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Chapter

Starch: A Veritable Natural Polymer for Economic Revolution

Obi Peter Adigwe, Henry O. Egharevba
and Martins Ochubiojo Emeje

Abstract

Amidst growing concerns for environmental degradation by anthropologic activities and use of non-biodegradable materials for industrial and household purposes, a focus on natural polymeric materials offers the veritable prospects for future survival. Although some synthetic polymers are biodegradable, the process of production that is usually non-green adds to environmental pollution. Natural polymers are naturally occurring organic molecules such as cellulose, starch, glycoproteins and proteins. They are mostly obtained from plant sources, but are also produced in animal and microorganisms. One of the most abundant natural polymers of multidimensional and multifaceted application is starch. Starch is used across wide-range applications spanning engineering, food and beverages, textile, chemical, pharmaceuticals and health, etc. This is because it can readily be modified into products of desired physicochemical characteristics, thus making starch a potential tool for industrial and economic revolution. The global trade balance for starch and derived products is about $1.12 trillion, presenting a huge opportunity for more investment in starch production. Africa’s negative starch trade balance of about $1.27 trillion makes it a potential investment destination for starch production. This chapter discusses the use of starch in various industrial sectors, its potentials for sustainable economic development and as a veritable natural polymer for economic revolution.

Keywords: starch, natural polymers, environmental protection, green economy, industrial uses, sustainable development, economic revolution

1. Introduction

The major form of stored energy as carbohydrate in plants is Starch. It is a naturally occurring biopolymer consisting of a mixture of highly branched amylopectin and linear amylose residues. The two alpha-glucan residues make up 98–99% of the total net weight of starch [1]. Amylopectin residue is made up of linear D-glucopyranose chains linked by O-\(\alpha-(1 \rightarrow 4)\) glycosidic bonds and branching occurring as O-\(\alpha-(1 \rightarrow 6)\) glycosidic bonds. Amylopectin biopolymers are brittle. On the other hand, amylose residue has O-\((1 \rightarrow 4)-\alpha\)-Dglucan linkages and is film-forming [2].

Naturally occurring starch has limited industrial applications its poor functionality such as poor water solubility at room temperature, retrogradation of its paste or
The functionality of starch can be modified through physical, chemical and/or genetic processes [3]. Due to the reactive nature of its monomers which is mainly as a result of their free hydroxyl (–OH), starch is easily modified to attain required functionalities for industrial purposes. For instance, if heated to high temperatures and in the presence of a plasticizer like glycerol, it exhibits comparable melt and flow characteristics as regular synthetic thermoplastic [4]. Undesirable characteristics such as hydrophilicity and low tensile strength are mitigated by introduction of hydrophobic fillers and materials that could enhance tensile strength. Likewise, different materials are used to improve thermal stability, plasticity and mechanical strength required in packing/packaging materials. Advancement in material science which created thermoplastic starch has made starch a veritable resource with tensile applications in packaging and mechanical parts [5].

The ability to modify starch into biomaterials of different functionality has made it one of the most versatile and renewable natural polymer in existence. As a major type of food, it could be modified to enhance flavor, texture, thickness, taste, stability and/or shelf-life. Thus, it has found industrial application in food and beverage industry as food products or additives for enhancing the texture, stability, shelf-life and quality of products. It malleability with new technologies such as nanotechnology has expanded its scope of application in health and pharmaceutical and cosmetics.

Starch could be used as both excipients and drug delivery vehicle [6].

The starch industry is at the very heart of food production: supplying hundreds of ingredients for use in thousands of food products and animal feed. At the same time, starchy play a vital role in a wide variety of products beyond food. Natural and modified food starches can be found in products and processes in the consumer products, pharmaceutical, energy, industrial and chemical sectors. With the world beginning a gradual shift away from fossil fuels as the primary engine of economic prosperity, there will be a larger opportunity for starch producers to contribute renewable, sustainable materials through the bioeconomy [7]. This chapter discusses the various industrial application of starch which if exploited economically could provide strong foundation for economic revolution.

1.1 Starch sources

Starch is the second most abundant renewable bioenergy resources after cellulose, with an estimated global production of over 56 million tons per annum since 2006 [8, 9]. A variety of plant serves as the sources of starch consumed by humans. Starch storage in these plants occurs in grains or root tubers. Although the list of these plants which are either cultivated or found in the wild are endless, the major sources of food starch include corn, cassava, sweet potato, wheat, and potato. Sorghum, barley, rice, millet, yam etc. serve as minor sources in different parts of the world [10, 11]. A huge number of unexploited sources exist and majority is in the wild. Table 1 shows the starch contents of some of these sources.

1.2 Contemporary application of starch and its derived products

By 2050, the population of the world is projected to exceed 9 billion and the demand for food is expected to rise by 70%. With growing environmental concerns and concept of green economy, reliance on fossil resources for energy and raw materials for industrial use etc. has attracted critical evaluation, and the prospect of a new trajectory for bio-based raw materials has become more imminent. Starch which
is one of the most abundant and affordable natural polymer poses a more reliable and sustainable substitute to the non-renewable, non-green, and exhaustible fossil sources. This opens prime opportunities for starch-based bio-economic revolution especially for countries with the right cultivation and production technologies for starch sources and starch-based products, respectively [7].

Starch can be used as biopolymers in many ways including as a raw material for human foods and animal feeds/feedstock, as bioethanol for food and fuel, as particulate filler and adhesive in paper and textile sizing, as well as bioplastics in packaging materials (Figures 1 and 2) [8, 9, 15]. It is also deployed in a wide array of other consumer goods in health and pharmaceuticals, and chemical sector. Corn starch product is used in 3-D printing inks, and emerging reports indicates its potential for nanomedicine technology as a tool for delivering treatments to specific sites. Some other categories of products include starch-based detergent products, starch-based binders, starch in biodegradable polymers, starch-based products for pharmaceuticals and cosmetics, and starch hydrolysates for fermentation [15].

### 1.3 Foods

The food industry is very large and diverse, and includes the raw unprocessed food and the processed and modified ones. Central to world food production and sustainability is the starch industry. Native starch is eaten in unprocessed raw or cooked form as grain or cereal meals, and flour dough or mashes with soups and other forms of condiments, in many developing countries. In West Africa, cooked

<table>
<thead>
<tr>
<th>Source</th>
<th>Plant storage part</th>
<th>% starch content</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soft wheat</td>
<td>Cereal grain</td>
<td>77.90</td>
<td>[10]</td>
</tr>
<tr>
<td>Hard wheat</td>
<td>Cereal grain</td>
<td>77.40</td>
<td>[10]</td>
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<tr>
<td>Waxy rice</td>
<td>Cereal grain</td>
<td>74.76</td>
<td>[10]</td>
</tr>
<tr>
<td>Millet</td>
<td>Cereal grain</td>
<td>70.00</td>
<td>[12, 13]</td>
</tr>
<tr>
<td>Fonio millet</td>
<td>Cereal grain</td>
<td>68.00</td>
<td>[10]</td>
</tr>
<tr>
<td>Sorghum</td>
<td>Cereal grain</td>
<td>67.70</td>
<td>[10]</td>
</tr>
<tr>
<td>Cassava</td>
<td>Root</td>
<td>65.71</td>
<td>[10]</td>
</tr>
<tr>
<td>Taro/cocoyam</td>
<td>Corm</td>
<td>63.74</td>
<td>[10, 14]</td>
</tr>
<tr>
<td>White yam</td>
<td>Tuber</td>
<td>58.02</td>
<td>[10]</td>
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<tr>
<td>Rye</td>
<td>Cereal grain</td>
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<tr>
<td>Sweet potato</td>
<td>Root</td>
<td>52.54</td>
<td>[10]</td>
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<tr>
<td>Yellow yam</td>
<td>Tuber</td>
<td>41.72</td>
<td>[10]</td>
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<td>Potato yam</td>
<td>Tuber</td>
<td>38.10</td>
<td>[10]</td>
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<tr>
<td>Sweet corn</td>
<td>Cereal grain</td>
<td>36.23</td>
<td>[10]</td>
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<tr>
<td>Water yam</td>
<td>Tuber</td>
<td>31.90</td>
<td>[10]</td>
</tr>
<tr>
<td>Bitter yam</td>
<td>Tuber</td>
<td>20.48</td>
<td>[10]</td>
</tr>
</tbody>
</table>

Table 1. Starch sources.
and mashed cassava (fufu) or fried cassava (garri) meals, corn grains and other starches from millet etc. are the bases for food security.

The food industry is very mindful of safety of chemical residues hence not all types of native or modified starches are used in the foods. Some modified starches are used as binder in assaulted foods, ready-made meat and snack seasonings. Others are used as anti-sticking agents and dustings for chewing gum and bakery products,
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Crisping coating for fried snacks, fillers to replace fats and in sauces or creams to enhance lusciousness in ice cream and salad dressings. Modified starches are also used as flavor encapsulating agents and emulsion stabilizers in beverages. They are used as creamers, in canned foods, foam stabilizer in marshmallows, gelling agents in gum drops and jelly gum, and as expanders in baked snacks and cereal meals [2]. Starch derived products are used for the production of animal feeds [15]. About 10–15% of corn produced in the US is processed annually for starch derived products by corn refiners. These starch derived products are used in across the food, beverage, healthcare, pharmaceutical and other sectors. This has a dominant multiplier effect on the United States economy [7].

2. Sweeteners (syrups and sugars)

The CRA 2019 report put US production volume of sweeteners from corn starch refining for 2018 at 14.45 mMt d.w. These include glucose syrups, high fructose corn syrups maltodextrins, dextrose, corn syrup solids etc. [16]. The many other forms of starch are now been adopted as substitute raw material for corn. These products find applications in foods, beverages and pharmaceuticals for taste, flavor, color and texture enhancements.

2.1 Bioethanol

Ethanol is one of the most important organic solvent in the chemical industry. It is also the basic raw material for the wine, brewery and beverage industries. Due to energy fuel sustainability concern, the world is focusing on renewable energy include energy for renewable biological materials like starch. According to the World Integrated Trade Solution (WITS) data of the World Bank, the global volume of ethanol export in 2020 was over 14.2 billion liters, with a net weight of over 13.3 billion kg, valued at over $10.2 billion USD. While the volume of imports was 9.3 billion liters of 9.2 billion net weight and valued at $10 billion USD, with the top 10 importers as Netherlands, European Union, Germany, USA, Canada, Japan, Brazil UK, France and Korea Republic [17].

The production of ethanol from biological materials such as starch has gained interest in recent years because of the low-cost raw materials, starch, and the uncomplicated process involved. These processes, either chemically or biotechnologically based, are environmentally friendly. Bioethanol is already being used in many countries as octane enhancer for gasoline to produce gasohol. Starch from corn and cassava can be used for ethanol production. Due to concerns on quality, corn starch maintains a premium as the primary source of food and pharmaceutical grade starch and may not be very feasible for use as biofuel based on demand. However, sources like cassava may offer a ready source. Nigeria is currently the world’s biggest producer of cassava starch although almost 100% of it is consumed locally as food. The rising demand for biofuel offers countries like Nigeria opportunity for economic revolution in the production of biofuel from cassava. Adeleye et al. [18] has report an ethanol yield of 1.5 L of 78% (v/v) from 2.5 kg wet weight of cassava. Countries like South Africa and China are already at advance stages of developing cassava plantations for production of starch for industrial uses [19, 20]. According to the 2019 Corn Refiners Association (CRA) report, the US produced about 6.06 billion liters of Ethanol, and about 3.37 mMt of Starch in 2018 [21].
2.2 Adhesives

Adhesives are mostly used in wood panels production, leather works and paper and packaging. The global volume of adhesive consumed annually is over 3 billion kilograms, mostly from petroleum derived feedstock and other synthetic materials. Due to environmental and safety concerns, a lot of studies have been ongoing to develop bio-material based hot melt adhesives (HMAs) from starch and its modification derivatives, (poly)lactic acid, soy protein, lignin and tannin [22].

Wood panels are composite products made by bonding wood particles or fibers with adhesive binders to form a board, which may be medium density fiberboard (MDF) or high density fiberboard (HDF). These panels find applications in home, office and industrial building construction. Wood panel makers currently almost depend exclusively on formaldehyde and amino-based adhesives with high formaldehyde emission, and polymeric 4,4-diphenylmethane diisocyanate, which are synthetic products. Concerns for indoor emission of formaldehyde, a known human carcinogen, led to the development of low-emission melamine-fortified urea-formaldehyde adhesives and other adhesive that exclude formaldehyde. Urea has been the primary formaldehyde scavenger for wood-based panels. Environmental consideration has raised interests for more green adhesives from biodegradable polymers like starch, lignin, tannin and protein. Organic scavengers like tannin powder, charcoal and wheat flour have shown promising potentials in reducing formaldehyde emission. Bio-based adhesive for industrial use are few and expensive. Tannin and starch adhesive, soy protein based adhesive and lignin-based adhesive are available for limited application in panel production [23].

Adhesives from native starch rely on hydrogen bonds which is weaker than chemical bonds. Due to their hydrogen bonding, they easily bond with water molecules and are therefore readily soluble and not-water resistant. Crosslinking starch produced with synthetic reagents such as epoxy chloropropane, sodium borate, hexamethoxymethylmelamine, formaldehyde, and isocyanates, tends to give better bonding force and water resist [23, 24]. Although no economically viable bio-based crosslinker reagents for starch are available, research on hot melt adhesives prepared by crosslinking modified propionyl starch with glycerol and polyvinyl alcohol (PVOH) has shown improved tensile strength of up to 2.0 MPa. Hence starch still offers a viable potential for future researches in 100% bio-based adhesive for wood-based panels industry [22].

The global volume of production and consumption of hot melt adhesive is on the increase and is about 15–21%, with an annual consumption growth rate which is 1.5–2 times higher than other adhesives [22]. This presents a huge market potential for starch-based HMAs.

2.3 Pharmaceuticals and cosmetics

They separate corn kernels into their component parts to make hundreds of products that touch consumer lives in countless ways every day. For years, those ingredients have been used to make food taste better, cosmetics last longer, pharmaceuticals easier to swallow and plastics environmentally-friendly [7].

The fundamental physiochemical and functional properties of natural starches for instance their good biodegradability and safety, make them suitable for a wide array of health and pharmaceutical applications. Several types of modified starch polymers and their application in bone tissue technology as bone tissue engineering
scaffolding [25, 26], drug delivery system as biodegradable nanomedicine-carrier based delivery system and implants [27, 28], and hydrogels have been studied by different scientists over the past few years [6]. Starch has also been demonstrated as a viable material for capping of nanoparticles from different metals like Au, Ag and Pt, because of their bio-tolerance and cost effectiveness [29]. It has also been demonstrated to have potentials for use as nanoparticles to stabilize emulsions, Pickering emulsions, which are useful in cosmetics, pharmaceuticals and foods [30]. Also, pharmaceutical grade starch from corn is use as coating and filler excipients in tablets and caplets as well as syrups in many pharmaceutical products. It is also applicable as disintegrating agents, carriers, lubricants, matrices for controlled release [15]. For its good qualities of being odorless, decolourisable, environmentally biodegradable and skin friendly, it is used in cosmetics and beauty products as emollients, humectants, thickeners, film forming agents and emulsifiers [15]. Many sources of natural starch have been studied and found to be effective for the production of pharmaceutical grade starch.

Starch and its modified derivatives have been used in medicine as biodegradable films, inexpensive cure for athlete’s foot, anti-sticking agents, relief rashes caused by prickling heat, relief skin itches caused by shingles, relieves rash caused by baby diapers, wound dressing and bandages and used to treat gastric dumping syndromes in children. It is considered a safe alternative to cancer causing talcum baby powder, and used to remove excess oil from scalps and relieves itching in children [31].

3. Thermoplastics and bioplastics

Plastic pollution and the global push for a more sustainable environment towards eliminating the use of non-biodegradable materials and reduction of hazardous emission form toxic materials has refocused the worlds efforts towards the use of biodegradable plastics based on natural polymers such as starch, cellulose, lignin and chitosan [32]. The current global annual production of plastics is estimated at about 368 million tonnes, out of which about 1% is bioplastics. It is estimated that bioplastic production capacity will increase from 2.11 million tonnes in 2020 to about 2.87 million tonnes in 2025 [33].

The starch-based bioplastics thermoplastic starch (TPS or TS) is produced obtained from gelatinize starch and plasticizers which is subsequently tuned pellets by extrusion is useless as a material. It can also be produced from polymerization of polyactic acid obtained from starch-derived sugars fermentation. Bioplastics from starch can be used for producing compost bags and disposable plastic household wares [32]. The desire for more ecofriendly plastics gives a huge economic prospect to the growth of biodegradable natural polymer-based bioplastics market [33].

3.1 Carbon/carbonaceous foams

Carbonaceous foams (CFs) are used all over the world and find application in military, industrial and domestic use, such as heat exchanger, electrode materials, catalyst carrier, adsorption, vibration damping and impact or sound absorption, electromagnetic shielding, radar absorption, filtration, and aerospace material, etc. Carbon/carbonaceous materials are generally made from non-renewable raw materials like coal tar pitch, mesophase pitch and synthetic materials, at high temperature (above 1000°C) and high pressure (in MPa). Although other materials such as sucrose
and tannin have been used, more cost effective biomaterials have been successfully investigated. A more energy efficient process of producing CFs with excellent compressibility and mechanical strength has been demonstrated by using starch as raw material. The production requires much lower temperature (<500°C) and lower pressure (about 190 Pa) than conventional approaches [34]. The world annual production of polysaccharides is in excess of 150,000 million tonnes. But the production of CFs from polysaccharides such as starch is still very much at low level. This gives good opportunity for economic exploitation.

3.2 Other industrial uses

In the industry, starch powder is used in textiles, paper, inks and paints. They serve as fast absorbent polymer in water treatment, as cleaning agent in detergents, as desiccants to prevent mildew from ruining paper documents in storage, as fabric stiffener and yarn sizing, remove wax from wooden furniture, and as organic pesticide [6, 15]. Starch based alkylpolyglucosides (APG) are used in detergents with superior skin compatibility.

3.3 Economy of starch

The economy of the starch industry largely depends on the availability of sufficient volumes of raw materials and the value of the so-called co-products. During corn starch processing, for example, all components of the maize grain are valorized: after steeping and coarse crushing the germ is separated and yields the valuable maize germ oil while the steeping water is concentrated and sold as nutrient for fermentations. The oil press cake together with the corn gluten (protein) and the hulls (fiber), which are separated after fine grinding in additional refining steps from the pure starch granules, are utilized as components in animal feed. The starch as the main product is either dried and sold as native starch, or chemically modified to make it more suitable for more demanding end uses, or hydrolyzed to yield refinery products such as hydrolyzates (dextrin), glucose syrups, and high fructose syrups [31].

In wheat starch processing, the value of the vital gluten is an essential source of income and could be regarded as the head product. In contrast to cereal and pulse starch production, the extraction of root and tuber starches does not deliver co-products of comparable value. As the processes for the extraction are different for the mentioned crops the starch industry cannot easily switch from one source to the other in order to adapt to fluctuating market conditions both on the raw material and on the end products.

Statistics on starch production and export are only available for the US, UK, the European Union and a few other countries. According to a 2014 report, Africa consumes the least starch per capita, and accounts for just about 2% of the global consumption market of starch and its derivatives. The two leading raw materials, cassava and maize are mainly consumed as food. Production of derived products is concentrated in few countries, Nigeria, Egypt and South Africa, with South Africa in the lead. While maize is the general source of starch for food in Egypt and South Africa, cassava starch plays an equally significant role as food in Nigeria and the West African region [19, 35, 36].

Importation and cultivation of *Manihot esculenta* for Cassava starch in commercial quantities for production of derived products for industrial use is now a major trade in
Asia countries of Thailand and China. A 2018 FAO report put the global production of cassava at 277 million tonnes (fresh root equivalent) and was project to rise by 0.5% annually. The 85.7 million tonnes production from Africa represents about 31%. Only 27.7 million tonnes were traded in same year. Wheat production and trade was 727.9 million tonnes and 173.2 million tonnes respectively. No country in Africa is among the top 10 importers and exporters of starch products [37].

The starch consumption per capita for 2012 was in the order of Africa < South America < Asia < Europe < North America. Country-wise is Nigeria < Egypt < Mexico < Turkey < Russia < UK < South Africa < China < US. Africa also consumes the least sweetener per capita. This is followed by Asia, South America, Europe and North America. Africa consumed less than 1 kg per person while North America consumed over 40 kg per person in 2012 [36]. This scenario has not changed significantly. South Africa produces over 280,800 tons of corn starch annually and is experimenting on local cultivation of *M. esculenta* for local production of cassava starch [19]. It is estimated that about 72% of Africa's population have yet to participate in the formal starch and syrup market. Apart from few cassava production plants, ethanol plants are springing up in Nigeria that targets cassava starch as raw material for production of ethanol for industrial use and biofuel.

According to the International Federation of Starch Association (IFSA), starch and its derived products accounts for an annual revenue of $47.50 billion in the United States in 2020, and supported about 167,786 jobs to the tune of about $10.01 billion wages. It accounted for about $1.91 billion worth of US export with the value of starch only products amounting to about $339.62 million [7]. The overall industry impact on US economic output (direct and indirect impact) was estimated by the Corn Refiners Association (CRA) to be about $7.16 trillion annually with an average growth rate of about 6% between 2017 and 2019 (Figure 3), while the value of impact on export was about $149.19 billion annually with an average growth rate of about 0.77% (Figure 4). However, the industry impact of export actually grew at 4.5% between 2017 and 2018. The impact on jobs (Figure 5) and wages (Figure 6) was actually higher in terms of growth. Capital investments in starch manufacturing were about $20.62 billion and $20.28 billion annually in 2018 and 2019, respectively [16, 21]. The US data presents a good indication of the potential of starch-economy as an economic revolutionary tool.

Figure 3.
Output economic impact of starch in the US, 2017–2019. (source: [16, 21, 38]).
for job creation and export revenue. This potential is estimated to be higher for developing economies with higher opportunities for more investment in both upstream and downstream starch products value chain.
In 20 of the 28 EU member states, the European starch industry’s 28 member companies process 24 million tons of EU agricultural raw materials into 11 million tons of starch-based ingredients and five million tons of proteins and fibers. Of starch-based ingredients, approximately 60% go to the food and beverage industry, and 40% to industrial applications (mainly to the paper, cardboard, pharmaceutical, and chemical industries as a renewable alternative to fossil fuel ingredients). Of the proteins and fibers, approximately 90% go to the animal feed industry and 10% to the food industry. The EU has 75 producers or plants and rely on Maize, wheat and starch potatoes, barley, rice, peas as feed stock to produce Native maize, wheat and potato starches, modified starches, maltodextrins, glucose syrups, dextrose, glucose fructose syrups, polyols, wheat gluten, other proteins. The industry supports 15,000 direct jobs, supports 100,000 indirect jobs, exports 1.6 billion Euros, and the annual industry turnover is 7.4 billion Euros [7]. The EU uses starch and starch products for confectionery, drinks, processed food, animal feeds, corrugating and paper making, pharmaceuticals and chemicals, as well as other non-food applications (Figure 7).

The Turkish starch industry contributes to local farming by processing 25% of locally grown maize from thousands of local farmers each year. The industry separates its starch from corn, drying it to native and modified starches or breaking it down to its sugars and other value-added products. Almost 100% of corn kernels are converted to economically valuable products. The industry supplies edible oils, fish, calf, lamb and poultry meat, paper, textiles and more to local and international food and beverage industries. With its wide-ranging portfolio, from basic to high-end products, the Turkish starch industry is competitive and has the capacity to grow. There are 9 producers which use maize as feed stock and produces Glucose and fructose syrups, native corn starch, modified corn starches, crystalline fructose, polyols, maltodextrins, corn gluten and feed, and ethanol. The industry supports 1,900 direct jobs and export over 400,000 tons annually.

Mexico has an evolving industry with annual output of between $300 million and $500 million USD. The industry supports 2,500 direct jobs and 7,500 indirect jobs. The brewing and paper markets depend largely on corn-based starch. The industry is growing due to investments in brewing capacity [7].

Figure 7. Uses of starch in the European Union (source: [15]).
Founded in 1984, the China starch industry association has 280 members. Revolution in starch development has rebound in progressive development in the food, medicine, biology and chemical industries. It has also significantly contributed to growth of the national economy especially in agriculture where it has helped to sustain livelihood of local farmers through agro-economy. The annual industry output for starch and starch-based deep-processing products is estimated at 30.1 million tons and 16.3 million tons, respectively, from 170 producers. Major products include native starch, pregelatinized starch, chemically modified starch, starch sugar, polyols and ethanol, from feed stocks of corn, potato, cassava, sweet potato and wheat [7].

Starch development in Russia has put the country in an upward trajectory for economic revolution. For instance, the industry has 30 starch enterprises and 23 production plants. Ten of the Russia’s 23 plants are responsible for 90% of all starch products from Russia. Annual production of starch and derivatives rose from less than 180,000 tons in 2013 to over 1.3 million tons in 2020. 70% of this production figures were sweeteners (Figure 8). The industry has a cumulative average growth rate (CAGR) of 8.65, 8.69 and 8.65 for starch, sugary products and total starch-based products, respectively. Corn accounts for about 800 thousand tons, wheat about 500 thousand tons, and potatoes about 30 thousand tons. The industry has invested about $358.4 million between 2013 and 2020 (Figure 9). Table 2 provides Russian industry statistics on starch production and derived sugary products as obtained from Russian Federation Starch Union (RFSU) for 2013–2016 [39]. The 2015 import and export data is as provided in Table 3. The industry supports 4,000 jobs, has an annual output of $600 million and exports worth $28.5 million. The major products include native corn, wheat and potato starches, modified starches, glucose syrups, HFS, dextrins, maltodextrins, wheat and corn gluten, from the feed stock of corn, wheat, potatoes [7].
3.4 Global starch trade and opportunities

The value of starch and starch derived products imported and exported globally in year 2020 was $20,367,050,000 and $19,251,015,000, respectively according to figures from Trade Map [35]. African import and export were $1,921,266,000 and $652,628,000 (Figure 10), respectively, representing about 9.4% and 3.3%, of global figures respectively. This deficit represents a huge investment opportunity in starch production for the entire world. Table 4 provides details of the starch products considered.

The high four years AGR of 10 for the global trade in flour (1105) and 7 for both cereal flour (1102) and inulin (1108) is a pointed to rising demands for these products. The imbalance in trade in wheat (1101) and malt (1107) for Africa expose the gap in export and import to Africa (Table 4). These rising demands and trade deficits could be bridged through more investments in starch production.

<table>
<thead>
<tr>
<th>Tons</th>
<th>2013</th>
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<th>2015</th>
<th>2016</th>
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<td>2547</td>
<td>2314</td>
<td>5216</td>
<td>7023</td>
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<td>Starches, except modified</td>
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<td>197,605</td>
<td>213,452</td>
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<td>Starch syrup</td>
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<td>173,340</td>
<td>437,033</td>
<td>464,349</td>
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Table 2. Production in 2013–2016.
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<table>
<thead>
<tr>
<th>Products</th>
<th>Export in 2015 Rubles</th>
<th>Import in 2015 Rubles</th>
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<tr>
<td>Corn Starch</td>
<td>12,538,346</td>
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<td>Glucose Syrup (Patoca Starch Glucose)</td>
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<td>Other Starch</td>
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<td>Potato Starch</td>
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</tr>
<tr>
<td>Manioc Starch</td>
<td>—</td>
<td>2,368,000</td>
</tr>
<tr>
<td>Rice Starch</td>
<td>159,900</td>
<td></td>
</tr>
<tr>
<td>Starches transformed into complex or simple ether</td>
<td>353,555</td>
<td>62,628,181</td>
</tr>
<tr>
<td>Wheat starch</td>
<td>341,147</td>
<td>3,181,534</td>
</tr>
<tr>
<td>Isoglucose</td>
<td>—</td>
<td>2400</td>
</tr>
<tr>
<td>Other, including syrup maltose</td>
<td>154,478</td>
<td>2,177,381</td>
</tr>
<tr>
<td>Dextrins</td>
<td>79,025</td>
<td>448,292</td>
</tr>
<tr>
<td>Other</td>
<td>50,720</td>
<td>1,919,326</td>
</tr>
<tr>
<td>Other starches modified</td>
<td>2,090,376</td>
<td>8,583,020</td>
</tr>
<tr>
<td>Other rice starch</td>
<td>300</td>
<td>—</td>
</tr>
</tbody>
</table>

Table 3. Starch products export and import in 2015 in Russia federation.

Figure 10. Comparison of value of imported and exported in year 2020.
4. Conclusion

Starch is an abundant natural polymer with great industrial versatility. Various sources including maize, wheat, cassava, potato, rice and millet, abound in different countries of the world. Many countries especially those in Africa have not fully realized their starch production capacity and export potentials for international trade. The negative world trade balance of about $1.12 trillion for starch means opportunity for more investment in starch production. Starch and inulin with the highest world trade imbalance, and Malt, cereal and wheat gluten with relatively high world trade imbalance, could benefit more in future investment prospect (Table 4). A closer analysis shows that Africa has a higher negative trade balance of about $1.27 trillion than the world. As bad as this may look for Africa, it presents a huge opportunity for investments in global starch production. But Africa will have to do more to reduce the widening trade imbalance in starch products, especially in wheat and malt.

Conflict of interest

The authors declare no conflict of interest.
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