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# Utilization of Starch in Food and Allied Industries in Africa: Challenges and Prospects

*Akeem Olayemi Raji*

## Abstract

The shortage of food supply has affected the food situation in most developing tropical countries, resulting into a high incidence of hunger and malnutrition. This has also affected the attainment of self sufficiency in starch production for food, pharmaceutical and industrial usage. The review critically appraised the challenges that food and allied industries are facing on the utilization of starch as their major raw material. Information on various conventional and non conventional starch sources were provided, starch forms, properties and recent advances in starch modification methods were discussed. Starch applications in food and allied industries were mentioned and various challenges facing common starch sources were stated. Possibly, utilization of unconventional lesser known crops as starch sources might broadening the present narrow commonly cultivated starch sources, while value addition and good agricultural practices might improve the productivity of conventional starch sources.

**Keywords:** starch, sources, utilization, challenges, prospects

## 1. Introduction

Starch or amyllum can be defined as a polysaccharide carbohydrate consisting of a large number of glucose units joined together by glycosidic bonds [1]. It comprises of two main components which are mainly linear amylose and highly branched amylopectin. It exists as a stored discrete semi crystalline granules in higher plants [2]. Starch is an important energy source for humans, produced by all green plant as an energy store [2]. Its production in the chloroplast occurs in the daylight and it was rapidly produced by plants. However, glucose chain produced biochemically by photosynthesis in plant cells is responsible for the synthesis of starch [3].

Amylose contains 1–4 D-glucopyranosyl units and it constitutes about 15–30% of common starch, while amylopectin possesses a large number of short chains linked together at their reducing end side by 1–6 glucosidic linkage [4, 5]. However, the formation of crystalline lamella in starch is linked to amylopectin and their branching points are part of the amorphous nature [6]. Starch is regarded as a semi crystalline entity because of the presence of amorphous and crystalline regions in starch granules [7]. Starch also contains some minor components such as lipids and proteins aside amylase and amylopectin. The sizes of starch granules range from 1 to 100  $\mu\text{m}$ , while its shape and composition depends on their botanical source [8].

Starch is derived from a range of raw materials such as corn, wheat, pea, potato, and cassava roots [9] and it has a wide range of applications beyond the food industry. It is also used in the paper/board sector for wet-end addition, size press, surface coating and in the production of recycled paper. It is also used as a binding agent in the pharmaceuticals sector, as an adhesive in industrial binding sector and as a stiffener in the textile sector [10]. Other non food applications of starch include utilization as alcohol-based fuel, low-calorie substitutes, biodegradable packaging materials, thin films and thermoplastic materials with improved thermal and mechanical properties [5].

Starch is the basis of our food and industrial economy, but the food situation in most developing tropical countries is alarmingly worsening owing to increasing population and shortage of fertile land [11]. The shortage of food supply has resulted into a high incidence of hunger and malnutrition [12, 13]. It also affected the demand for starch as food, pharmaceutical and industrial uses coupled with the need to attain self-sufficiency in starch production. However, the focus of this review is to critically appraise the challenges that food and allied industries are facing on the utilization of starch as their major raw materials and to suggest possible way outs.

## **2. Sources of starch**

Starch is a source of carbon and energy, it is predominantly found in different part of a plant such as stem, roots, flowers, seeds, and fruits [3]. Starch can be derived from tubers and cereals, such as cassava, potatoes, maize, yam, rice, etc. [14]. **Table 1** shows the starch compositions of some crops. The starch contents of cereals and tubers presented in **Table 1** ranged from 20.48–77.90%, with soft wheat having the highest value and bitter yam having the lowest value.

### **2.1 Cassava**

Cassava (*Manihot esculenta* Crantz) is a tropical valuable root crop, used both as food and industrial raw material, due to the high starch content in tubers [22, 23]. It is one of the world's most important food crops, with annual global production at approximately 276 million metric tons in 2013 [24]. Its price is often decided by the industrialists based on the percentage of starch in the tubers. In 2013, the top producing countries globally were: Nigeria (accounting for 19% of the total), Thailand (11%), Indonesia (9%), Brazil (8%) and Democratic Republic of Congo (6%) [24]. It is a source of livelihood for at least 300 million people. Nearly 90% of cassava produced in Africa is used as a staple food for human consumption, which provides calories for 500 million people and it constitutes 37% of the population's dietary energy requirements [24]. Cassava is perceived in most African countries both as a food security crop and also as a raw material for various types of industries. It can be transformed into several types of products ranging from traditional foods and feeds to novel food products [24, 25].

### **2.2 Potatoes**

Potato is one of the top four staple food crops in the world. Majority of its production is meant for human consumption (50–60%), while the rest are used for production of animal feeds, industrial products and as seed tubers [26, 27]. The tuber is a carbohydrate reserve and it also contains high quality protein, substantial amounts of vitamins, minerals and trace elements. Potatoes grow best in moderate

Food Plants	Starch Contents (%)	Sources
<b>Cereals</b>		
Waxy rice	74.76	Moongngarm [15]
Hard wheat	77.40	Ragae <i>et al.</i> [16]
Soft wheat	77.90	Ragae <i>et al.</i> [16]
Barley	53.60	Ragae <i>et al.</i> [16]
Millet	67.40	Ragae <i>et al.</i> [16]
Rye	58.00	Ragae <i>et al.</i> [16]
Sorghum	67.70	Ragae <i>et al.</i> [16]
Fonio	68.00	Cruz <i>et al.</i> [17]
Sweet Corn	36.23	Moongngarm [15]
<b>Roots/ Tubers</b>		
Sweet potato	52.54	Moongngarm [15]
Lesser yam	54.70	Moongngarm [15]
White yam	58.02	Moongngarm [15]
Water Yam	31.90	Brunnschweiler <i>et al.</i> [18]
Bitter yam	20.48	Ezeocha and Okafor [19]
Potato yam	38.10	Shajeela <i>et al.</i> [20]
Yellow yam	41.72	Oladebeye <i>et al.</i> [21]
Taro	63.74	Moongngarm [15]
Cassava	65.71	Moongngarm [15]

**Table 1.**  
 Starch compositions of cereals and tubers.

climate, where continuous cultivation throughout the year is impossible [26]. Among the potato varieties, sweet potato (*Ipomoea batatas* L (Lam)) is regarded as one of the most economically important species, as it can grow in great abundance on marginal soils [27]. It is rich in starch (58–76% on a dry basis) and the starch is widely used in starch noodles, bakery foods, snack foods and confectionary products [27].

### 2.3 Yams

Yams belong to the family *Dioscoreaceae* and they are annual or perennial tuber-bearing and climbing plants. It is an important major food crop in Nigeria [28] and ranked as the fourth major root crop in the world after cassava, potatoes and sweet potatoes, having an annual production of above 28 million metric tonnes [29]. However, Nigeria was rated as the world's largest producer of yams, with *Dioscorea rotundata* and *Dioscorea alata* as the two most cultivated yam species [30]. Yam can be explored for commercial starch production because of their high starch content of about 70 to 80% dry weight [31], and it plays a prominent role in ensuring food and livelihood security of at least 60 million people in West Africa. Globally, roughly about 57 million tons of yams (representing 93% of annual global production) are produced on 4.7 million hectares annually in this sub-region which comprise of Benin, Côte d'Ivoire, Ghana, Nigeria, and Togo [24, 32]. The yam species that are majorly grown globally include: *Dioscorea alata* (water yam), *Dioscorea bulbifera* (potato yam), *Dioscorea cayenensis* (yellow yam), *Dioscorea dumetorum*

(bitter yam), *Dioscorea esculenta* (lesser yam), *Dioscorea opposita* (Chinese yam), *Dioscorea rotundata* (white yam), and *Dioscorea trifida* (cush-cush yam) [33]. Among the species mentioned above, *Dioscorea rotundata* and *Dioscorea cayenensis* are the most commonly grown for consumption and commercial production. Yam contains mainly carbohydrates with little amount of proteins, lipids and vitamins, and it can provide around 110 calories per 100 grams of products [34]. Yam possesses high in moisture, dry matter, starch, dietary fiber, vitamin B<sub>6</sub>, but low in saturated fat, sodium and vitamin A contents. Yams contain about 5–10 mg/100 g of vitamin C, and the limiting amino acids are isoleucine and sulfur containing amino acids. They also contain a compound called “diosgenin”, which can be extracted and used as base for drugs such as cortisone and hormonal drugs. Some species contain alkaloids (e.g. dioscorine C<sub>13</sub>H<sub>19</sub>O<sub>2</sub>N) and steroid derivatives [34]. However, the nutrient content of yam is compared with other crops in **Table 2**.

## 2.4 Yam varieties

### 2.4.1 *Dioscorea alata*

It is widely called “water yam”, “winged yam” and “purple yam”. It is the most widely cultivated specie globally and it is second to white yam in popularity [36, 37]. Water yam is economically important yam specie which serve as a staple food for millions of people in tropical and subtropical countries, and with a great potential for increase in consumers demand due to its low sugar content necessary for diabetic patients [38]. Aside from being source of carbohydrate, it also possesses higher content of protein and low lipids than *D. cayenensis*, *D. esculenta*, *D. rotundata* and *D. trifida* [39].

### 2.4.2 *Dioscorea bulbifera*

It is usually cultivated in Africa and Asia, with slight differences between those found in each place. It is a large vine of about 6 meters (20 ft.) or more in length and produces tubers (bulbils) which grow at the base of its leaves. It is an important food product and it is about the size of potatoes (hence the name “air potato”), weighing from 0.5 to 2 kg (1 to 5 lbs.) [40]. Some known varieties of air potato can be eaten raw while some need to be detoxified by either soaking or boiling before eating. Its growth for commercial purpose is hampered by its moderately unpleasant

Staple	Crops						
	Maize/Corn	Rice	Wheat	Potato	Cassava	Soybean (Green)	Yam
COMPONENT (PER 100G PORTION)							
Water (g)	10	12	13	79	60	68	70
Protein (g)	9.4	7.1	12.6	2	1.4	13	1.5
Fat (g)	4.74	0.66	1.54	0.09	0.28	6.8	0.17
Carbohydrate (g)	74	80	71	17	38	11	28
Fiber (g)	7.3	1.3	12.2	2.2	1.8	4.2	4.1
Sugar (g)	0.64	0.12	0.41	0.78	1.7	0	0.5

Source: Kumar et al. [35].

**Table 2.**  
Nutrient content of white yam in comparison with other crops.

flavor, making other yam to be mostly preferred by consumers [41, 42]. The aerial or air yam is popular in home vegetable gardens, because it produces its first tubers only after four months of growth and thereafter throughout the life of the vine, as long as two years [41, 43].

#### 2.4.3 *Dioscorea cayenensis*

This yam species got its common name from its yellow flesh, due to the presence of carotenoids. It is a West African native; it has a longer period of vegetation and a shorter dormancy than white yam [44]. Yellow and white yam were considered in past as two separate species, but now they are been considered as same species by most taxonomists with about over 200 cultivated varieties between them [44]. They are large and their vines are as long as 10 to 12 meters (35 to 40 feet). The tubers can weigh up to about 2.5 to 5 kg (6 to 12 lbs.) each for an average size, but extra large tubers can weigh as much as 25 kg (60 lbs.) [40]. The maturation stage after planting is 7 to 12 months [45]. It is commonly used in Africa for the traditional popular dish known as “*iyam*” (pounded yam) [46].

#### 2.4.4 *Dioscorea dumetorum*

The tuber is commonly referred to as cluster yam, bitter yam or trifoliolate yam. It is called “*ona*” by the Igbos of Southeast Nigeria and ‘*esuru*’ by the Yorubas in Southern Nigeria [42, 47]. The tuber contains fleshy edible part having a yellowish or whitish color which can be boiled and eaten as snacks. Extract from the tubers can be used for the treatment of *diabetes mellitus* in traditional medicine [48, 49]. It has been reported that the tuber is rich in fiber and contains an alkaloid, dioscorentine, which possesses hypoglycemic activity [50, 51]. It is fairly high in protein and possesses a well balanced amino acid profile, making it the most nutritious of the commonly consumed yam species. It has been established that trifoliolate yam contain 15–38% starch on wet weight basis and 70–80% dry weight basis [52].

#### 2.4.5 *Dioscorea esculenta*

This type of tuber is popularly referred as ‘Chinese yam’; it is smaller than other known yam species grown in Africa [24]. It possesses ability to tolerate cold temperature and can be grown in much cooler conditions than other yams. It is commonly grown in China, Korea, and Japan and it was introduced to Europe in the 1800s when the potato crop was affected by diseases [53]. In France, it is still grown for Asian food market. The tubers mature in 6 months and can be eaten immediately after harvest, while others are used as ingredients for other dishes, including noodles and traditional medicines [24, 54].

#### 2.4.6 *Dioscorea rotundata* Poir (*white yam*)

This yam species is native to Africa. It produces edible tubers that possess economic importance [55]. It is among the most important cultivated yam species and it is mostly consumed in West Africa and Cameroon [56]. It has a long shelf-life which makes it available all year round. White yam are subjected to different cooking methods in Western and Central Africa, however, the most common ones are boiling, frying and roasting [29]. It is mostly used in Africa for the traditional popular dish known as “*iyam*” (pounded yam). Sun-drying of parboiled yam pieces and then milled into a light-brownish powder (*elubo*) is another method of processing

in Nigeria. A thick brown starchy paste known as "amala" which is consumed with local soups and sauces can be prepared from the light brown powder [55].

#### 2.4.7 *Dioscorea trifida* (cush-cush yam)

This specie is a native of Guyana region of South America and it is the mostly referred to as "New World" yam, their growth cycle is less related to seasonal changes than other yam, since they originated from the tropical rain forest. They can be easily cultivated when compared to other yams and also they have good flavor, which may serve as a great potential for increase production [54, 57]. Its starch contains amylose content in the 34.7–43.3% range for white and purple varieties [57].

#### 2.4.8 *Dioscorea villosa* (wild yam)

It is a perennial vine that grows in moist thickets and hedges [57]. It possesses a reddish-brown stem, having heart-shaped leaves with prominent veins and inconspicuous greenish yellow flowers that flourish from September to October. It is usually cultivated as food source and its roots are harvested in the fall. Its taste is usually bland and then acrid, but under special preparation herbalist use its fresh and dried roots for medicine [58]. Also, it is a common herbal remedy for pains associated with rheumatism and arthritis, colic and intestinal cramps, as well as a reliable antispasmodic and anti-inflammatory [59]. It is also applicable in contraceptive manufacture. High content of saponin in species of *Dioscorea villosa* made them useful for the preparation of steroids in the pharmaceutical industry [60, 61]. Studies also revealed that *Dioscorea villosa* had antioxidant activities [62] and the anti-inflammatory activity could be linked to the antiphlogistic effect of the steroidal saponins.

## 2.5 Cereals

Cereals are edible grains or seeds that belong to the grass family *Gramineae* (Figure 1). Grains are developed from flowers or florets and their structures vary from one to another with some typical features [64, 65]. They possess *embryo* (or germ) which is a thin-walled structure, containing the new plant. The embryo is separated by the *scutellum* (which is involved in mobilization of food reserves of the grain during germination) from the main part of the grain. The endosperm surrounded by thin-walled cells (*aleurone*), packed with starch grains [66, 67]. The *aleurone* layer present in grains consist of one or three cell layers (wheat, rye, oats,

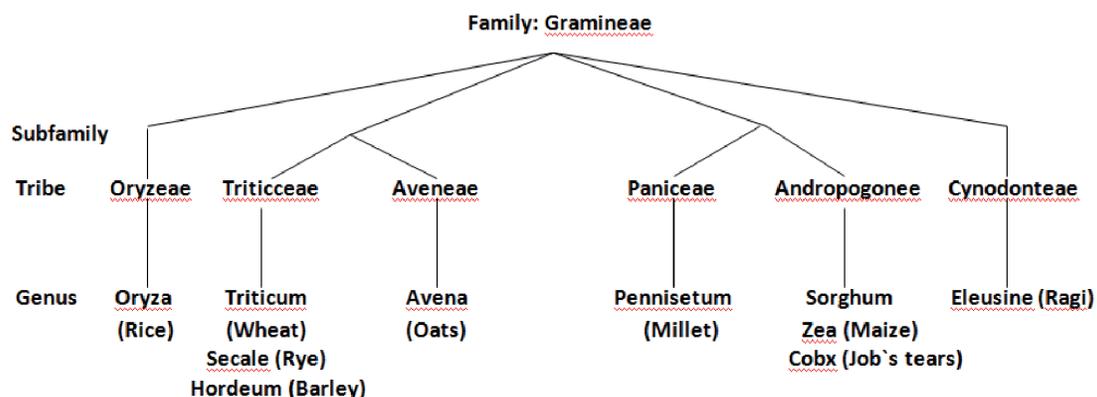


Figure 1. Taxonomy of the Graminae family. Source: Shewry et al. [63].

maize and sorghum have one; rice and barley have three). The pericarp is the outer layers of the grain (derived from the ovary of the flower) that surround the *seed coat* (the testa), while the bran is formed from the outer thick-walled structures. They are staple foods both for direct human consumption and indirect through livestock feed [68]. Cereal based foods are good sources of energy, protein, B vitamins and minerals for the world population. Cereals are inexpensive to produce, they are easy to store and transported, and they do not deteriorate readily if kept dry.

However, in cereal products, a proportion of this starch is not digested and absorbed in the small intestine. This is referred to as resistant starch and it appears to act in a similar way to dietary fiber. Four categories of resistance have been defined [65, 69].

- RS1 refers to starch that is physically inaccessible for digestion as it is 'trapped' (e.g. intact whole grains and partially milled grains).
- RS2 refers to native resistance starch granules (e.g. found in high amylose maize starch).
- RS3 refers to retrograded starch (e.g. found in cooked and cooled potatoes, bread and some types of corn-flakes).
- RS4 refers to chemically modified starch (e.g. commercially manufactured starches).

### 2.5.1 Wheat

Wheat is ranked as a major cereal crop in many parts of the world and belongs to the *Triticum* family of which there are many thousands of species [65, 67]. Among the known species, *T. aestivum* subspecies *vulgare* and the hard wheat *T. durum* are the most commercially viable [65, 70]. Wheat is grown in both winter and spring but their cultivation in winter or spring is dependent on the species, varieties and their adaptability. However, wheat is grown in many countries around the world, but the most prominent great wheat-producing countries are USA, China and Russia. Wheat grains are also present extensively in India, Pakistan, the European Union (EU), Canada, Argentina and Australia. Estimation showed that 556.4 million tons of wheat might have been produced in 2003; resulting to 30% of the world's cereal production [71]. The wheat grain is sandwiched between the lemma and the palea of each spikelet, possessing an elliptical, oval or ovate shape, and has short or long brush hairs.

### 2.5.2 Rice

Rice is an important staple food crop for many of the world's population, especially those living in Asia. Rice is cultivated mainly for human consumption and this include utilization as breakfast cereals, and its use in Japan as brew saké [65, 67]. There are a lot of rice varieties but only a few are grown widely (e.g. varieties of the improved semi-dwarf plant type with erect leaves). The rice grain possesses an outer protective coating which is referred to as the hull or husk and the edible rice caryopsis. Also, the brown rice contains an outer layer called pericarp (which contains pigment), seed coat, the embryo and the endosperm. The endosperm comprises of the aleurone layer which encloses the embryo, sub aleurone layer and the starchy or inner endosperm. However, wild rice is less common and it is the grain of a North American plant, *Zizania aquatic*. It is difficult to harvest and it is more expensive than other grains. It possesses higher protein content than rice [64].

### 2.5.3 Maize

*Zea mays* L., alternatively referred to as corn is a native of the Western Hemisphere and its production in the USA exceeds that of other countries [72]. The kernel which is the reproductive seed of the plant has four main parts, and these are the germ, the endosperm, the pericarp and the tip cap. It is an inexpensive source of starch and it is a major source of energy for animal feed [65, 70]. Among the hundreds of different varieties of wheat grains, only four varieties listed below are of commercial importance:

1. Dent maize (identified by the dent in the crown of the kernel);
2. Flint maize (hard, round kernels);
3. Sweet corn (a dent-type maize);
4. Popcorn (flint-type maize which expands when heated).

### 2.5.4 Barley

Barley is a resilient plant that can tolerate a wide range of conditions, which might have been cultivated since 15,000 BC [72]. The head or spike of barley is made up of spikelets that are attached to the rachis in an alternating pattern. The barley kernel's outer layers consist of the husk, the pericarp (to which the husk is tightly joined in most species), the testa or seed coat and the aleurone which completely covering the grain. Barley (*Hordeum vulgare*) is mainly cultivated for malting and brewing in the manufacture of beer and for distilling into whisky manufacture [65, 70]. The spent grains from the brew are used as animal feed, especially for pigs. However, a small amount of barley is used for food. Pearled barley is used in cooking soups and stews in the UK and in the far Middle East. Barley flour is also used in bread production and can be cooked as porridge in some countries [67].

### 2.5.5 Oats

Among the several different species of oats, spring or white oat (*Avena sativa* L.) is the most important cultivated form. *Avena byzantine* is a red-oat type or alternatively known as a winter oat is cultivated in warmer climates [65, 70]. A spikelet of oat consists of oat kernels. A hull which is made up of two layers called the lemma and palea, enclosed each kernel, the hull is only loosely attached to the groat. However, the groat is made up of 65–85% of the oat kernel and it is enveloped by bran layers (pericarp, seed coat and aleurone cells) [65]. It grows well on poor soil and in cool, moist climates and has mainly been grown for animal feed. Its cultivation for human consumption is at minimal level, products made from oats are oatmeal for porridge and oatcakes, rolled oats for porridge and oat flour for baby foods and for ready-to-eat (RTE) breakfast cereals [67]. Non-food uses of oats include their utilization in the production of cosmetics and adhesives [70].

### 2.5.6 Rye

Rye is generally a hardy plant and it is widely cultivated in cool temperature zones, where other cereals can merely survive. Rye can also be grown in semi-arid areas and at high altitudes. It is cultivated as a winter crop, which is sown in early autumn and harvested in early summer [65]. The plant varies in height from 30 cm

to more than 2 m. It is a major crop grown in Russia, Poland, Germany and the Scandinavian countries for crispy bread, alcohol animal feed production [67]. The grain is protected with a bearded *glume* husk, arranged in an alternating pattern along the rachis. Rye is thinner and more elongated than wheat; it possesses a grayish yellow color and varies from 1.5 mm to 3.5 mm in size. The grain comprises of the starchy endosperm, the pericarp and the testa. Other constituents include the bran, accounting for 10% of the grain with the remainder consisting of the germ (the embryo and scutellum).

#### 2.5.7 Millet

Millet is an annually cultivated cereal which possesses different species of small grains [64, 70]. Among the various species of millet, pearl millet is the only one that is mostly of economic concern. Other known species of millet include, finger (or ragi), proso and foxtail, but the minor millets account for less than 1% of the grains produced for human consumption, they are less important in terms of world food production [65, 70]. Cultivation of millet is of utmost importance in certain locations in Africa and Asia where major cereals cannot be solely depended on to provide sustainable yields [73]. The species type influence climatic and soil requirements, length of growing period, grain consistency, size and taste of millet [64].

#### 2.5.8 Sorghum

Sorghum (*Sorghum bicolor* L. Moench) is wild regarded as a warm season crop, intolerant of low temperatures but fairly resistant to serious pests and diseases. The known varieties are great millet and guinea corn in West Africa, kafir corn in South Africa, jowar in India and kaoliang in China. It is one of the staple foods in many parts of Africa, Asia, and parts of the Middle East [65, 70]. However, most of the sorghum grains produced in North and Central America, South America and Oceania are used for animal feed [73]. The grain comprises of a naked caryopsis, which is made up of a pericarp, endosperm and germ. Based on huge range of physical diversities, such as the color of the pericarp (white, yellow or red) and presence/absence of pigmented testa (with/without tannins), sorghums are classed into one of four groups and these are (1) grain sorghum, (2) forage sorghum, (3) grass sorghum or (4) Sudan sorghums and broom corn [70].

#### 2.5.9 Acha

Acha, which is also referred to as “fonio”, “findi”, “fundi”, “pom, and kabug” “hungry rice” and “petit mil”, is a small-grained cereal that is native to West Africa, which is generally classified among the millet [74, 75]. It is cultivated in various parts of Nigeria, Sierra Leone, Ghana, Guinea Bissau and Benin Republic on less fertile sandy soils that could not support the growth of other more demanding cereals. There are two known varieties of acha which are *Digitaria exilis Kippis stapf.* and *Digitaria iburua Kippis Stapf.* It is regarded as one of the lost crops in the West Africa sub region. Its production is important to West African Farmers, though hindered by several factors among which are poor agronomic performance because of unimproved seeds and husbandary practices. Its West Africa annual production is about 250,000 tonnes [17]. The annual yields of 3098 metric tonnes, 112,000 metric tonnes and 126,000 metric tonnes of fonio were reported in Nigeria [76]. The economic returns of acha when compared with other crops like rice, sorghum, and cowpea showed that it was profitable to grow the crop on a commercial scale [77]. Fonio are the most nutritious and testiest of all grains [77] and it contains 7%

crude protein that is high in leucine (19.8%), methionine and cystine (7%) and valine (5.8%) [78]. Fonio grains are mostly consumed wholly, they are also milled into flour and constitute a versatile raw material for preparation varieties of food such as gruels, porridges, couscous, bread, beer, and beverages [79]. Starch extracted from fonio possesses good disintegrant and binding properties [80] and it also has good glidant properties [81].

## 2.6 Food starch properties

The starch granules sizes obtained from different crops vary in properties, because of their sources, extraction methods and cultivars [82]. The purity as well as the granules size can be determined using scanning electron microscopy [83]. The amylose content of starch is one of the most important factors influencing the cooking and textural qualities of whole storage root, and quality of starch-based foods [84]. *Dioscorea* starch granules possess varying shapes, which are spherical, oval and polygonal, depending on the species with granule size varying from 2 to 50  $\mu\text{m}$  [85]. Also the X-ray diffraction pattern of the *Dioscorea* starch granules range from the B to C-type, depending on the *Dioscorea* specie [18]. *Dioscorea* starches contain 18 to 30% amylose contents and their gelatinization temperature vary from 70 to 92°C [84].

Starch particle sizes obtained from white and yellow yam varieties showed similar patterns with a single symmetrical distribution centered at approximately 32 and 35  $\mu\text{m}$  respectively. Sources, varietal differences and growing conditions significantly influence size and shape of starch granules. However, due to better mouth feel, small sized starch granules has been suggested as possible lipid substitute in food systems [86]. They are also used as laundry-stiffening agents because they possess good fabric penetration ability, better glossiness and stiffness, which are required in textile industries [87].

Sweet potato starch granules possess spherical, oval, and polygonal shapes, and they are about 2–46  $\mu\text{m}$  in size. The X-ray diffraction patterns of the sweet potato starch granules are of type A and they also exhibit 38% crystallinity [88]. The starch in sweet potato is made of 16.1–24.4% amylose, having a swelling power of 80% at 90°C and gelatinization temperature of 64.6–84.6°C [84]. Cassava starch possesses small spherical granules, having an average granule size of 14.7  $\mu\text{m}$ . Its amylose content ranges from 13.6 to 23.8% [84, 89] and its crystallinity has been reported to be 38% [84], while the gelatinization temperature varies from 59.6 to 87.2°C [84, 89]. The X-ray diffraction patterns of the cassava starch granules depict type A [90]. The cocoyam granules (Taro) are small rounded and ellipsoidal-truncated, with their sizes varying from 0.5 to 5  $\mu\text{m}$  in diameter, making them to be more easily digestible [84]. Taro starch has been used in the preparation of some baby foods and diets of people who are allergic to cereals [91]. The X-ray diffraction patterns of the taro starch granules exhibit the typical A-type pattern, while the starch contains 14.0–19% amylose with the pasting temperatures varying from 81 to 85°C [92]. Interestingly, starch from Tannia (*Xanthosoma sagittifolium*) comprises of small rounded and large truncated ellipsoidal-shaped granules, which possesses granular diameters which range from 2 to 50  $\mu\text{m}$  [91]. The amylose contents of different cultivars range from 21.3 to 25.4% [93]. Tannia starch possesses a type A X-ray diffraction pattern, higher pasting temperatures and lower paste viscosity than those of other starches, such as potato starch [89]. Also, it has higher swelling power and solubility at relatively high temperatures than sweet potato starch granule [84]. The maize starch granules exhibit polyhedral granule shapes and differences in their mean granule size range from 2.3 to 19.5  $\mu\text{m}$ . The starch samples show A-type diffraction pattern with strong reflection at 15.25, 18.11,

and 23.33° [94]. The gelatinization temperatures of maize starch range from 69.16 to 76.98°C [95] and the amylose content varies from 24.74 to 30.32% [94]. Fonio starch granules are polygonal in shape with diameter ranging from 2.0–14.3 mm. Their X-ray diffraction patterns are of the type-A crystalline form [96], with the amylose contents ranging from 18.7% to 19.6%. The millet starch granules are small, spherical to polygonal in shape, but may vary from specie to another. The granular sizes range from 0.8 to 10 mm. The gelatinization temperatures of millet starch ranged from 75.8 to 84.9°C and the amylose content vary from 16.0 to 27.1% [84]. The starch granules obtained from sorghum are typically 3–27 mm and the gelatinization temperature range 61.1–81.2°C [97]. The starch showed the A-type crystalline diffraction pattern and its amylose content varies from 11.2–28.5%, depending on both genetic and environmental factors [98].

## **2.7 Forms of starch**

### *2.7.1 Native starch*

Native starches are crude starches that are extracted directly from their sources and they are mainly used as food, but irrespective of their sources they are undesirable for many applications because of their inability to withstand processing conditions. Each starch has unique functional properties, and much of the starch used industrially is modified before use, giving a wider range of useful products [99]. Starch can be readily converted chemically and biologically into many useful and diverse products such as paper, textiles, adhesives, beverages, confectionery, pharmaceuticals, and plastics, so as to improve desirable functional properties in order to meet the requirements of specific industrial processes [13].

### *2.7.2 Extraction techniques*

Starch granules' settling is often prevented by presence of various components like mucilage and latex, which may lead not only to loss of starch, but also reducing the quality of extracted starch. However, microbial growth can also be promoted if the extraction residence time is prolonged than necessary, which may also result into breakdown of starch and resultant loss of starch quality. It also affects the color of the starch limiting its utilization in food and industrial applications. Therefore, optimum recovery of starch having physicochemical and functional qualities coupled with economical extraction of starches from cereals and tubers is important. Extraction of starch with water is the most common form of starch extraction, but this has been improved upon over time. The Central Tuber Crops Research Institute, Trivandrum, India research on various chemicals that could improve the yield of starch from various tubers [100, 101]. It was discovered that ammoniacal solutions gave the best results. However, when aqueous ammonia (0.03 M) was used for starch extraction, the yield, paste viscosity and swelling capacity of the extracted starch improved. Ammonia formed a complex with the mucilagenous material in the slurry, thereby releasing the starch granules and promoting faster settling of starch in less viscous slurry, which prevents microbiological damage of the starch due to short residence time. Moorthy [101] observed that lactic and citric acids improved the yield and color of starch from sweet potato tubers. Interestingly, an enzymatic method for enhancing the recovery (26% increase) of starch from cassava tubers using pectinase and cellulase enzymes [101]. The aforementioned enzymes work by altering the integrity of the pectin-cellulosic matrix of cell membranes and thereby promoting the release of the starch granules. The same technique was used to promote starch recovery from sweet potatoes by 20% without affecting starch properties [101].

### 2.7.3 Modified starch

Modified starches are native starches whose physical and chemical characteristics have been altered in order to improve their functional characteristics [102]. However, modification of starch is done to tailor starch to a specific food application, to stabilize starch granules during processing and make it suitable for many foods and industrial applications. During modification, starch properties are altered, including solution viscosity, gelatinization properties, pasting properties, retrogradation behavior, association behavior, and shelf-life stability in final products [102, 103]. Modification can be achieved through etherification, esterification, cross-linking/grafting of starch, decomposition (acid or enzymatic hydrolysis and oxidization of starch) and physical treatment of starch using heat or moisture [104].

Modified starches produced from different methods and sources are usually used as thickening agents to provide desired structures in food products [105]. Acid-thinned starch is starch that has been treated in acid slurry [1]. This starch possesses faster gelatinization, low viscosity, and could produce a weak gel (Abbas *et al.*, 2010). Oxidized starch is a starch which has undergone oxidation and it has a low hot paste viscosity. Both of acid-thinned and oxidized starches are suitable for confections because they allow rapid and efficient cooking of starch solution in the presence of concentrated sugar syrups [106]. Stabilized starch is a type of modified starch that possesses a resistant property against acid degradation under dry acidic storage. Stabilized starch can be produced by adding buffer (pH 6–9) to starch slurry and drying the starch-buffer slurry in a conventional oven [107]. Stabilized starch has a reduced starch gelatinization temperature; it's easier to cook and allows for the formation of stronger gel with increased clarity and longer self-life. Converted starch, such as dextrin, which possesses a good film forming capacity, can be used with high-sugar solutions to produce stable and flexible coatings [108]. Thin boiling starch is a modified starch that can be produced by treating the starch with amylase enzyme to hydrolyze the  $\alpha$ -1, 4 glycosidic bonds. This starch possesses gelling properties and low hot paste viscosity, which make it suitable for gum drops since this type of starch allows better evaporation and pouring [104].

Octenyl succinic anhydride (OSA) starch is a recent type of chemically modified starch, possessing surface active properties [109]. Octenyl succinic anhydride (OSA) starch is produced by esterification of different sources of starch with anhydrous octenyl succinic acid under alkaline conditions [110]. The adsorption of the OSA starch molecules at the oil/water (O/W) interface might be as a result of hydrophobic short octenyl succinate side chains in octenyl succinic anhydride (OSA) starch molecules and the long amylopectin backbone which protect the droplets against flocculation by the mechanism of steric stabilization [111]. OSA behaves like a typical surfactant and forms a strong film at the O/W interface which provides a good resistance against re-agglomeration [111]. The increase in the viscosity of the continuous phase in conjunction with its ability of adsorption at interfaces enables OSA starch to behave as a stabilizer and also as an emulsifier in O/W emulsion systems. OSA starch type of modified starch has been approved as a food additive by the Food and Drug Administration (FDA) and European Union [112].

## 2.8 Utilization of starch in food industries

Starch plays a crucial role in food systems by stabilizing and creating the food structure. Starch also co-exists with other components to deliver or maintain nutrient and flavor [113]. However, starch importance in some food applications are elaborated below.

### 2.8.1 *Snack foods*

Starch is generally used in the production snack foods to achieve desired textural and sensory attributes by improving crispiness, oil binding properties, expansions, and overall eating quality [113]. The properties of the amylopectin and amylose of starch are important for the texture creating of this kind of foods. The highly branched amylopectin might increase dough expansion and viscosity, which could result to production of light, crispy, and expanded products. The amylase on the other part strengthens the dough and improves its forming and cutting properties. Consequentially, a more crunchy final texture could be obtained [114]. Furthermore, a high quality fiber-fortified snack could be developed by incorporating modified starch [108].

### 2.8.2 *Baked products*

Starch contribution to baked products quality is through its important properties, such as gelatinization, water absorption, and retrogradation [115]. The gelatinization property of starch is very important in building the structure and texture of baked products. However, starch ability to bind water could reduce the stickiness of dough, improve handling, and increase cake volume. It could also improve the moistness and softening the texture of baked products [108].

### 2.8.3 *Confectionery*

Starch behaves as a structure builder in coatings and also acts as a medium for molding to support desired shapes in confectionaries. Starch is used in the production of pastes, gums, and molds; it is also in the manufacture of dusting sweets to prevent them from sticking together. Starch is selected because of its ease of cooking in high-sugar environments and also based on its ease of handling during processing [108]. In most cases, starch is modified to possess specific properties that suit certain applications.

### 2.8.4 *Gravies, soups, and sauces*

Starch application in gravies, soup, and sauces depends on the production process, which is usually influenced by pH of products and heat during processing [114]. Compared to neutral products, high acid products ( $\text{pH} < 4.5$ ) require a higher-degree of cross-linking starch. The production of cross-linked starch is achieved by the reaction in which a small number of hydroxyl groups on the glucose units of amylose and amylopectin, mostly in the amorphous are modified without destroying the granular nature of starch [116]. Since sterilization of acidic products require shorter processing time and lower temperature, other factors such as shelf-life requirements, fill-viscosity, and heat penetration also influence the suitability of starch used in these types of food products. Hydroxypropylated starch which possesses high freeze thaw stability is suitable for chilled and frozen foods [108]. Hydroxypropylated starch is produced by reaction of starch with propylene oxide. Aside its better freeze thaw stability, modification improves hydroxypropylated starch shelf-life, cold-storage stability, past clarity and texture properties of its paste. Generally, gravies, soups, and sauces require starch with opaque paste [108].

### 2.8.5 *Mayonnaise and salad dressing*

The function of starch in these products is mainly to thicken and stabilize the dispersed phase [108]. Basically, these food products are produced under acidic

condition and the process involves application heat and shear thinning. Therefore, starch which has ability to tolerate acidity, heat, and shear is suitable for these products. Also, lipophilic starch which has potential to stabilize emulsions, other modified starches such as cross-linked starch and stabilized starch are the most commonly used for these products [117]. Lipophilic starch is produced by esterification with n-octenyl succinic anhydride, which led to a starch structure comprising both hydrophilic and lipophilic properties. This starch can be used for mayonnaise and salad dressing, lipophilic starch might be used to replace animal-derived sodium caseinate and gum Arabic [102].

#### *2.8.6 Emulsion stabilizer*

A scientific study suggested that starch could be used as a stabilizer in oil-in-water emulsions [117]. The study further revealed that emulsion prepared with equivalent volume ratio of water and paraffin could be stabilized by adding an aliquot of starch dispersion [117]. Kim *et al.* [117] established that the introduction of starch nano particles of more than 0.02% wt kept the emulsion longer than 2 month of storage without coalescence of oil droplets. Starch might be used in various emulsions not only for foods but also for cosmetics and pharmaceuticals [117].

### **2.9 Utilization of starch in allied industries**

Some non food uses of starch in allied industries are described below:

#### *2.9.1 Packaging component*

Nanoparticle from starch can be used as a material in barrier films for food packaging. The primary focus of the barrier properties of the packaging films is on water vapor transmission and oxygen permeability [117]. However, a decrease in water vapors permeability was observed when the maize starch was used. Kristo and Biliaderis [118] revealed addition of 30–40% waxy maize starch significantly decreased the water vapor permeability in the component. Similarly, García *et al.* [119] observed a 40% decrease in the permeability of cassava starch film, reinforced with 2.5% starch nanoparticles.

#### *2.9.2 Drug carrier and tablet binder*

Starch has been described as a nontoxic, biodegradable, and biocompatible polymer [117]. Its nanoparticles possess the ability to deliver an ample range of molecules to any location in human body for sustained periods of time. Starch has been useful in tablet formulation and binding due to its relative inertness, abundance, low cost, and suitable physicochemical properties [31].

#### *2.9.3 Binders in paper making and paper coating*

Starch possesses a binding property and can be used as a binder in papermaking and paper coating. Cooked starch is widely used as paper-making additive and the retention of the cooked starch on the paper matrix is based on starch absorption [108]. However, the amount of starch absorbed is limited by the cellulose substrates absorption saturation. Another problem which might cause operational problems is the high viscosity of the starch paste after cooking. Bloembergen *et al.* [120] revealed that the modified starch possessed better paper binding capacity than cooked starches.

#### 2.9.4 Starch as energy source

Starch bioconversion into ethanol is a two-step process. Saccharification is the first step, which involves conversion of starch into sugar using an amylolytic microorganism or enzymes such as glucoamylase and  $\alpha$ -amylase. Fermentation is the second step, which involves conversion of sugar into ethanol using *Saccharomyces cerevisiae* [121]. An alternative to the conventional multistage process of starch fermentation which offers poor economic feasibility is the use of amylolytic yeasts for the direct fermentation of starch. Despite the fact that there are over 150 amylolytic yeast species, they possess limited industrial use because of their low ethanol tolerance [121]. Therefore, most research effort has been geared towards the development of genetically engineered amylolytic strains of *S. cerevisiae*, and in these strains, heterologous genes encoding  $\alpha$ -amylase and glucoamylase from various organisms have been produced including their products and their products [121].

### 3. Challenges facing common starch sources and way outs

Starch is the basis of our food and industrial economy, but the food situation in most developing tropical countries is alarmingly worsening owing to increasing population, fragmented farms with rudimentary technologies, poor pre-harvest and postharvest farm practices and shortage of fertile land [11, 24, 108]. The shortage of food supply has resulted into a high incidence of hunger and malnutrition [12, 13]. It also affected the demand for starch as food, pharmaceutical and industrial uses coupled with the need to attain self-sufficiency in starch production.

However, self-sufficiency in starch production could be attained if the following suggestions described below are given utmost attention:

- i. Some lesser known and unconventional crops could be good sources of nutrients and starch, and even have the potential of broadening the present narrow food base of the human species (Viano *et al.*, 1995). *Dioscorea villosa* L (common name wild yam or atlantic yam) is one of the underutilized starch sources, and it is less explored due the presence of anti nutritional factors. Processing techniques can reduce the anti-nutritional factors in food and make them readily available for consumption.
- ii. Efficient and effective development of the various starch based crop value chains such as cassava in order to increase their productivity [24].
- iii. Encouraging small and medium scale investments in order to enhance production, processing and delivery of high quality and quantity of cassava products to the larger industries [24].
- iv. Promotion of effective pest/pathogens integrated management programs and reduction of the occurrence of mycotoxin in starch based crops, to prevent emerging and endemic pests and diseases as well as reduction of mycotoxin contamination in starch [108].
- v. Access to high yielding, climate-resilient and affordable quality seeds, advances in breeding technology using genomic approaches that is cost-effective and field-relevant high throughput phenotyping approaches will accelerate and contribute significantly to mass production starch-based crops [24].

## 4. Conclusion

Conclusively, suggested way outs should be given utmost attention, most especially research efforts should be geared towards utilization of lesser known non conventional crops as sources starch such as wild yams. Sufficient to say, the current level of research on wild yams starches, such *Dioscorea villosa*, *Dioscorea bulbifera* and other lesser known starchy crops is limited. Therefore, the properties and potential utilization of starch obtained from *D. villosa*, *D. bulbifera* and other lesser known starchy crops should be established in order to broadening the present narrow commonly cultivated starch sources. Also, value addition and conceptual efforts towards good agricultural practices might enhance the productivity of conventional starch sources such as cassava and maize.

## Conflict of interest

The author declared that there is no conflict of interest.

## Author details

Akeem Olayemi Raji

Department of Food Science and Technology, College of Agriculture and Veterinary Medicine, Kwara State University, Malete, Ilorin, Nigeria

\*Address all correspondence to: [akeem.raji@kwasu.edu.ng](mailto:akeem.raji@kwasu.edu.ng)

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