

Starch Metabolism in Plant and Its Applications in Food Industry

Fabien Nsanzabera^{1*}, Evangeline Irakoze², Alexis Manishimwe¹, Aimable Mwiseneza¹, Jean Bosco Nsengiyumva¹, Fabien Nkurikiyimana¹

¹Department of Education in Sciences, Faculty of Education, University of Technology and Arts of Byumba (UTAB), Byumba, Rwanda

²African Center of Excellence in Innovative Teaching and Learning Mathematics and Science (ACE-ITLMS), College of Education, University of Rwanda, Kayonza, Rwanda

Email: *nsanzabera@gmail.com

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Abstract

Starch, a polymer of sugars in plants, is widely used in various industries due to its properties. It is synthesized through ADP-glucose formation and enzyme-mediated processes. Starch is formed during the day and broken down into sugars at night, which are then transported and converted back to starch in storage tissues. This review explores starch metabolism pathways and its role in the food industry, providing valuable insights on energy storage in plants.

Keywords

Starch Metabolism, Gelatinization, Retrogradation, Starch Biosynthesis, Starch Degradation

1. Introduction

Starch has been many years commonly employed in human day-to-day life. Egyptians cooked wheat flour paste with diluted vinegar to strengthen strips of papyrus, whereas in prehistoric Chinese booklets were first layered with a high fluidity starch to deliver resistance to ink penetration, then engulfed with pulverized starch to offer weight and thickness [1] [2]. Starch is a white soft formless powder, tasteless, and odorless, it is insoluble in water, ether and alcohol and it is a non-reducing carbohydrate [3] [4]. From a labelling perspective, starches is mainly classified into two clusters, such as native and modified. Native starches are manufactured via the extraction of naturally occurring starch from grain or root crops (including corn, potato, rice, cassava, and tapioca) and can be em-

ployed directly in making specific foods, including noodles; while modified starch is made from the native starch through either chemical or physical modifications [5].

The modification of starch is done to increase its functionality (e.g. its capacity to tolerate low pH environments and high temperatures during processing); starch modification is an important process as native starches are habitually not process friendly [1] [5]-[10]. Native starches are regarded clean label constituents, while chemically altered starches have an E number title and are not recognized as natural [5]. The physical modification of native starches is used to make them as useful as their chemically altered equivalents, thus maintaining the label affirmation native which gives them a lucrative benefit. Apart from its carbohydrates content, starch granules normally hold 10% - 20% moisture and minor-quantities of proteins, lipids and traces of inorganic materials [5].

The moisture content of starch foodstuffs depends on the relative humidity (RH) of the atmosphere in which they have been stored. At RH zero, the moisture content of starches is near zero while at RH 20 %, the moisture content of all starches is about 5% - 6% (w/w). Standard water of hydration in starch granules is positioned on carbon 6 of the glucose units. Starches of potato tuber and tapioca root contain a very small amounts of lipids of nearly 0.1% contrast to the cereal starches of maize, wheat, rice, and sorghum, which hold 0.8% - 1.0% lipids. The increase of fatty substances in cereal starches reduces their suitability for use in food products due to the tendency to increase the rancidity upon storage [5] [11]. The increased amounts of lipids in starch granules do not only cause rancidity upon storage but also can reduce the swelling power of starch paste [12].

Starch has found to have different properties, most of which are associated to the temperature-dependent interactions of starch with water in the processes recognized as gelatinization, pasting, and retrogradation [13]. Starch gelatinization is linked with the interruption of granular structure making starch molecules to scatter in water and highly influences thickening and gelling of sauces and pastry fillings processes [14] [15]. Pasting properties refer to the variations in viscosity before, during, and after the process of gelatinization and during retrogradation [13]. Starch retrogradation on the other hand refers to the reassociation and recrystallization of amylose and amylopectin molecules upon cooling [13] [16] [17] [18]. Being renewable natural synthetic polymer, starch has been used in many industrial applications where it can be used in food industry, tissue engineering, drug delivery systems, and agriculture [4].

2. Starch Structure

Starch comprises of two macromolecules: a highly branched amylopectin and a linear amylose (**Figure 1**). Amylopectin is a large macromolecule with linear chains containing regularly 20 - 25 linked α (1 - 4) D-glucopyranosyl residues, and with 5% to 6% of α (1 - 6) bonds making the branch points. Amylose on the

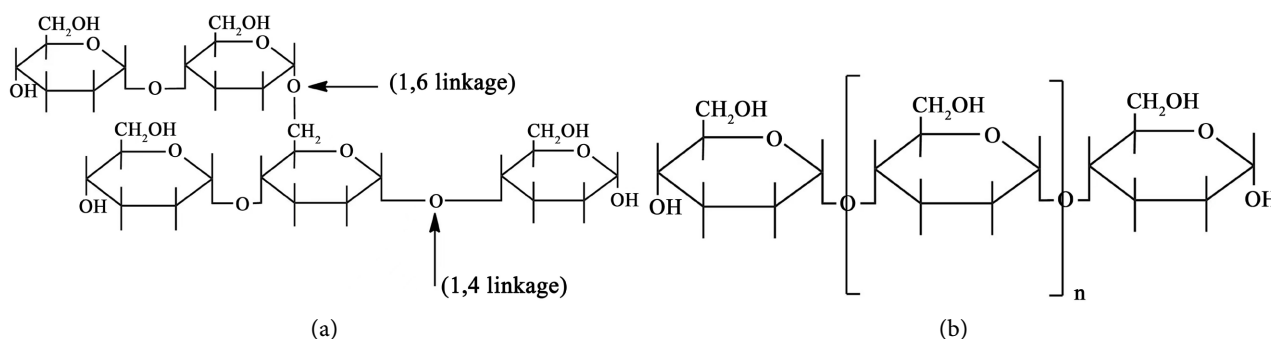


Figure 1. Highly branched Amylopectin (left) and linear structure of Amylose (right). Adapted from [22].

other hand is the smaller constituent by weight in common starches and comprises a single or few long chains of α (1 - 4) D-glucose units making it linear [4] [5] [19] [20] [21]. The number of side chains found per amylose molecule refers on the vegetal source, with wheat starch holding ~ 2 and potato starch ~ 7 chains on average, the amylose having branches have been confirmed by the partial hydrolysis of amylose fraction by β -amylase [16].

Starch functionality depends significantly on the molecular weight, size, and structure of its constituents, amylose and amylopectin, the greater the amylopectin content, the better the starch quality [20]. Both amylose and amylopectin constitute about 98% - 99% of the dry weight of starch, botanical source reveals that starch chain commonly contain of 20% water soluble amylose and equal to 80% water insoluble amylopectin by mass depending on the starch source, this makes the starches from different botanical sources vary in physicochemical characteristics owing to variance in their amylose content, grain size, chain length and amylopectin distribution [4] [21]. Amylose contributes to the shear resistance, pasting and gel textural properties of cooked and cooled starches while amylopectin is responsible for the stability, thickening and firmness properties of starch preparations but it does not contribute to gel creation [4] [5] [20].

The starch chain length vary with the botanical source but will be between 500 and 6000 glucose units, this is to say, the starch structure, properties and its functionality is correlated with its origin (Table 1) [23]. Because of its simple polymeric structure, amylose has a superior tendency to deposit in a regular way making crystals [23]. Due to its aptitude to form complexes with compounds like aliphatic alcohols, lipids, and iodine, the presence of amylose in samples can be concluded from the observed strong blue color of amylose/iodine complex [16] [23].

3. Starch Gelatinization and Retrogradation

Starch is the utmost common carbohydrate in human foods and employed as pasting and thickening agents in foods, paper production and other industries. The physicochemical properties of starch gained from diverse botanic sources

Table 1. Amylose content and structure in selected starches.

Source	Amylose (%)	DP _n	Reference
Wheat	25	980 - 1570	[24] [25]
Rye	26 - 30	13 - 24	[26]
Triticale	23 - 27	n.a.	[27]
Barley	22 - 27	1220 - 1680	[28]
Oat	18 - 29	n.a.	[27]
Rice	17 - 29	920 - 1110	[29]
Maize	20 - 28	960 - 830	[25] [30]
Sorghum	22 - 30	6 - 15	[31]
Sweet potato	19 - 20	3280	[25] [32]
Potato	25 - 31	4920 - 6340	[25] [32]
Corn	28	800	[11]

n.a.: no data available, DP_n: the number average degree of polymerization.

diverge due to difference in their amylose content, grain size and chain length distribution of amylopectin molecules. Starch gelatinization in water is a process of breakdown of the intermolecular association between amylose and amylopectin molecules at solid state (granules) with heating. After dissolving the starch molecules on heating, it displays great viscous solution and varies into strong gelling (retrogradation) state on storing for long times. The intermolecular link might take place between the O-6 of amylose and the OH-2 of amylopectin molecules owing to hydrogen bonding [21].

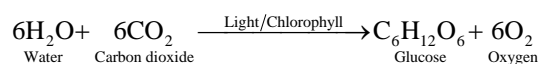
Normal starch is insoluble in water, when heated in water, it reaches a temperature where it undergoes a granular structure destruction, this process is termed gelatinization and the temperature is gelatinization temperature [14] [19] [23] [33]. During gelatinization, the granules expand to high fold their original size, this swelling is the result of water absorption by starch granules; the leaching of water soluble amylose occurs during this process and the starch lose its crystallinity and birefringence, granule swelling results in the increased starch solubility, paste consistency and paste clarity. Starches from diverse botanic sources, diverging in composition, displayed different transition temperatures and enthalpies of gelatinization [14] [19] [23] [33].

Upon cooling, amylose and amylopectin chains progressively reassociate into a well-ordered structure in a process called retrogradation [16] [18]. Starch retrogradation goes with different physical modifications such as intensified viscosity and turbidity of pastes, gel formation, elimination of water and intensified crystallinity [18]. Starch retrogradation is assigned to the reassociation or the recrystallization of the polysaccharides in gelatinized starch that is amylose and amylopectin. It happens after the starch-based foods are exposed to freeze/thaw cycles, or when moisture transfer happens in starchy foods, influencing the textural and nutritional features of foods. Starch retrogradation is a key mechanism

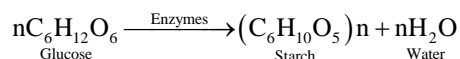
for staling of bakery produces, intensifying firmness of crumb, varying flavor and aroma, and causing loss of crispness [34]. The retrogradation of starch furthermore happens during the softening of half products of many snack products and breakfast cereals, leading to textural variations such as intensified hardness and decreased stickiness. Apart from changing the texture and flavor, retrogradation of starch can more over reduce the starch digestibility [35].

4. Metabolism of Starch in Plants

In green leaves and plants in general, starch is formed by condensation polymerization of glucose with the assistance of starch synthesizing enzymes, the used glucose was formed during the process of photosynthesis as it is shown in the below Equation (5).



The general equation of the conversion of glucose into starch can be written as follows (5).



Throughout the day, starch is formed in leaves of plants and in the night, the starch is crashed by enzymes into sugars mainly sucrose and is transported to other parts of the plant, some of these sugars are re-converted to starch in tubers, seeds, and roots of different plants as storage starch. These storage sources provide numerous commercial starches. Starch granules are deposited in the seeds, tubers, roots and stem piths of plants as a stock of food supply during periods of growth, germination and dormancy [5]. Starch biosynthesis is completed by the harmonization and interaction of numerous key enzymes with conventional functions, such as ADP glucose pyrophosphorylase (AGPase), soluble starch synthetase (SSS), granule bound starch synthetase (GBSS) and starch branching enzyme (SBE) [36].

Generally, starch biosynthesis initiates with the creation of ADP-glucose, the glucose moiety is then transferred to an acceptor, several plastid-localized enzymes contribute in the processes and at the end the final structure of starch granule is formed [23] [37].

4.1. Starch Biosynthesis in Leaves

Even if the same general enzymatic reactions have to be catalyzed in both, leaves and tubers, there are deep differences among both tissues. In leaves, starch is manufactured and degraded during the daytime serving as a nighttime energy source to uphold energy supply for biological processes [38]. In leaves, ATP required for starch biosynthesis is produced throughout photosynthesis. Furthermore, the source of glucosyl donors for starch biosynthesis varies amongst phototrophic and heterotrophic tissues. In leaf chloroplasts, the formation of ADP-glucose is directly connected to the formation of photoassimilates within the Calvin-Benson-Cycle (Figure 2) [39]. The differences in starch biosynthesis

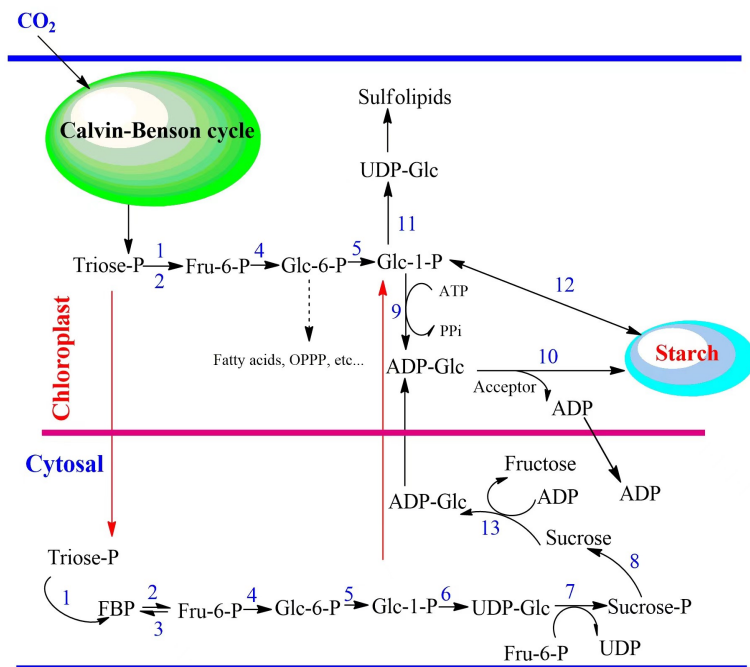


Figure 2. General pathways of starch metabolism in leaves. Adapted from [37] [40] [41]. **Abbreviations:** Fru-6-P: fructose 6-phosphate; Glc-6-P: glucose 6-phosphate; Glc-1-P: glucose 1-phosphate; UDP-Glc: uridine diphosphate glucose; ATP: adenosine triphosphate; PPi: inorganic pyrophosphate; ADP-Glc: adenosine diphosphoglucose; FBP: fructose biphosphate; SP: starch phosphorylase; OPPP: oxidative pentose-phosphate pathway.

provide motives to consider that diverse regulatory mechanisms act in leaves and tubers.

Starch can be synthesized from ADP-Glc produced in the chloroplast, Glc-6-P produced in the cytosol pass through the membrane to the chloroplast to be used in starch synthesis. The ADP-Glc produced in the cytosol is transported to the chloroplast with the aid of a yet to be identified ADP-Glc translocator [41].

A number of at least thirteen enzymatic reactions out of reaction involving in Calvin-Benson-Cycle are necessary to starch biosynthesis. The enzymes involved are numbered from one to thirteen: **1.** Fructose-1,6-bisphosphate aldolase, **2.** Fructose-1,6-bisphosphatase, **3.** PPi: fructose-6-P-1-phosphotransferase, **4.** Phosphoglucose isomerase (PGI), **5.** Phosphoglucomutase (PGM), **6.** UDP-Glc pyrophosphorylase (UGP), **7.** Sucrose-phosphate-synthase, **8.** Sucrose phosphate phosphatase, **9.** ADP-Glc pyrophosphorylase (AGP), **10.** GBSS: granule bound starch synthase; SS: starch synthase; BE: branching enzyme; DBE: debranching enzyme, **11.** Plastidial UGP, **12.** Plastidial starch phosphorylase (SP), **13.** Sucrose synthase (SuSy).

4.2. Starch Biosynthesis in Potato Tubers

Several non-common enzymes, including isoamylase (ISA), starch phosphorylase (PHO) and glucan water dikinase (GWD) have correspondingly been testified to

participate in starch biosynthesis of potato tuber [36]. In tubers of potato, starch aggregates during development and is stored over a long period of time. It preserves the energy need of the dormant tuber and energizes the development of new shoots after dormancy is broken [38]. In tubers, ATP needed for starch biosynthesis has to be imported into the plastids. The glucosyl donor for starch synthesis in sink tubers is resulting from sucrose which is transported through the phloem from the photosynthetically active leaf tissues to the growing tuber. In potato tuber, sucrose getting in the cytosol has to be transformed into glucose 6-phosphate (G6P) which is afterward transported into the amyloplast where it undergoes additional metabolism to ADP-Glc and starch (**Figure 3**) [38] [42].

4.3. Starch Biosynthesis in Cereals

The yield of different crops depends on several factors including environmental conditions and nutritional inputs, and the genetic ability for plant growth and development. The plant development and growth is controlled by source-sink interactions where sugars and amino acids produced by the photochemical and dark reactions of photosynthesis and nitrogen metabolism in origin leaves are conveyed and digested by heterotrophic sink organs [44] [45] [46]. Throughout the vegetative period, the majority of the photoassimilates (e.g. sucrose and amino acids) are used for plant growth and development. Conversely, through the reproductive phase, plants transform the bulk of the photosynthate into storage reserves as proteins, carbohydrates and lipids. Consequently, the ability for biosynthesis of starch, proteins and lipids in seeds of staple monetary crops, including rice, maize and wheat, is a significant consideration for improving crop yield. In cereals, the major storage reserve is starch, which makes up nearly 78% of the dry weight of the grain. The main regulatory step that manages the fluctuation of carbon into starch is catalyzed by ADP-glucose pyrophosphorylase (AGPase) (**Figure 4**) [46].

In the majority of tissues where starch is biosynthesized, AGPase is confined in the chloroplast or amyloplast, the site of starch biosynthesis and storage. The starch biosynthesis in amyloplasts of the cereal endosperm presents an exception where two forms of the enzyme are existent: a major cytoplasmic form and a minor plastidal form [47]. Starch synthesis in the cereal endosperm involves the synchronized activities of numerous starch synthase enzymes, comprising adenosine 5' diphosphate-glucose (ADP-Glc) pyrophosphorylase (AGPase), granule-bound starch synthase (GBSS), soluble starch synthase (SS), starch branching enzyme (BE), starch debranching enzyme. Rice has a total of 10 starch synthase isoforms, with two GBSS isoforms (GBSSI and GBSSII), one SSI isoform, three SSII isoforms (SSIIa/SSII-3, SSIIb/SSII-2, and SSIIc/SSII-1), two SSIII isoforms (SSIIIa/SSIII-2 and SSIIIb/SSIII-1), and two SSIV isoforms (SSIVa/SSIV-1 and SSIVb/SSIV-2) [48] [49]. In addition, some unusual non-enzymatic proteins, for instance protein targeting to starch (PTST), have also been found to contribute in starch biosynthesis in the cereal endosperm [50].

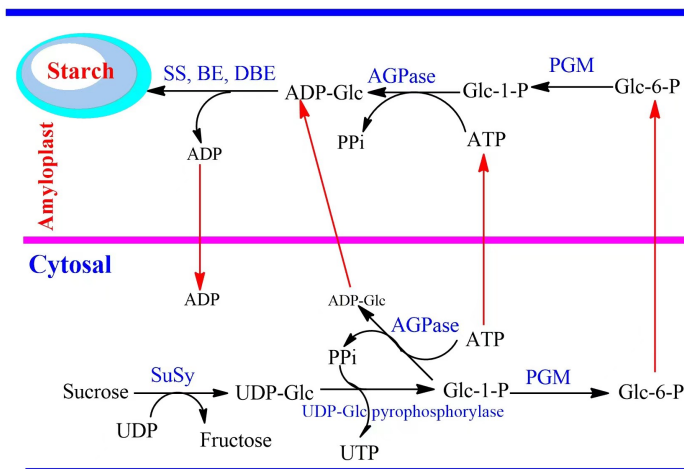


Figure 3. Starch biosynthesis in heterotrophic tissues of potato tubers. Adapted from [40] [41] [43]. **Abbreviations:** SuSy: Sucrose Synthase; UTP: Uridine Triphosphate; PGM: Phosphoglucomutase; AGPase: ADP-Glc pyrophosphorylase.

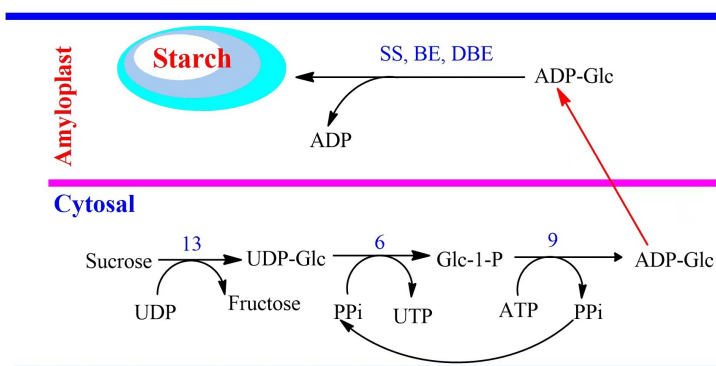


Figure 4. Starch biosynthesis in heterotrophic tissues of cereals. Adapted from [41]. Abbreviations and enzyme numbers are as those in **Figure 2**.

By the mechanism of the plastidial phosphoglucomutase (PGI), starch is reflected as the end product of a metabolic pathway that is interconnected to the Calvin-Benson cycle [40]. This enzyme catalyzes the transformation of Fru-6-P from the Calvin-Benson cycle into Glc-6-P, which is then transformed into Glc-1-P by the enzyme Phosphoglucomutase (PGM), in the biosynthesis of starch, the reaction catalyzed by AGPase is well-thought-out as the first and the main step, this step involves the transformation of Glc-1-P and ATP into inorganic pyrophosphate (PPi) and ADP-Glc necessary for starch biosynthesis [37] [40] [41]. Note that these three reactions are reversible except that the hydrolytic splitting of PPi by alkaline pyrophosphatase makes the conversion of Glc-1-P to ADP-Glc irreversible [40]. In heterotrophic tissues, the sucrose-starch conversion process has different pathways in dicotyledonous and monocotyledonous plants [41]. In the cereal endosperm, the enzyme AGPase is mainly located in the cytosol and ADP-Glc is made in the cytosol and carried immediately into the amyloplasts. On the other hand, in the storage tissues of other starch-rich crops, AGPase

seems to be placed in amyloplasts and Glc-6-P is trafficked to support ADP-glucose biosynthesis within the amyloplasts [41] [51]. In the formation of ADP-Glc, in autotrophic tissues ATP used is obtained from the photophosphorylation in the thylakoid membrane while in heterotrophic tissues it is obtained as a result of mitochondrial respiration, the formed ADP-Glc acts as the glucosyl donor for the reaction catalyzed by starch biosynthases [41] The final step of starch biosynthesis is the conversion of ADP-Glc into Starch, this step requires a number of enzymes in which we can say: Starch synthases, starch branching enzymes (BE), starch debranching enzymes (DBE), and starch phosphorylase (SP) [51]. All these mentioned enzymes participate in the formation of starch granules, SSs catalyzes the addition of glucose moieties from ADP-Glc to the acceptor (normally malto-oligosaccharides), the newly formed glucosidic linkage results in the biosynthesis of the insoluble glucan polymers (amylose and amylopectin) [37] [51]. It has been found that in plants five forms of starch synthases exist, granule bound starch synthase (GBSS), SS1, SS2, SS3, and SS4. GBSS is involved in the synthesis of amylose, the SS1, SS2 and SS3 are involved in amylopectin synthesis, SS4 controls the starch granules initiation [37] [41]. The cleavage of α -(1,4) linkages by SBE introduces the α -(1,6) linkages in the chains. It is from this fact that SBE is said to be responsible for branch points in amylopectin. The other identified enzymes that are required in starch biosynthesis are starch debranching enzyme (DBE) and starch phosphorylase (SP). In plants, two types of DBE are known which are isoamylase and pullulanase, DBE is capable to cleave the α -(1,6) linkages. However, in starch synthesis it plays a role in cleaning by eliminating soluble glucans that are not attached to the granule from the stroma. The activity of DBEs removes branches that appear at incorrect location which might interrupt the crystallization of starch granule. SP catalyzes the reversible transfer of glucosyl units from Glc-1-P to the non-reducing end of α -1,4-linked glucan chains as DBE, SP plays a role in clearing the soluble glucans not connected to starch granules [37] [41] [52].

4.4. Starch Degradation

It is evident that throughout the day, starch and sucrose are biosynthesized as the products of photosynthetic carbon assimilation, while in the night, starch is degraded into precursors for sucrose synthesis. From the fact that starch degradation provides carbon skeleton and energy required for plant growth, plants with a reduced capacity of starch degradation are found to have reduced growth rates [53].

Starch degradation is done in two stages: initiation of degradation, and digestion of amylopectin and amylose into maltose, glucose and maltotriose, with the inability of both β -amylase and isoamylase (a debranching enzyme) to directly attack the ordered, semi-crystalline surface of the granule, the initiation of starch breakdown is required, in this process, the starch is phosphorylated as a result of dikinase enzymes (GWD/PWD) [37] [53]. β -amylase and isoamylase hydrolyses the α -1,4- and α -1,6-glycosidic bonds respectively. Maltose is obtained as the

principal product of their combined activity and is transported from the chloroplast to the cytosol via MEX1 transporter. Glucose is the second product of starch hydrolysis and is as well transported to the cytosol through a glucose transporter [37] [53]. Reaching in the cytoplasm, the activity of hexokinase and transglucosidase (DPE2) catalyzes the transformation of glucose and maltose into hexose phosphate (Glc-1-P) (Figure 5). The transformation of maltose to hexose phosphates in the cytosol is a part of the mechanisms governing the degree of starch degradation and depends on the plant's appeal for carbohydrates [37] [53].

The general steps for the degradation of starch into precursors of sucrose synthesis are illustrated in the below figure.

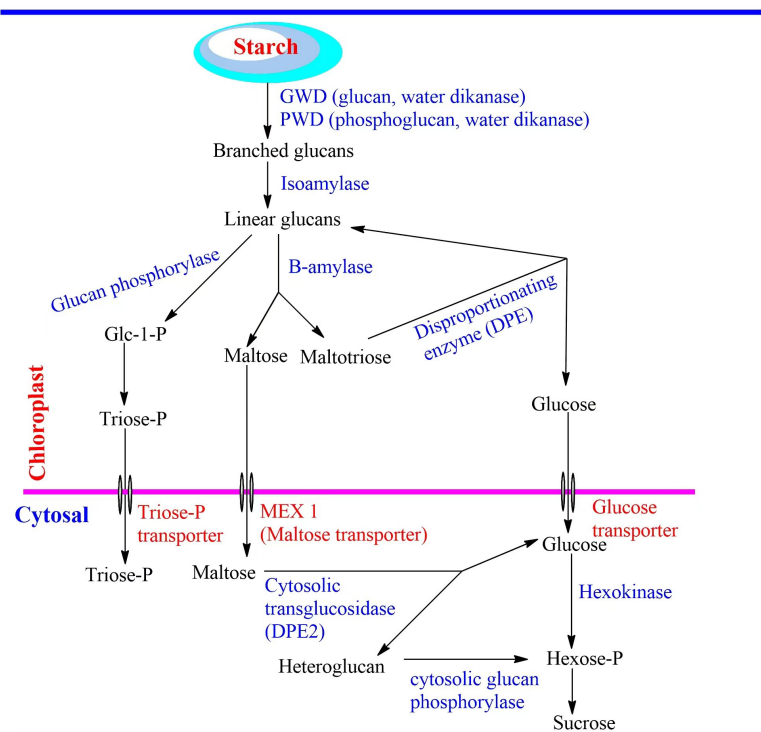


Figure 5. The pathways of starch degradation in leaves. Adapted from [37] [53].

5. Starch in Food Industry

Starch is present in many staple foods and is the utmost common carbohydrate in human diet. The main sources of starch are cereals, including wheat, corn, and rice, and root vegetables like sweet potatoes, cassava, and irish potatoes [54]. Polysaccharides that are manufactured commercially from sea-weeds, micro-organisms, plants, and animals have been used in cosmetic, paper, food, oil, pharmaceutical, textile, medical, and other industries as gelatinous boosting, coating, emulsifying, water-holding, encapsulating, oil-drilling, protective, gelling and other agents. Definitely, attention has been directed to polysaccharide gels for several decades [21].

In food industry, starch is used to adjust the texture and appearance of foods.

Starch changes the adhesiveness, thickening, glazing, emulsion stability, binding, clouding, foam stability, moisture retention, dusting, expansion, crisping, and gelling [55]. As starch is easy to chemically process and inexpensive, several starch-based products have been developed. Modified starch-based products are used in various processed foods, for instance, starch sugars, like glucose or isomerized sugars, glucose syrup, maltodextrins, and modified starch which are the utmostbroadly manufactured starch-based products and are mainly used as sweeteners [54].

As illustrated in **Figure 1**, glucose is the main component of starch. In industry, the sugar in starch is liquefied by heat-resistant α -amylase and broken down by glucoamylase or a mixture of pullulanase (a debranching enzyme) and glucoamylase. The resultant sugarsolution is afterwards bleached with activated carbon, desalted with ion exchange resin, purified, and concentrated to produce liquid glucose (with almost 96% purity). This liquid glucose is then transformed to anhydrous glucose through crystallization by means of the decoction method, crystallization, bees waxing, and drying in crystal cans [54] [56].

As glucose is mostly used as isomerized sugar, that is produced through reaction of glucose produced via a succession of processes like starch dissolution, saccharification, and purification with the immobilizing enzyme (glucose isomerase), which as a result guides to the production of a glucose syrup with 42% fructose content. Furthermore, the purity of fructose is improved by the mean of chromatography employing a strong acidic ion exchange resin to make high fructose corn syrup with 55% fructose content and high fructose syrup with 95% fructose content [54] [56].

In industry, erythritol is produced from starch, it is a zero-calorie sugar alcohol made from glucose by the fermentation process of *Trichosporonoides megachiliensis*. It is endothermic (tastes cold) in the mouth and around 70% - 80% sweeter than sugar and less probable to cause tooth decayn [54]. Even though erythritol does not have a reducing end, it has the most important energy value. Nearby 90% of consumed erythritol is eliminated in the urine and nearby 10% arrives into the colon. Fermentation of the whole quantity in the colon leads to the formation of 0.2 kcal/g energy, which makes 10% of the 2 kcal/g total energy formed by fermentation with intestinal bacteria. Erythritol is considered as a zero-kilocalorie sweetener in several countries' nutrition labeling systems [54]. In food industry, starch is mostly employed to thicken, stabilize and enhance the mouth feel of canned foods such as soups, puddings, gravies, pie-fillings, and sauces. In puddings, starch is employed to enhance viscosity and smoothness; once starch is supplemented into surimi seafood; it alters the texture, ameliorate freeze-thaw stability, and reduces the product cost [57]. Starch has been found to be used in the below products for improvement of their properties [57].

Bread manufacturing to ameliorate bread crumb attributes and baking performance. Gelling and thickening agent in pie and salad dressing for development of clear or opaque based on anticipated product, such as cantonese noodles, fish paste products to improve desirable color and texture. Starch is

used in frozen food and canned products for better consistency, stability and texture of product. When starch is supplemented, product get a better freeze thaw stability, high temperature cooked food as stabilizing agent, the texture of the product doesn't change on heating. In Jellies and fruit for improved paste clarity, superior stability of the starch structure, enhancement of inter and intramolecular bonding, and in dairy products as texturizers and stabilizers. The below **Table 2** covers the uses and functionality of some cereal starches [55] [56] [58].

Table 2. Cereal starches, their functions and application in food industry.

Starch	Functions	Food applications	References
Maize	Thickener, binder, filling, stabilizer, gelling, and food additive.	Sweetener products, thick sauce, smooth food texture, glutinousness, formed meat, confectionary fillings, candies and batters, jamfilled waffles, emulsifiers, and encapsulators of antioxidant compounds, Desserts, cream.	[59]
Wheat	Gas by fermentation and rigid network binder, thickener, adhesive agent.	Bakery products, batters, ice cream, soups, gravies, dressings, and yogurts.	[60]
Rice	Binder, fat mimetic, freeze thaw stability, whiteness, dusting, crispness agent, and thickener.	Confectionery, pastries, puddings, custards, smooth gravies, sauces, soups, snacks, ice cream, baby foods, and freeze thawed cake.	[61]
Barley	Gelling and thickness agent	Desserts	[59]
Oat	Fat replacer and emulsifier.	Frozen desserts, ice creams, instant breakfast drinks, dressings, gravies, and sauces.	[62]

6. Future Perceptive of Starch

The starch is a plentiful, low-cost, comestible, and biodegradable natural polymer, due to its enhanced intrinsic properties gained after breaking its granular structure starch exhibits the ability to form delivery vehicle and great potential in the development of delivery systems for nutraceuticals [63]. Moreover, the world and humankind are threatened with the climate change which results to the use of plastics derived from non-degradable petrochemicals, these in turn once in soil impend food security, health, and the environment. There is a need in modern agriculture for production of biodegradable materials used in protective cultivation such as mulch films, nets, packaging, piping, and silage, the best alternative to petrochemical derived materials is the use of starch as one of the utmost profuse biodegradable biopolymers from renewable sources which further more holds tunable thermoplastic properties suitable for diverse applications in agriculture [64].

7. Conclusions

The present review presents the main pathways of starch metabolism and its

uses especially in food industry. The starch metabolism in plants has been found to be bound on the activities of many enzymes. In the biosynthesis of starch in both leaves and heterotrophic tissues of plant, the formation of ADP-Glc has been found to be the key in starch synthesis. The conversion of ADP-Glc into starch in the final step of starch biosynthesis is linked with the activity of different enzymes, namely, Starch synthase that catalyzes the addition of glucose moieties from ADP-Glc to the acceptor, Branching enzymes that introduce the α -(1,6) linkages in the chains and hence responsible for amylopectin branch points, Debranching enzymes which on the other hand cleave the α -(1,6) linkages to remove branches that appear at the incorrect position which might disrupt the crystallization of starch granule and also remove soluble glucans that are not attached to the granule from the stroma.

Starch has been found to play vital role in many food applications such as in bread making, gelling and thickening agent in pie and salad dressing, cantonese noodles, frozen food products, canned products, high temperature cooked food, jellies and fruit, and in dairy products. All starch functions depend on its molecular weight, size, and components' structure which are the driving forces of starch functionality.

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Ethics Approval

The article does not contain any studies with human participants performed by any of the authors.

Data Availability

Data sharing not applicable to this article as no datasets were generated or analysed during the current study.

Conflicts of Interest

The authors declare that they have no conflict of interest.

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