

Recent Advances in Physical, Enzymatic, and Genetic Modifications of Starches

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ABSTRACT

The current review presents the potential physical modification devised into thermal which includes pre-gelatinization and hydrothermal processing (i.e., annealing (ANN) and heat-moisture treatment (HMT)) and nonthermal modifications (i.e., high-pressure processing (HPP), micronization, ultrasonication, and pulsed electric field (PEF)). Rather than physical modification; enzymatic modification by single enzyme treatment, debranching enzymes, and multienzyme synergetic treatment was discussed. Genetic modification was also discussed as a potential starch modification for better utilization of starch.

Keywords: Dual modification, Enzymatic modification, Genetic modification, Physical modification, Physicochemical properties

INTRODUCTION

The availability of a dependable source of starch produced from agriculture is regarded to have been a significant influence on the advancement of humanity (Copeland et al., 2009). Starch plays an essential role in developing food products (Abegunde et al., 2013). Starch is usually employed as a food additive, such as a thickening, stabilizer, or texture enhancer to improve some of the products' quality characteristics including

moisture retention, the potential to be employed as a delivery vehicle for chemicals of interest to the food and pharmaceutical sectors such as antioxidants, colorants, flavors, and pharmaceutically active proteins, among other things (Abegunde et al., 2013).

However, its low resistance to shear, high retrogradation, and poor freeze-thaw stability, limit the use of starch in industrial applications. Fortunately, these natural shortcomings can be overcome by different methods of modification, rather than chemical modification also we can use, physical, enzymatic, and genetic techniques (Tang et al., 2020).

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The physical treatment of starch granules generally destroys or causes changes in the packing arrangements of the polysaccharide molecules contained within the granules; however, such structural changes can alter the properties and functions of the starch, including the characteristics of its hot pastes and gels and their digestibility (Punia, 2020).

Physical treatments can produce starches properties somehow like those obtained by chemical modifications (especially like those of lightly cross-linked starches, such as increased tolerance to low pH, high temperatures, and high shear), but the changes are not as dramatic and as thermostable as those produced by chemical modification (BeMiller, 2018).

Physical modification

Physical treatments can produce starches with properties that are similar to those obtained through chemical modification, particularly those of lightly cross-linked starches, such as increased tolerance to low pH and high temperatures, as well as increased shear resistance. The changes, however, are not as dramatic or as thermostable as those obtained through chemical modification (Punia, 2020). For physical modifications, starch is usually subjected to extrusion cooking (processing and drying), radiation, sonication, and/or pressure treatments. These methods of modification have become widely accepted. Different modification methods in different sectors can acquire the required functional features such as heat tolerance, texture, adhesion, and solubility (Obadi & Xu, 2021).

Physical modification of starches refers to changes in starch properties caused solely by physical treatments, with no chemical modification of the starch polysaccharide molecules (BeMiller, 2018). These modifications are taken into consideration because they are simple, cost-effective, environmentally friendly, and safe techniques and because they do not involve the use of chemicals or biological agents that are dangerous to human consumption. A variety of temperature and moisture combinations, shear pressure, irradiation, and mechanical attrition are applied to native starches to

modify the physical size of the starch granules (Ashogbon et al., 2014)

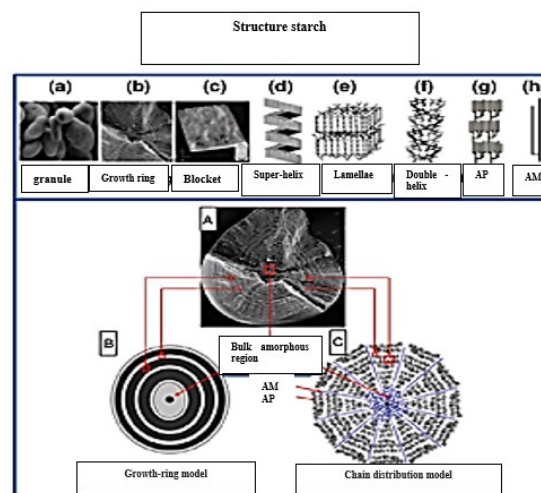


Fig. 1. Starch structure and functional

properties. (a) Native pea starch granules as viewed by scanning electron microscopy (SEM); (b) growth rings as observed by SEM; (c) blocklet structures as revealed by atomic force microscope (AFM); (d–h) representations of the super helix, lamellar, and double-helical structures and amylopectin and amylose molecules, respectively. Source: (Wang et al., 2020).

Physical starch modification can improve water solubility and reduce particle size. The methods involve treating native starch granules in different combinations of temperature and humidity, pressure, shear, and irradiation (Alcázar-alay et al., 2015).

Hydrothermal modifications

The two most widely accepted hydrothermal treatments are (ANN) and high moisture treatment (HMT) to modify starches without losing the integrity of the granules. The distinctive feature of these methods is that they take place below the gelatinization temperature of granules, which eventually helps preserve the granular structure. In addition, during these hydrothermal modifications, the starch granules must remain in the mobile rubber state (Zia ud et al., 2017).

The above-mentioned modification methods require specified temperature and humidity levels. For instance, during the HMT modifications, low humidity is usually employed while in ANN modifications, low or medium humidity levels are usually employed (Zia ud et al., 2017). Both physical modifications occur at temperatures above the glass transition temperature (T_g) and below starch granule gelatinization. Hydrothermal modification can take place only when the starch polymers in the amorphous phase are in the semi-crystalline region's mobile rubbery state. When low moisture levels (less than 35% w/w) are applied, the term HMT is applied. In contrast, ANN refers to the treatment of starch in excess water (less than 65% w/w) or intermediate water (40–55% w/w) (Zia ud et al., 2017).

Annealing (ANN)

Annealing is the hydrothermal treatment of starch in the presence of excess water for an extended time (Siroha et al., 2020). The ANN of starch granules can be conducted in an excess amount of water (i.e., 76 percent w/w) or at an intermediate water content (i.e., 40 percent w/w) and maintained at a temperature above the T_g but below the onset (T_o) temperature of gelatinization for a specified time (Ashogbon et al., 2014). The annealing process is an effective method of reorganizing molecular chains. This method has the advantage of increasing the material crystallinity and weakening structural relaxation (Lv et al., 2015).

Annealing reduces the solubility of amylose during the swelling process below 100°C, therefore limiting amylose from the leaching of granules (Hoover & Vasanthan, 1994). The enhanced amylopectin interaction finally resulted in a homogeneous crystal structure and an annealing stability starch, protecting the integrity of granules by increasing the gelatinization temperature and reducing the thermal transition temperature range. In addition, the enhanced interaction of clusters of amylopectin leads to lower paste viscosity by inhibiting normal starch granule swelling (Wang et al., 2014).

High moisture treatment (HMT)

High moisture treatment is usually carried out under restricted moisture content (i.e., 10–30%) and higher

temperatures (i.e., 90–120°C) in comparison to annealing the method that involves a significant excess of water and relatively low temperatures that fall below the gelatinization point (Siroha et al., 2020). The High moisture treatment technique causes modifications to both crystalline and amorphous regions to a different degree. Moisture and heating time had a significant effect on the characteristics of maize starch (Sui et al., 2015). High moisture treatment -treated starches find industrial uses where they are utilized in the manufacture of infant foods.

High moisture treatment treated potato starches to increase their baking and freeze-thaw stability in the food industry (Zia ud et al., 2017). This was attributed to the enhancement of amylopectin interaction that results in a homogeneous crystal structure and annealing stability of starch that in turn protect the integrity of granules by increasing the gelatinization temperature and reducing the thermal transition temperature range.

A study showed that High moisture treatment repetition has different effects on sweet potato starch granule morphology, with more repetitions resulting in more considerable damage to starch granules (Vasanthan et al., 2001). This morphological change can be due to partial gelatinization of the granules of starch. The effect of High moisture treatment on the characteristics of gelatinization is inconsistent. For example, the enthalpy changes (i.e., after High moisture treatment) of starch growth decrease or even remain unchanged. The decrease of ΔH is explained by the dissociation of some double helices or the breakdown of some unstable crystallites in starch granules (Hormdok & Noomhorm, 2007). In general, the temperature of the thermal transition (activated temperature (T_o), peak temperature (T_p), and final temperature (T_c) of starch after HMT increases (Wang et al., 2020).

Yoenyongbuddhagal and Noomhorm (2002) reported that rice flour treated with heat moisture might increase rice noodles' cooking quality and texture. Applied high moisture treatment and annealing to noodle rice starches and showed the feasibility of using these starches to make

noodles of acceptable quality in composites with poor quality rice flour (Ashogbon et al., 2014).

Non-thermal physical modification of starches

Many types of food are preserved by exposing it to extremely high temperatures for a short duration. These procedures destroyed vital nutrients, vitamins, and tastes. To overcome these shortcomings, pathogenic and spoilage-causing organisms are killed using non-thermal technology. Compared to standard thermal methods, non-thermal treatments can be employed to maintain the color, texture, flavor, nutrients, and other food components. Non-thermal treatments of various types have varying effects on the physicochemical properties of starches (Zia ud et al., 2017).

Non-thermal starch therapy may include physical field techniques such as ultrahigh-pressure (UHP) (Stute et al., 1996), microwave (Eliasson, 2004), ultrasound (Zia ud et al., 2017), irradiation (Eliasson, 2004), and pulse electric (PEF) therapy (Góngora-Nieto et al., 2002). Due to high equipment costs, the use of physically modified starches is limited, except for the study that ultrasound-treated starch is used as a sizing agent in paper coating (Li et al., 2019) Ultra-high pressure therapy. Initially, UHP technology was used to sterilize and kill enzymes.

In the food industry, the treatment of food materials using pressure between 100 and 1000 MPa at room and low temperatures includes a certain degree of damage to the weak, non-covalent link to modify and sterilize the food material (Hendriekx & Knorr, 2012). The changes in starch structure and functionalities can be controlled by increasing or decreasing pressure (Eliasson, 2004). The degree of structural deterioration gradually increases with increasing pressure. When the starch is wholly gelatinized, the granules stay relatively intact (Stute et al., 1996).

Physical field

The physical field consists mainly of the electromagnetic field, velocity field, heat flow field, force field, and temperature field. It is usually utilized in research in the extraction of ingredients, sterilization, cell fragmentation, emulsion diffusion, organic synthesis, and the food industry (Góngora-Nieto et al., 2002). During the

development of technology, several physical field techniques, such as ultrasonic, microwave energy, and radiation, have been utilized to modify starch in recent years. These physical treatments are used mainly to change the structure of the granules, the molecular weight distribution, and the starch granule function to increase processing performance and expand their field of application (Zia ud et al., 2017).

Microwave Treatment

Microwave heating is faster than traditional heating methods, so time and energy can be saved. Microwaves are electromagnetic waves ranging from 300 to 300,000 MHz. Microwaves interact and charge food particles to generate heat with polar molecules. The starch molecules rotate, collide, and rub under microwave processing, causing changes in the molecular structure in turn, in the functional qualities of starch (Fan et al., 2012). Frequency, water content, and treatment time are the main factors affecting starch modification in microwave treatment. When treated at a low frequency, the morphology of starch granules slightly changes. The starch granules are swollen or perhaps destroyed when the frequency is high enough (Wang et al., 2020).

At low moisture, microwave treatment is similar to HMT in several ways. Starch crystallites get more organized in this case than native starch. Following microwave treatment, the B-type starch becomes A-type, while the starch of type A is unchanged (Wang et al., 2020).

Microwave treatment damages the starch structure, with higher frequency and moisture content resulting in more significant damage. Starch treatment exhibits reduced melting enthalpy, swelling power and solubility, and elevated temperature of gelatination (Bemiller & Huber, 2015). While the microwave treatment can effectively modify the functional properties of starch, there are certain disadvantages, such as the difficulty of controlling the sample temperature and the heterogeneous heating effect (Wang et al., 2020).

Ultrasonic treatment

The term ultrasound refers to sound waves of 16-18 kHz, the human hearing threshold. The power output and

frequency of the equipment used can vary significantly. Ultrasound treatment can be used as green technology to modify the structure of the chains and granules and function of starches from various botanical sources, mainly by mechanical breakage and radical redox reaction (Bemiller & Huber, 2015).

Ultrasonic treatment hardly affects the size and shape of starch granules but can lead to cracks and pores forming on the granule surface that enhance the efficacy of following chemical or enzymatic reactions. Increased ultrasonic power or more prolonged treatment duration will exacerbate surface damage. In most experiments, ultrasonic treatment reduces viscosity and enhances solubility and starch swelling (Wang *et al.*, 2020).

The rays used in irradiation treatments include X-ray, gamma (γ)-ray, and high-energy electron-beam radiation, of which the ^{60}Co - γ -ray is the most commonly used. In two aspects, radiation effects on starch occur mainly: (1) directly on starch molecules by radiation, and (2) starch molecules are triggered through ionization to form free radicals that influence starch molecules indirectly. The structure of the starch granule is thereby disrupted and the physical and chemical characteristics are altered (Eliasson, 2004). Starch might be transformed into soluble starch after irradiation by gamma rays as early as 1961 (Samec, 1961).

Pulsed electric field treatment

Pulsed electric field technology is used to kill and inactivate pathogenic microorganisms and enzymes. This resulted in minimum loss of original taste, color, nutrients, texture, and heat-sensitive functional components of food (Knorr & Angersbach, 1998). The pulsed electric field technique uses high-intensity electric pulses (over 10 kV/cm) with a short time (less than 40 s) to treat pumpable liquid material in a processing chamber. Apart from non-thermal pasteurization, pulsed electric field technology has been widely utilized to change giant molecules and enhance chemical processes. Pulsed electric field treatment has several advantages: continuous processing, homogeneous treatment intensity, low processing temperature, and short treatment duration. Pulsed electric field treatment can result in an intra-

granular molecular rearrangement of potato starch granules, resulting in changes to the treated starch's various physicochemical properties, resulting in the emergence of some novel properties and functions (Han *et al.*, 2009).

The action of the pulsed electric field in slurries with minor quantities of KCl on maize, potato, and tapioca starches leads to the loss of granule shape and the disruption of starch crystallites (Wang *et al.*, 2020). Gelatinization and ΔH have decreased with increased field strength for maize and tapioca starches. Maize starch peak, trough, final and decayed viscosities declined with increasing field strength. The peak and breakdown viscosities of potato and tapioca starches increased, but the trough and final viscosity decreased with increased strength (Han *et al.*, 2012).

Consequently, we can summarize most of the physical modifications in the following:

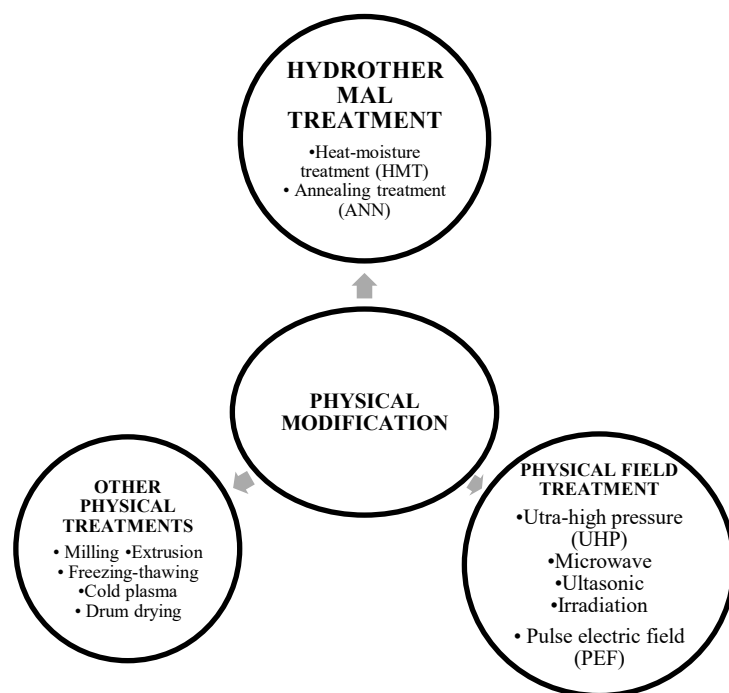


Fig. 2. Common physical modification of starch (Wang *et al.*, 2020).

Table1. Summary comment on physical modification used in the food industry

Types of modification	Properties	Applications	References
Pregelatinization	<ul style="list-style-type: none"> Improves cold water dispersibility, water absorption, water solubility 	<ul style="list-style-type: none"> Applied as a thickener in many food products such as baby food, instant soups, and instant desserts. Pie filling, ready-to-eat breakfast cereal, and used to make noodles from other than traditional ingredients like rice, jackfruit, etc. 	(Nakorna <i>et al.</i> , 2009)
Annealing	<ul style="list-style-type: none"> Suppress granule swelling, retard gelatinization, increase starch paste clarity and alter gel structure and increase gel hardness. 		(Radha, 2014)
Heat moisture treatment	<ul style="list-style-type: none"> Improve its baking qualities and freeze-thaw stability in the food industry. 	<ul style="list-style-type: none"> Preparation of infant foods. 	(Pranoto <i>et al.</i> , 2014)
Non-thermal physical modification (Deep freezing, Multiple deep freezing and thawing, Osmotic pressure treatment, Pulse electric fields treatment, freezing, ultrasonication)	<ul style="list-style-type: none"> Preserve color, texture, taste, nutrients, and other components of food. 	<ul style="list-style-type: none"> Pressurized starch could be used as a fat substitute. 	(Haq Nawaz & Dure, 2020)

Enzymatic modification of starches

Enzymes were also widely explored for the environment and consumers in healthier and safer starch foods than those generated by chemical methods. In addition, enzyme treatments have been used for starch hydrolysis (Obadi & Xu, 2021). Enzymes can be used by transfer reactions to modify starch structures and obtain desirable behaviors and characteristics in starch products.

Starch-converting/modifying enzymes are currently utilized to fabricate maltodextrin, glucose, and fructose syrup (Miguel *et al.*, 2013). For example, one of the main objectives of enzymatic starch modification is to reduce starch molecules to different oligosaccharides and increase the products' functional characteristics and nutritional value for broader industrial applications (Wang & Copeland, 2015).

Carbohydrate enzymes, therefore, play an essential role in the food and noodle industry in the manufacturing of food products. Their functions involve producing food products, improving product quality, and increasing food processing performance (Obadi & Xu, 2021). Several enzymes, including α -amylase, β amylase, glucoamylase, debranching enzymes, cyclodextrin glycosyltransferase, glucose isomerase and so on, are used in enzymatic alteration to starch (Wang *et al.*, 2020).

Enzymatic changes mainly involve hydrolyzing enzymes to alter starch properties. The internal structure of starch granules may be explained by starch enzyme hydrolysis. Enzymatic technology has been a valuable tool for food processing, especially in the bakery sector for a long time. High-quality wheat flour with a white appearance and proper dough strength should be produced to produce noodles of the most excellent quality. For these goals, various oxidants, such as potassium bromate and benzoyl peroxide have been added to raw wheat flour to enhance wheat gluten. Such chemical oxidants are harmful to health and have finally been prohibited in numerous nations (Li *et al.*, 2012). Studies focused on the replacement of these prohibited substances. Enzymes are biocatalysts obtainable from plants, animals, or microorganisms. They are widely used to improve the various aspects of food processing and are generally recognized as safe (GRAS) (Obadi & Xu, 2021).

Single enzymatic treatment

Endo and exoamylases.

The endoamylases can split α -(1, 4) glycosidic bonds inside amylose, amylopectin, and related polysaccharides but not the amylopectin glycosidic α -(1,6) linkages. Hydrolysis products have different chain lengths of oligosaccharides and the α -configuration on the C-1 in reducing the glucose unit produced. The endoamylases act in the interior areas of the substrates and so rapidly lower the pasting viscosity and iodine complexation of the hydrolyzed starches. α -Amylase (1,4- α -D-glucanohydrolase), a well-known endoamylase, occurs randomly at any (1,4) link within the starch chain to

rapidly lower the molecular sizes of starch and starch solution while pasting. Modifications in the location of the starch chain during hydrolysis lead to a change in its digesting rate (Dura *et al.*, 2014).

α -amylase is found in plants, mammalian tissues, and microorganisms, mainly bacteria and fungi, which are utilized in the industry (Dura *et al.*, 2014). Starch hydrolysis is based on oligosaccharides with different chain lengths, alpha-configuration, and alpha-limit dextrans (Rana *et al.*, 2013). Exoamylase is either exclusively cleaved α -(1,4) glycosidic links like β -amylase or is cleaved both α -(1,4) and α -(1,6) from the nonreducing ends of starch chains like amyloglucosidase or glucoamylase and α -glucosidase (Rana *et al.*, 2013).

Exoamylases act on the exterior amylose or amylopectin glucose residues and produce glucose (glucoamylase and α -glucosidase) or dextrin- β (β -amylase). The recognized exoamylases β -Amylase (1,4- α -D-glucan maltohydrolases) and glucoamylase/amyloglucosidase (1,4- α -D-gluconic glucosidase) also convert the freed maltoses' anomeric structure from α to β (Rana *et al.*, 2013). The former can hydrolyze only the α -(1,4) glycosidic bonds; the latter can also hydrolyze not just glycosidic bonds but α -(1,6). The preference of glucoamylase and α glucosidase is different from their substrates: α -glucosidase prefers short maltooligosaccharides and releases α -configuration glucose, whereas glucoamylase notably hydroses the long-chain polysaccharides (Wang *et al.*, 2020).

A large variety of bacteria have also found glucoamylases. The surface of the starch granules has pores of α -amylase and amyloglucosidase with pore sizes, depending on the kind and degree of the enzyme used. Higher solubility but reduced swelling and viscosity relative to native starches are present in enzymatically modified starch. The enzyme hydrolysis of starch by endo- and exoamylases is widely used as a green and safe way of modifying starch in the food sector. For example, α -amylase and amyloglucosidase are utilized in various food applications to produce porous starch (Wang *et al.*, 2020). Treatment with α -Amylase increases the number of short chains of amylopectin and decreases molecular

weight with extended incubation time. Starch treatment with α -amylase and transglucosidase is also used to produce new, slowly digested starch structures (Miao *et al.*, 2014). The most significant use of glucoamylase is in high-glucose (96-98% glucose) or high-fructose (55% fructose) syrups (Wang *et al.*, 2020).

De-branching enzymes

De-branching enzymes catalyze the hydrolysis of α -(1, 6) glycosidic linkages in amylopectin, glycogen, and related macromolecular substances (e.g., limit dextrin), resulting in the formation of linear glucans and dextrin. De-branching enzymes are classified into two categories based on their mechanism of action: direct de-branching enzymes and indirect de-branching enzymes (Nakamura *et al.*, 1996). The former can hydrolyze unmodified amylopectin or α -(1,3) glycosidic bonds in glycogen, whereas the latter can only act on amylopectin or glycogen that has been modified by other enzymes (Nakamura *et al.*, 1996).

The de-branching enzymes can be split into isoamylase and pullulanase, depending on the specificity of the substrate (Wang *et al.*, 2020). Pullulanase and isoamylase vary dramatically in the ability to hydrolyze pullulan, a polysaccharide having a repeating unit of maltotriose connected to α -(1, 6). Pullulanase is produced by mesophilic microbes such as aerogenes from *Klebsiella*. The ideal temperature for pullulanase activity is around 60°C, which is particularly useful for the purification of starch in the industry to make glucose syrups. In conjunction with amyloglucosidase and α - or β -amylase, pullulanase is commonly utilized. Isoamylase was discovered in 1949 and developed by several bacteria like *K. aerogenes* and *Pseudomonas* sp. It can only hydrolyze amylopectin α -(1,6) linkages. This enzyme degrades amylopectin exclusively, creating linear glucans. Pullulanase is the main enzyme used in the saccharification of starch, with the leading industrial application of pullulanase in the production of high glucose syrups (30-50% glucose; 30-40% maltose) and high maltose (30-50% maltose; 6-10% glucose) (Wang *et al.*, 2020).

Multi-enzyme synergistic treatment

The research and development of starch modification technology eventually emerged through the synergistic action of two or more enzymes. Many research findings suggest that the effectiveness of hydrolysis in the synergistic action of two enzymes is often higher than that of one enzyme. Each enzyme has a particular action site and action mode when starch is treated with two or more enzymes. Starch can therefore be simply modified by controlling enzyme reaction conditions. The following two methods are frequently used: 1. Starch is treated sequentially with a single enzyme, and the temperature, pH, substrate concentration, and other reaction system parameters are modified individually according to the optimal conditions for each enzyme, allowing for precise control of the degree of enzyme reaction. As a result, the degree of reaction can be adjusted to match the intended modification effect. In the same reaction system, dual- or multi-enzymes are utilized to modify starch at a specific temperature, pH, substrate concentration, and action time (Wang *et al.*, 2020).

The appearance of a V-type X-ray pattern and a decrease in crystallinity in dual-enzyme modified starches is observed. Through the treatment with β -amylase / transglucosidase, the molecular weight of maize starch decreases, and short chains and α -1,6 linkages rise. This indicates that the α -1, 4 linkages of starch are cleaved, and nonreducing D-glucosyl residues of maltose are transferred to form the α -1,6 branch linkage. Dual enzymatically modified starch has higher resistant starch (RS) and slowly digested starch (SDS) than single-enzyme treated starch in native maize. Therefore, the principal application of these coupled enzymes is in the synthesis of RS and SDS (Wang *et al.*, 2020).

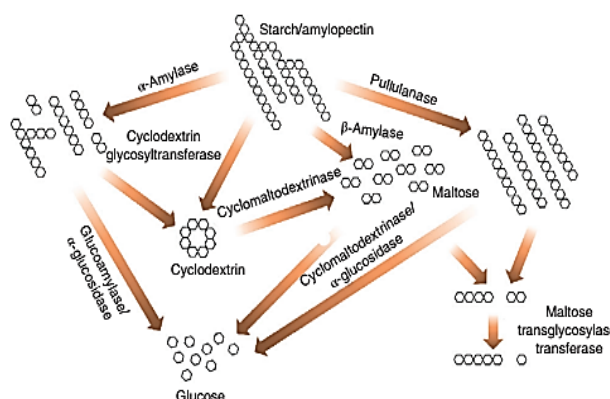


Fig 3. Representative enzymatic hydrolysis of starch and its derivatives(Wang et al., 2020).

Genetic modification

The advancement of genetic engineering technologies has made the genetic modification of starch in plants possible by targeting the enzymes of the starch biosynthetic pathway. This transgenic technology can create new starches that can reduce or remove the application of environmentally hazardous chemicals and enzyme modifications after harvest (Davis *et al.*, 2003). The activity of these enzymes affects the reactivity,

functionality, and application of these modified starches in food processing and food applications. Hence, enabling the market for "niche" products. Genetic modification by traditional plant breeding techniques or biotechnology can be achieved (Kaur *et al.*, 2012).

Wischmann *et al.* used *Escherichia coli* glg B expressing a glycogen branching enzyme from a patatin promoter onto potato lines (Kaur *et al.*, 2012). Starch was created with amylopectin molecules containing considerably more amylopectin branches and more significant amounts of short amylopectin chains with reduced phosphate content. This starch also gave rise to hard and adhesive gels. AGPase (ADP-glucose pyrophosphorylase) was used as a catalyst to increase the total cassava root biomass by 2.6 fold (Ihemere *et al.*, 2006). When a total length of cDNAs encoding a second starch branching enzyme (SBE A) is a form was isolated and an antisense SBE A RNA was generated on transgenic potato plants, SBE A was completely reduced was observed. This led to an increase in apparent amylose and greater phosphorus levels were also reported (Jobling *et al.*, 1999).

Table 2. Characteristics of genetic modification of starch

Modified	Starch	Enzyme	Properties	Reference
High-amylose starch	Maize-commercial (50, 70, 90% amylose), cereals, potato.	<ul style="list-style-type: none"> Mutation of SBE IIb, Inhibition of SBE I & SBE II for amylose 60% and greater, Inhibition of SBE II for still higher amylose content, SS IIa is missing 	<ul style="list-style-type: none"> High gelling strength Film forming ability Resistant starch Adhesive Starch does not swell when heated to 100°C 	(Kaur <i>et al.</i> , 2012)

Dual modification

In recent years, the combination of diverse modification methods has been considerably investigated to increase further the functional qualities and use of starches in different industries. Combined starch modification generally involves chemical/physical modification, physical/enzymatic modification, and enzyme-chemical modification. The most commonly used chemical double modifications, including acetylation/oxidation, cross-linking/oxidation, cross-linking/acetylation, and cross-linking/hydroxypropylation. These modified starches have the physicochemical, pasting, or rheological properties of the two types of substituent groups, so their use has increased.

In many applications, dual chemically changed starches are used as binding agents, thickeners, emulsifiers, and adsorbent substances in the non-food industry (Wang *et al.*, 2020). Starch's structural and functional properties are also significantly altered by dual physical and dual enzymatic changes. For example, Sonication following ANN or HMT may raise the peak viscosity of single ANN or HMT Pinho starches. The swelling power, solubility, pasting viscosity, and freeze-thaw stability of taro starch are improved using a microwave/autoclave and a microwave/hot air oven combination. Dual enzymatic modified yam starch has superior anti-constipation and hypo-lipidemic properties than native starch, indicating its potential applications in the pharmaceutical and food industries.

Chemical and physical alterations of starches are frequently used in combination to alter their properties, including HMT/cross-linking, HMT/acid hydrolysis, PEF-assisted acetylation, and acetylation/gamma irradiation. Pulsed electric treatment followed by acetylation improves the retrogradation property and freeze-thaw stability of modified starch by shortening the reaction time and increasing the DS. At the moment, chemical and enzymatic modification and physical and enzymatic modification are limited. Dual modification of modified normal and waxy rice starches with

hydrothermal and amylosucrase treatments significantly decreases the digestibility by increasing resistant starch fractions.

Having been added to the cakes, this dual-modified starch reduces the hardness, cohesion, and adhesion of baked cakes and improves their elasticity, volume, height, crust color, and appearance compared to native starch (Sahnoun *et al.*, 2016). With the repeated treatment of heat moisture and enzyme compound hydrolysis, the combination significantly increases the specific surface area and the total porous volume of wheat starch (Wang *et al.*, 2020). Added to cakes, this dually-modified starch reduces baked cakes' hardness, cohesion, adhesion, and masticatory, while increasing their elasticity, volume, height, the color of the crust, and appearance as compared to native starch (Sahnoun *et al.*, 2016).

To further improve the functional properties and use of starches in many kinds of applications, different kinds of starches have been introduced with chemical dual and other types of dual modification methods. Dual modification of starches involves the combined methods of chemical and physical modification or chemical and enzyme modification. The most commonly used method of dual chemicals modification is widely used to modify starches by combining two chemical modification methods, such as acetylation/oxidation, cross-link/acetylation, or hydroxypropylation (Zia ud *et al.*, 2017).

There are several applications in the food industry, such as binders, thickeners, and emulsifiers for chemical dual-modified starches. In contrast, these can be used as heavy metal absorbents in the non-food industry. The chemical and physical properties of the original plantain starch have been shown to improve success by exposing the indigenous starch to the process of dual chemical change (oxidation/acetylation) (Zamudio-Flores *et al.*, 2010). The swelling power is the most prominent factor in determining the outcome of the final product during the process of dual modification (hydroxypropylation and cross-linking) (Wattanachant *et al.*, 2002).

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آخر التطورات الحديثة في التعديلات الفيزيائية والإنزيمية والوراثية للنشاء .

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ملخص

تعرض الورقة الحالية التعديلات الفيزيائية المحتملة التي تم تطويرها والتي تنقسم الى المعالجة الحرارية والتي تشمل المعالجة المسبقة الجيلاتينية والمعالجة المائية الحرارية مثل (التلدين (ANN) ومعالجة الرطوبة الحرارية (HMT)) والتعديلات غير الحرارية (أي، المعالجة بالضغط العالي (HPP)، التتعيم، الموجات فوق الصوتية والتسريع بالمجال الكهربائي (PEF)). بالإضافة الى من التعديلات الفيزيائية؛ تمت مناقشة التعديل الأنزيمي عن طريق العلاج بالإنزيم الفردي، الإنزيم المشذب والمعالجة التآزيرية متعددة الإنزيمات. كما تمت مناقشة التعديل الجيني كتعديل محتمل للنشا من أجل استخدام أفضل للنشا.

الكلمات الدالة: التعديل المزدوج، التعديل الإنزيمي، التعديل الجيني، التعديل الفيزيائي، الخصائص الفيزيائية والكيميائية.