylose content (≥ 70%). The amylopectin molecule cannot adequately form films; the branched structure imparts poor mechanical properties to the film, reducing its tensile strength and elongation (Bourtoom, 2008; Dhall, 2013).

Polysaccharides are typically hygroscopic and therefore are poor barriers to moisture and gas exchange. The use of plasticizers in the film composition improves the barrier against moisture exchange and restricts microbial activity. The starch used in edible film preparation is incorporated to partially or completely replace the plastic polymers. Native starch does not produce films with adequate mechanical properties and requires pre-treatment, the use of a plasticizer, mixture with other materials, genetic or chemical modification, or a combination of these treatments. Among the plasticizers, for hydrophilic polymers, such as starch, are glycerol and other low-molecular weight polyhydroxycompounds, polyether, and urea. Processes such as extrusion adjust the parameters of temperature and mechanical energy over the starch paste, making it a thermoplastic material that is also suitable for the production of edible films (Dhall, 2013).

2. Starch for non-food applications

New processing techniques and the current demands of biodegradable and renewable resources have highlighted the versatility of starch and introduced it to new markets. Furthermore, starch is a chemical feedstock for conversion into numerous products with considerable value (Ellis *et al.* 1998). In the pharmaceutical industry, starch is used as an excipient, a type of bonding agent to active drugs. Because of its content of amylose, starch is capable of forming an inclusion complex with many food ingredients, such as essential oils, fatty acids and flavoring ingredients. It therefore acts as an encapsulant and increases the shelf life of products. Plastics obtained from oil are being replaced by natural polymers; starch is known for its ability to form films in food packaging applications (Jimenez *et al.* 2012). Edible and biodegradable starch films can be obtained from native starch or its components amylose or amylopectin by two main techniques: a wet method that includes a starch suspension and posterior drying or a dry method that involves a thermoplastic process (Paes *et al.* 2008). Modified starches can also be used in film production (Bourtoom, 2008; Campos *et al.* 2011; Dhall, 2013; Lopez *et al.* 2010).

For new industrial applications of starch, especially in plastic polymer production, the hygroscopicity of starch is a disadvantage because the main feature of plastics films is their hydrophobic property. Starch granule size, its form and associated molecules influence film production. Wheat starch is typically associated with a significant amount of protein, which may result in a Maillard reaction and cause bleaching; therefore, this type of starch is not used in to manufacture biodegradable plastics films (Ellis *et al.* 1998). In the textile industry, starch films are also used during textile production as fiber coatings. Native starch forms rigid and brittle films due to its cyclic structure. Brittle films are not advantageous because they reduce protection, increase friction and thus damage the thread. The polarity of native starch minimizes the adhesion of synthetic fibers, affecting the tensile strength and abrasion. Starch is commonly modified to improve the physical properties, emulsifying ability and film formation (Zhang *et al.* 2014).

Many industrial processes use starch after partial or complete destruction of its structure. When this occurs, the properties of its components and the relationships between them increase their importance. Differences between the amount and type of lipids originally present in the native starch may cause two starches with the same amylose-amylopectin ratio to have different physical properties, such as viscosity. Starch solutions are viscous, and the ability of starch to change the viscosity of other solutions and pastes is well known and exploited in the food industry.

This property is also used in the oil drilling industry, where starch is used to adjust the viscosity of the mud used during drilling operations. Highly viscous starch solutions are desirable for industrial processes involving starch pastes for mechanical manipulation, such as the paper, corrugated and textile industries (Ellis *et al.* 1998).

It is possible to produce a new generation of detergents in which the surfactants and bleaching components are derived entirely from starch. An estimated 50 to 60% of chemical products in formulations for powder detergents and 65 to 75% of liquid detergent formulations could be substituted with products derived from starch. High viscosity is important in the adhesive field. Most native starches do not maintain a stable viscosity when transformed to pastes and or subjected to high shear velocity or longer heating periods. However, chemically modified starch behaves properly under these conditions (Ellis *et al.* 1998).

The production of biodegradable plastics is still young when compared to the petrochemical plastic industry. Starch will play an important role in its growth in container production and in the form of biodegradable materials that conform to suitable matrices because it is a relatively inexpensive material compared to other polymers (Bourtoom, 2008; Dhall, 2013). In recent years, starch has been studied for the production of nanoelements as nanocrystals that result from the breakdown of the amorphous region in semicrystalline starch granules by acid hydrolysis or for the production of nanoparticles from gelatinized starch (Le Corre *et al.* 2010). These nano compounds have unique properties due to their nano size compared to conventional size materials. Nanoparticles can be used as fill material in filtration and form effective barriers in flexible packaging (Bondeson *et al.* 2006).

The tuber crop products such as gluten-free spaghetti from sweet potato, *nutriose* fortified sweet potato noodles, high protein starch noodles from sweet potato, functional sago with high protein content, functional sago with high calcium content, cassava starch noodles using resistant starch enhanced (annealed) cassava starch, cereal grain type pasta cassava- maida and cassava-rice blends, sweet potato spaghetti enriched with bioactive pigments and purple yam flour based pasta rich in anthocyanins were developed.

CONCLUSION

Starch is one of the most versatile biomaterials in the food, textile, cosmetics, plastics, adhesives, paper and pharmaceutical industries. It is a renewable and almost unlimited resource material. About 54 % of the starches produced globally are utilized for food applications with 46 % for non-food applications. The diverse industrial usage of starch is premised on its availability at low cost, high caloric value, inherent excellence physicochemical properties and the ease of its modification to other derivatives. The industrial utilization of starch is determined by starch morphology and its physicochemical characteristics. Starch is important in bread making, as a meat binder in confectionary and as an additive in most food and beverages. This is in addition to its use in textiles, paper and plywood industries, as filler in biodegradable plastics and in the mining and construction industry. The use of starch in these applications depend on its physicochemical and functional properties which are determined by its structure that depends on its granule and crystalline properties. These properties also depend on the amylose amylopectin ratio, chemical properties and molecular characteristics of amylose and amylopectin.

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