Chapter 1
Starch: Current Production and Consumption Trends

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1.1 Introduction

Starch is an important component of many diets worldwide and provides a slow, steady release of energy to the body. It is also used in various industrial and commercial applications, such as pharmaceuticals, textiles, paper, glue, packaging, and printing materials. The properties of starch can vary depending on its source, and it can be modified through cooking and processing to change its texture, taste, and other characteristics. Starch exists in the form of granules consisting of glucose units joined together by glycosidic linkages, which are mostly comprised of two components amylose (15–30%) and amylopectin (70–85%). Amylose is a linear polymer with a molecular weight of less than around 500,000 Da linked together by α-1,4 glycosidic bonds, depending on its physiological perspective. Amylopectin molecules, in contrast, have a molecular weight between ranges between 10^7 and 10^9 Da linked by α-1,4 and α-1,6 glycosidic bonds and are substantially larger and heavily branched (Krithika & Ratnamala, 2019; Park & Kim, 2021). For commercial applications, starch is mainly classified based on its amylose content: low (<20% amylose), medium (21–25%), and high (>26%) (Juliano, 1992).

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V. S. Sharanagat et al. (eds.), *Starch: Advances in Modifications, Technologies and Applications*, https://doi.org/10.1007/978-3-031-35843-2_1

The size of starch granules is microscopical; their diameter ranges from 0.1 to 100 μm, and their morphology is mostly oval, ellipsoidal, spherical, smooth, angular, and lenticular, depending on the botanical source. The size distribution of these granules can be uni, bi, or polymodal, and they are present individually or collectively in amyloplasts (Jane et al., 1994). Two types of granules exist in common cereals such as wheat, barley, and rye: type A, large and with a lenticular shape; and type B, spherical and smaller in size (Tester et al., 2006; Vamadevan & Bertoft, 2015). The morphology of starch granules is characterized mainly by the presence of a Maltese cross or birefringence, which can be observed under polarized light, indicating a high order in the amylose and amylopectin layer structure. When a molecular disorder occurs, the starch loses birefringence and gelatinization increases. The starch is dispersed in molecular components and swells; amylose leaching modifies properties such as viscosity and clarity. These are key parameters for analysis and implementation in the industry.

Starch can contain lipid molecules such as phospholipids and free fatty acids, which are commonly associated with the amylose fraction (Tester et al., 2004). The presence of lipid complexes in starch granules is observed as a hydrophobic nucleus within the helix formed by amylose chains in starches, mostly cereals. These complexes represent between 0.15% and 0.55% of the amylose fraction. The lipid structures vary according to the botanical source; for instance, corn starch contains free fatty acids and triglycerides, while wheat, rice, barley, and rye starches usually contain a significant amount of phospholipids. In contrast, phosphate monoesters are widely distributed in potato starch and other native starches from roots and tubers (Srichuwong & Jane, 2007). These lipid molecules can significantly reduce the swelling capacity of starch despite representing a very small fraction (Morrison & Azudin, 1987). On the other hand, starch can contain up to 0.6% of the protein associated with the molecule. This protein and lipid proportion is usually located on the surface of the starch granule, affecting and/or modifying its functionality. Additionally, they contain a relatively small amount (<0.04%) of minerals, such as calcium, magnesium, phosphorus, potassium, and sodium (Pérez & Bertoft, 2010). Phosphorus is another component in starch, found as phosphates and phospholipids. Phosphates are generally linked to the amylopectin fraction by covalent bonds, as phospholipids tend to create complexes with amylose (Singh et al., 2003).

Besides these starch components, other factors, including the presence of proteins and lipids and environmental factors, also affect the functionality of various grain starches. Therefore, various components as additives, such as salts, sugars, and sugar syrups, have also been used to improve or modify the characteristics as well as the functionality of starch (Shikha et al., 2019). In addition to physical modifications (hydrothermal and pre-gelatinization), chemical methods, including esterification, grafting, cross-linking, and etherification etc., as well as enzymatic modifications such as treatment with hydrolases and transferases of starch, have also been performed to enhance its applications (Chen et al., 2015; Ashogbon & Akintayo, 2014; Hj Latip et al., 2021; Zhong et al., 2022). However, to overcome the problems associated with native starch, researchers continuously explore different starch sources with desirable physicochemical properties such as syneresis, turbidity, and freeze-thaw stability to improve its industrial applications (Wani et al., 2013). It is important to characterize different starches based on their product-specific end-use as the properties of native starch are not optimal enough for many applications and require further modification using additives or ingredients to improve the functional properties (Raina et al., 2006).

The modification of starch not only enhances the paste clarity and sheen, film formation, texture of paste and gel, and adhesion but also reduces the retrogradation, pastes gelling tendency, and syneresis of gel (BeMiller, 1997). Therefore, to overcome such limitations, starch modifications are widely practiced in food processing industries. The modification of starch results in the stabilization of starch granules slows the rate of retrogradation, enhances solubility, and improves the pasting properties and gel texture during processing. Several starch-based food items like bakery goods, vermicelli, syrups, jellies, and edible coating have starch as a prime component (Abegunde et al., 2013). Despite this, native starch imparts various detrimental effects, like reduced solubility, deprived paste clarity, etc. (Sun et al., 2017). Also, starch retrogradation and recrystallization are two major aspects that are considered unfavorable under certain conditions of using native starch. Hence, the unpredictable processing attributes of native starches bound the appropriate utilization of starch (Krstonošić et al., 2011). So, to conquer such adverse effects of starches, several methods were designed with great security, *viz.* physical, chemical, and enzymatic treatment methods (Chiu et al., 1998). These techniques allow for modifying the starch polymer, altering its physicochemical and structural properties, and increasing its value in the food and non-food industries.

1.2 Overview of Starch Sources and Production

Starch, as a major carbohydrate source, is a primary component of various plant-based food materials, including grains sources such as corn, high amylose corn, waxy starch, wheat, rice, millet sources, tubers, and roots including potato, cassava, yam, and sweet potato, legumes (soybean, green pea, navy bean, lentil bean, cowpea, and groundnut) (Waterschoot et al. 2015; Pérez & Bertoft, 2010; Zhong et al., 2022). In the United States, maize (corn) is the primary source of starch for industrial applications, accounting for about 80% of total starch production. Corn is an abundant and versatile crop well-suited to produce high-quality starch, making it a popular choice for manufacturers. The USA is one of the largest producers and exporters of corn in the world, and the demand for corn-based starch continues to grow due to its widespread use in various industries, including food and beverage, paper and packaging, and chemical and pharmaceutical industries. Additionally, demand for corn starch is driven by the growing use of gluten-free ingredients in the food and beverage industry due to the rising incidence of gluten intolerance and celiac disease.

Cassava is a major source of tuber starch and is primarily produced in Southeast Asia and Brazil. Cassava is a drought-tolerant crop that can be grown in various soil types, making it an important food crop for subsistence farmers in many parts of the world. Cassava is also a valuable source of starch for industrial applications, and the demand for cassava-based starch continues to grow in regions such as Southeast Asia, Africa, and South America. In addition to cassava, other tuber crops such as sweet potato and yam are also important starch sources in some regions, particularly in Africa and South America. Most of the starch production in Europe comes from cereal grains, with maize (corn) being the largest source, followed by wheat. According to the European Starch Industry, maize is the largest source of starch in Europe, accounting for 47% of the total production, followed by wheat (39%) and potato (14%) (Schwartz et al., 2009; Mitchell, 2009). Potato is also an important starch source in Europe, although to a lesser extent. The European Union uses around 8.6 million tons of starch and its derivatives, mostly in food (51%) and non-food uses such as paper making (47%).

The global starch market was estimated at 119.6 million metric tons in 2020 and is projected to reach 160.3 million metric tons by 2026, with a compound annual growth rate of 5%. Additionally, the global starch market was valued at $97.85 billion in 2020 and is projected to grow at a compound annual growth rate of 7% from 2020 to 2028. This indicates a positive outlook for the industry and suggests that demand for industrial starch is expected to increase in the coming years. The growth of the food and beverage industry, as well as the increasing use of industrial starch in various industries, are likely to be key drivers of this growth. The U.S. starch market is estimated at 33.4 million metric tons in 2021, accounting for 27% of the global market.

Starch production is a significant industry worldwide, with millions of tons produced yearly. The technology and methods used for starch production have greatly advanced in recent years, making the process more efficient and cost-effective. Overall, the starch market is expected to grow in the coming years due to the increasing demand for food, biofuels, and industrial applications. The increasing demand for natural and organic ingredients, the growing demand for biofuels, and the growing demand for convenience foods will likely drive the market's growth.

1.3 Need for Starch Modification

Native starch mainly consists of two components, amylose, and amylopectin, which contribute to its structural and functional properties and make it useful as a thickening agent, additive, and gelling agent. However, native starch has certain limitations, such as poor solubility and swelling properties and the tendency of amylose to retrograde and form solid and tough gels, while amylopectin forms weak, soft gels. Moreover, native starches have also been identified as lacking applications during processing under different pH, temperature, and shear conditions. Starches are modified by physical, chemical, and enzymatic methods to overcome these limitations. Physical modifications involve the application of temperature, pressure, and shear conditions to alter the particle size and enhance properties such as solubility and swelling. Chemical modifications involve using chemicals, involvement of certain functional groups, etherification, and esterification to obtain new derivatives and desired qualities such as digestibility and nutritional value. This method is an efficient and inexpensive way to develop starch products with desirable properties (Ashogbon & Akintayo, 2014; Zhong et al., 2022). In addition, enzymatic modifications involve using enzymes to overcome the limitations of native starches. While all three methods can be effective, physical modifications are preferred for consumer health and safety. Unmodified starches have also been identified as lacking in their applications during processing under different pH, temperature, and shear conditions, as well as being resistant to enzymatic hydrolysis. Therefore, starches must be modified to increase their functionality using physical, chemical, and enzymatic methods or combinations thereof. Studies of starch structure and composition have shown that modifications can improve starch properties for various applications (Khunae et al., 2007; Watcharatewinkul et al., 2010; Vieira & Sarmento, 2008).

Modified starches are excellent flavor carriers, meaning they can enhance the taste and aroma of food products. This makes them a popular ingredient in ready-to-drink mixes, where they can help improve the beverage's overall flavor profile. In addition, modified starches can add a slight amount of viscosity to a drink, which can help to create a smooth and silky texture. In the baking industry, modified starches can help improve the texture and mouthfeel and enhance the stability and shelf life of products such as pasta, soup, and mayonnaise to improve their quality. In recent decades, modified starches have also been beneficial for emulsifying end-use products, particularly those containing flavored oils. They can be used as the particle in Pickering emulsion to stabilize the oil droplets, making them a popular ingredient in the food, personal care, and pharmaceutical industries. Additionally, the properties of modified starch, such as water binding, flocculation, adhesiveness, pH stability, acidic stability, thickening, shear stability, and film-forming abilities, make it popular in various applications.

Among the different modified starch, the most popular are pregelatinized, cross-linked, and resistant starch. Pregelatinized starch is widely used in instant and convenience foods due to its quick solubility and dispersibility. Crosslinked starch is commonly used in frozen and refrigerated foods due to its heat, acid, and shear resistance. Resistant starch is gaining popularity as a dietary fiber ingredient due to its potential health benefits, such as improved digestion, glycemic control, and the gut microbiome. Therefore, due to the increased demand for processed foods, the demand for modified starch is expected to grow, especially in regions like the US, Canada, Japan, China, and Europe. The global market for modified starch is estimated to be worth $12.1 billion in 2023 and is expected to grow to $19.8 billion by 2033, with an average annual growth rate of 5%. The modified starch market is currently dominated by North America, with a share of 42%. However, China and India are the fastest-growing markets due to the increasing demand for convenience foods and the expanding middle-class population. Conclusively, the increasing demand for convenience and processed foods, the growing awareness about the functional benefits of modified starch, the rising population and urbanization, and the expanding application scope of modified starch in various industries will drive the global modified starch market in the next decades.

1.4 Industrial Utilization and Future Trends

Starch is a versatile and widely used ingredient in various industries, including food and non-food. Its properties as a natural polymer make it an excellent additive, stabilizing agent, and thickener in the food industry. Starch is also used in non-food industries such as paper, textile, pharmaceuticals, and cosmetics, where its properties as a binder, adhesive, and filler are useful in product development applications. Most commercially available starch is chemically modified or altered using cross-linking or oxidation processes to enhance its functional properties, improving its utilization in food and non-food industries (Abbas et al., 2010; Sharma et al., 2015; Verma & Srivastav, 2022). Starch from various sources such as wheat, corn, potato, and tapioca are gluten-free starches, which increases their value for people with gluten allergies, as shown in Table 1.1 (Horstmann et al., 2016).

Table 1.1 Industrial utilization of starch from major starch-source

Starch-source	Utilization/function	Reference
Corn	Corn syrup production, thickeners in baby products, increase fiber content in cake, gravies, puddings, sauces, soups, etc.	Guadarrama-Lezama et al. (2016); Li et al. (2015); Sitohang et al. (2015)
Potato	Film-making properties, pasting, gelling applications,	da Rosa Zavareze et al. (2012); Pongjaruvat et al. (2014)
Rice	Freeze-thaw stability and retrogradation application in frozen foods, Flavor encapsulation: volatile aromatic compounds such as ethyl hexanoate, limonene and β-ionones Bakery foods, paper industry, emulsion stabilizer, textile industry	Sun et al. (2017); Shrivastava et al. (2018); Márquez-Gómez et al. (2018); Mun & Shin (2018); Villanueva et al. (2019); Yang et al. (2017)
Wheat	Cookies production, gelling properties etc.	Majzoobi et al. (2016)
Tapioca	Thickeners in soup production, gluten-free products	Li et al. (2013); Wongsagonsup et al. (2014); Agudelo et al. (2014)
Sweet potato, chestnut, quinoa, and underutilized starches	Emulsion stabilizer, bread production, starch industry, gel stabilizer, corn-starch substitute, and many other applications.	Cruz et al. (2013); Tsatsaragkou et al. (2014); Spada et al. (2017)

In the USA, the food industry consumed 57% of total starch consumption in 2020, followed by paper (26%), textile (7%), and pharmaceutical industry (4%). The consumption pattern of starch in various industries is similar in many parts of the world, although the exact distribution may vary by region and country. In addition, the food industry (sweeteners, starches and flours, and other ingredients such as hydrocolloids and emulsifiers) in the European Union accounts for around 60% of the total starch consumption, followed by the paper and board industry (25%) and industrial applications (15%) such as textiles, adhesives, and bioplastics.

The future trends of starch consumption and utilization are likely to be influenced by various factors such as technological advancements, changing consumer preferences, and sustainability concerns. As consumers become more health-conscious and demand transparency in food labeling, there may be a shift towards natural and minimally processed starches in food products. Additionally, as the trend toward plant-based diets continues to grow, there may be an increased demand for starches derived from alternative sources such as pulses, legumes, and tubers. Ongoing research into the starch modification and functionalization may also enable starch application in new areas of various industries. However, the most interesting development in the near future could be the use of starch-based biodegradable materials and packaging due to growing concerns over environmental sustainability and the need to reduce waste.

1.5 Conclusions

Starch is an essential component in our daily lives and is widely used in various industries. However, native starch has certain limitations, modifying an essential step in starch processing. The global production and consumption of starch have continued to increase in recent years due to the growth of the population and the rising demand for processed foods and industrial applications. The increasing demand for convenience foods and the expanding middle-class population in developing countries like China and India will allow the starch market to grow and innovate. Therefore, research and development become crucial to meet the industrial expectations of starch and to develop new and improved products that meet the changing demands of consumers and industries. The upcoming chapters will provide great knowledge about the current developments in starch modification.

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