A review of the chemical modification and applications of starch

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Abstract. The modification of starch using esterification, etherification, oxidation, and Schiff base formation has garnered significant interest owing to its wide-ranging applications in different sectors. This overview delves into the various techniques utilized for modifying starch molecules and examines their utilization in adsorption, adhesive formulations, pharmaceuticals, nanoparticle synthesis, and film manufacturing. The article delves into the synthesis pathways associated with esterification, etherification, oxidation, and Schiff base formation, underscoring their influence on the physicochemical characteristics of starch. Furthermore, it thoroughly examines the application of modified starch in pollutant adsorption processes, as adhesive agents in industries, as excipients in pharmaceutical formulations, and as crucial elements in the creation of starch-based nanoparticles and films.

1 Introduction

Carbohydrates play a fundamental role in all living organisms since basic metabolism is based on the conversion of carbon and energy. This conversion is essential in both autotrophic and heterotrophic nutrition and remains focused on carbohydrates. So, it's hardly surprising that polysaccharides are the most widely distributed polymers in the biosphere [1].

Starch, a type of polysaccharide, is naturally found in agricultural produce such as corn and potatoes. It is referred to as native starch when it is directly extracted from these plants. However, when it undergoes biological, chemical, or physical alterations, it is then referred to as modified starch [2]. It primarily consists of two macromolecules: amylopectin and amylose [3]. Amylose is made up of glucose units that are organized in a straight line and linked by $\alpha$-(1,4) glycosidic bonds. On the other hand, amylopectin is composed of glucose units that form a branched structure, connected by $\alpha$-(1,6) glycosidic bonds [4-6]. The proportion of amylose within starch granules typically ranges from 20 to 30%, whereas amylopectin comprises approximately 70 to 80% of the starch composition [6-8]. Since starch is composed of amylose and amylopectin, then organized in semi-crystalline structures called granules [9], it is a major source of energy for humans [10]. Due to its functional attributes, biodegradability, renewable nature and widespread availability [11], Starch finds extensive application across various industries due to its functional versatility. In the food sector, it serves multiple purposes as a gelling agent [12], thickener [13], emulsion stabilizer [14] and fat replacer [15]. Starch is also used in pharmaceutical production, paper manufacture [16], packaging material design [17], adhesive formulation [18] and textile manufacture. It should be noted that native starches are intrinsically hydrophilic [16]. Starch is extensively used as a functional element in numerous fields. Nevertheless, its inherent disadvantages, such as high hot viscosity, susceptibility to heat and shear forces, propensity

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for rapid retrogradation, inadequate stability during cold storage, and weak resistance to acid, shear, and high temperatures, can lead to a decline in its quality. Consequently, these limitations might impede the broad utilization of starch in the food sector [4]. The modification of starch using agents such as anhydrides, oxidants, and benzyls aims to introduce specific changes in its chemical, physical, or functional properties. This modification can enhance the chemical reactivity of starch, thereby facilitating the formation of new functional groups. Additionally, it can adjust the solubility of starch in various solvents, which is crucial for its use in different formulations such as adhesives, coatings, pharmaceuticals, and foods. Furthermore, it can enable the modification of starch viscosity and hydrophobicity as seen in the case of starch modification using benzyl bromide, which is advantageous in applications such as thickeners, binders, and texture agents used in foods, pharmaceuticals, and personal care products. Therefore, it is essential to explore suitable techniques for altering starch to improve its characteristics and broaden its potential applications [19].

Chemical modifications introduce fresh functional groups without changing granule morphology or size distribution. These alterations affect the physicochemical properties of starch, inducing structural modifications that render it suitable for diverse industrial applications. These chemical adjustments influence starch behavior, dough properties, gelatinization capacity, and retrogradation power. Therefore, these chemical modifications have the potential to enhance starch characteristics and expand its utilization in both food and non-food industries [20].

2 Chemical modifications

Different chemical alterations, such as cross-linking [21], esterification [22], etherification [23], oxidation [24] and acid hydrolysis [25], are utilized to modify the molecular configuration and functional characteristics of starches. These methods of chemical modification act as effective means to enhance particular aspects of starch functionality, like swelling [26], gelatinization [27] and retrogradation [28]. The main objective is to meet the specific requirements of industrial applications [29].

2.1 Esterification

Esterification, a crucial chemical procedure in starch modification, induces notable alterations in the gelatinization and aging traits of starch obtained from different plant origins. This technique entails substituting the hydroxyl groups in starch with an acid or an anhydride (Fig.1) to yield esterified starch, this process involves the substitution of the hydroxyl groups of starch by an acid or an anhydride to produce esterified starch. Typically, these reactions are carried out at temperatures ranging from 50 to 90 °C, with a reaction time varying from 1 to 6 hours [30]. Utilizing either alkaline catalysts like potassium carbonate, sodium hydroxide, and sodium hydrogen phosphate, or acidic catalysts such as p-toluene sulfonic acid, hydrochloric acid, and sulfuric acid [31]. The application of succinic anhydride as a crosslinking agent has led to significant improvements in adhesive properties. Succinic anhydride-modified starch containing both hydrophilic and hydrophobic bifunctional groups exhibits effective emulsification properties, which contribute to enhancing its flame-retardant features [32].

The process involving cellulose and a cyclic anhydride does not produce any by-products. Instead, it facilitates the formation of a modified polymer that includes carboxyl groups [33, 34]. By modifying the cellulose surface with succinic anhydride in this study, it is conceivable to use the same modifying agent for starch, given that the latter also possesses hydroxyl groups [35].
Fig. 1. The illustration depicts the chemical alteration of starch using succinic anhydride.

Compared to glucose, starch possesses a greater molecular weight and is more cost-effective [36]. Ammonium dihydrogen phosphate (ADP) stands out in industrial applications for its exceptional chemical stability and adaptability, attributes that are further enhanced by its cost-effectiveness. Notably, ADP is esteemed for its role as an efficient fire retardant, applicable to materials such as wood, paper, and textiles, distinguishing it from citric acid [37, 38], as a medicinal product [39], and as a feed supplement for ruminants [40]. Additionally, it serves as a strengthening component in adhesives, fostering an acidic setting conducive to the reaction of its hydroxyl groups with those in wood under elevated temperatures [41].

Prior studies have demonstrated that starch displays reduced viscosity and heightened reactivity following gelatinization under alkaline conditions [42, 43]. In essence, the esterification process between gelatinized starch (GS) and ADP should be straightforward, aiming to create an adhesive with outstanding properties. This research endeavors to formulate a cost-effective and readily prepared fire-retardant adhesive for wood, utilizing a novel starch composite comprising GS and ADP (Fig. 2). An earlier method outlined the fabrication of a flame-resistant adhesive by esterifying starch and phytic acid, resulting in the formation of an expanded polystyrene foam [44]. Nonetheless, this method of preparation is complex and time-intensive. On the contrary, our investigation directly employs gelatinized starch (GS) as the main ingredient in formulating flame-retardant adhesives, which are subsequently utilized in plywood manufacturing. Furthermore, we meticulously optimized the reaction between GS and ADP, assessing the performance of the resulting GS-ADP resin adhesive in terms of water resistance, adhesive strength, and fire resistance [45].

Fig. 2. The chemical modification reaction of starch with ADP [45].

The alteration and derivatization of starch necessitate a solvent medium to ensure the efficient solubilization of starch granules and the subsequent dissolution of its constituents, amylose and amylpectin. Upon dissolution, the hydroxyl groups on the polysaccharide
chains become available for electrophilic substitution during the esterification process. Historically, starch solubilization during esterification has been conducted in aprotic solvents like LiCl/dimethylacetamide and dimethyl sulfoxide. Nevertheless, these solvent systems posed risks and were challenging to eliminate from the end products, making them unsuitable for biomedical purposes. However, effective starch esterification in aqueous media with a moderate degree of substitution has been documented. It's notable that sodium hydroxide is frequently utilized as a catalyst in the aqueous esterification of starch, thereby obviating the need for toxic reagents like N,N-dimethyl aminopyridine and methane sulfonic acid. The enhanced solubility of starch in an alkaline environment has facilitated better accessibility to the reagents, ensuring consistent substitution [46].

While the preparation of starch esters containing hydrophobic terminal groups, like acetylated starch, has been extensively studied and reported in the literature [47, 48], Starch monooesters originating from dicarboxylic acids, such as maleic acid, fumaric acid, and succinic acid, have garnered less research attention in comparison to acetylated starch and similar derivatives [48]. Biswas and colleagues synthesized starch maleate half-esters achieving a degree of substitution (DS) of up to 0.25. Their approach involved employing microwave-assisted heating with dimethyl sulfoxide as the solvent and pyridine as the catalyst. Maleic acid and fumaric acid reacted with starch, leading to the production of unsaturated polyesters. These large molecules were stabilized by forming cross-linked networks through the photodimerization of the unsaturated double bonds present in the dicarboxylic acids. This method of modification (Fig.3) offers a simple and environmentally friendly approach to producing cross-linked and water-soluble gel particles of starch-maleate monooester from native sago starch. The process begins with sago starch reacting with maleic anhydride in an aqueous medium, followed by precipitation in absolute ethanol. Upon UV irradiation in the presence of cerium (IV) ammonium nitrate, the starch-maleate gel transitions into cross-linked gel particles, with an average diameter of 445 ± 115 nm. FTIR spectroscopy analysis confirmed the integration of maleic anhydride substitutions onto the starch chains. The degree of substitution (DS), as determined using the back-titration method, varied between 0.03 and 0.21. Starch-maleate with DS values less than 0.03 displayed notably reduced water absorption and hydrophilicity in contrast to those with DS values exceeding 0.08. Due to their non-toxic characteristics, biocompatibility, and economic viability, these gel particles hold significant promise as carriers for drug delivery across various biomedical applications [46].

Fig.3. A visual representation showing the chemical interaction between sago starch and maleic anhydride.

2.2 Etherification

The incorporation of substituents into starch granules is a practice frequently employed to alter its properties [49].

When the aim is to increase the hydrophobicity of starch, hydrophobic substituents such as benzyl, allyl, methyl, etc. are generally sought. However, these additions often entail
complex modifications. The study of benzylation of cellulose (Fig.4) has been explored to consider its potential use as a resin, however, this is not yet common practice [50]. Research indicates that treating starch with benzyl chloride, resulting in a moderate degree of substitution, is associated with a decrease in the gelatinization temperature [51].

As of now, there have been few studies conducted in this domain. For example, an innovative method involves the partial grafting of benzyl entities onto HEC (Hydroxyethyl cellulose) at 60°C for 6 hours in a basic medium was explored for the purpose of extracting metal ions from water via coordination interactions [52]. Similar work on starch could be explored to discover new potential applications, such as the adsorption of other metals.

![Etherification reaction scheme](image.png)

**Fig.4. Etherification reaction scheme** [50].

Hydroxypropylation involves incorporating ether groups into starch molecules. This process yields hydroxypropyl starch (HPS) derivatives (Fig.5), achieved by treating starch with propylene oxide as the etherifying agent. This reaction results in the integration of hydroxypropyl groups into the starch polymer chain this process involves the deprotonation of the hydroxyl groups of starch, typically at a temperature of 40°C for 12 hours. Propylene oxide is known for its high reactivity, attributed to the significant strain in its three-membered epoxy ring, which possesses average bond angles of 60 degrees, making it highly reactive. During the formation of HPS, specific hydroxyl groups of the anhydroglucose unit (AGU) are transformed into -O-(-2-hydroxypropyl) groups. The molar substitution (MS) measures the number of propylene oxide moles replacing hydroxyl groups on an AGU, with a maximum value of 3, as an AGU has only three available hydroxyl groups for substitution. Additionally, oligo (propylene oxide) substitution may occur if propylene oxides react further with another propylene oxide molecule. The effectiveness of the reaction relies on the diffusion or penetration of the alkaline catalyst and etherifying agent into the starch granules, as well as the likelihood of reactivity between the nucleophilic starch alcolate and the propylene oxide molecule. Higher temperatures facilitate the diffusion of the alkaline catalyst and the penetration of the etherifying agent. To prevent gelatinization of the granules under high pH and elevated temperature conditions, it's essential to perform the reaction in the presence of a swelling-inhibiting salt. Sodium sulfate is commonly selected due to its capability to strike a balance between protecting the granules and ensuring reaction efficiency. Numerous factors affect the molar substitution (MS) of HPS, including the concentration of reagents, the ratio of starch to water, the duration of the reaction, the concentration of alkali, and the proportions of amylose and amylopectin [53]. Hydroxypropylation is acknowledged for its capacity to reduce starch retrogradation by introducing bulky hydroxypropyl groups. These groups create steric hindrance, which interrupts the proper alignment of starch chains during aggregation and crystallization. Moreover, the addition of hydroxypropyl groups to starch chains leads to notable changes in other starch properties, including gelatinization temperature, paste viscosity, and clarity [54].
2.3 Oxidation

Starch oxidation involves a chemical reaction where starch interacts with an oxidizing agent like sodium hypochlorite, under carefully controlled time conditions [55], pH and temperature [56]. The oxidation of the primary or secondary hydroxyl groups of starch leads to the formation of aldehyde or carboxyl groups. (Fig.6) [57]. Consequently, this modification alters the physical, chemical, and structural attributes of starch. The escalation in active chlorine levels during oxidation facilitates the gradual development of these groups, thereby causing a continuous rise in the carbonyl content observed in barley starch during the process [55]. Two widely used starch derivatives, carboxymethyl starch and starch dialdehyde, can be obtained by oxidizing starch. In this process, starch oxidation to produce dialdehyde occurs at low temperature, around 35°C, for 4 to 6 hours. These derivatives find extensive application in adsorption processes [58].

Starch dialdehyde is produced by controlled oxidation, specifically targeting α-1,4 bonds within starch molecules and α-(1,6) linked anhydroglucoside units using NaIO4. This procedure transforms starch into a product characterized by the presence of aldehyde or dialdehyde groups [59], as illustrated in the (Fig.6).

2.4 Schiff base

Starch dialdehyde, a modified form of starch, possesses numerous active aldehyde groups, facilitating the formation of Schiff bases. Furthermore, the amino group existing on a compound's surface can undergo chemical interactions with the aldehyde group [59].

Starch plays a vital role in biomass-derived adhesives due to its viscosity and economical nature. However, its limitations in terms of water resistance and bonding efficacy pose...
constraints on its utilization in the wood industry. To tackle these obstacles, we formulated an environmentally sustainable renewable adhesive by combining oxidized starch with hexanediamine via the Schiff reaction (Fig. 7). Two widely used starch derivatives, carboxymethyl starch and starch dialdehyde, can be obtained by oxidizing starch. In this process, starch oxidation to produce dialdehyde occurs at low temperature, around 35°C, for 4 to 6 hours. To enhance the production process of this adhesive, we investigated the impact of varying oxidation durations and concentrations of oxidant on the mechanical properties of plywood, aiming for optimization. Additionally, we evaluated the curing kinetics, thermomechanical characteristics, and thermal stability of the adhesive through techniques such as differential scanning calorimetry (DSC), dynamic mechanical analysis (DMA), and thermogravimetry (TG). Fourier transform infrared spectroscopy (FTIR) and liquid chromatography–mass spectrometry (LC-MS) were employed to gain insights into the underlying reaction mechanisms. Our results indicate that the adhesive exhibits remarkable adhesion properties after undergoing a 12-hour oxidation process with 11% (w/w, based on dry starch) NaIO4 as the oxidizing agent. Plywood bonded with this resin displayed dry shear strength, resistance to cold water for 24 hours, and resistance to hot water for 3 hours (at 63°C) measured at 1.87 MPa, 0.96 MPa, and 0.91 MPa, respectively, meeting the standards outlined in GB/T 9846:2015 (≥0.7 MPa) [60].

Fig. 7. The starch oxidation reaction leads to the formation of Schiff bases [60].

Until now, ligands containing nitrogen, including N-heterocyclic carbenes, Schiff bases, amines, oximes, and hydrazones, have garnered increasing attention and thorough investigation for their potential applications as catalysts in coordination chemistry and catalysis (Fig. 8). In contrast to phosphines, these phosphine-free systems based on nitrogen are simpler to prepare and exhibit resistance to moisture. This stands in contrast to the toxicity, sensitivity to moisture, synthesis complexity, and high cost typically associated with phosphine [61, 62]. Schiff bases, resulting from the condensation of primary amines and aldehydes, are recognized as a significant category of nitrogen-based ligands. They coordinate metals through the lone pair of electrons on nitrogen. Schiff base complexes have gained notable attention across various domains, ranging from catalysis to biological applications [63]. Because of their adaptable steric and electronic characteristics, as well as their non-toxicity and straightforward synthesis, Schiff bases present potential advantages over phosphines in catalysis. For instance, Yahya et al. demonstrated the application of Schiff base-modified ionic nanocellulose, derived from rice straw, in the bio-reduction of Pd (II) to Pd nanoparticles (Pd NPs). Subsequently, they immobilized these nanoparticles to develop a supported catalyst [64]. The catalyst exhibited exceptional efficiency in catalyzing the synthesis of biphenyl derivatives through Suzuki coupling reactions. The unique characteristics of Schiff bases and starch offer promising prospects for employing Schiff
base-functionalized starch as a supportive matrix in crafting valuable heterogeneous systems [65]. In this investigation, considering the aforementioned traits, we devised a modified starch (Starch-SB) aimed at stabilizing palladium. This altered version (Starch-SB) underwent analysis employing a variety of analytical methods such as FT-IR, XRD, TGA, SEM, EDX, TEM, and $^{13}$C NMR (Fig.8).

Fig.8. Diagram illustrating the synthesis process of Starch-SB [65].

Fig.9. Diagram illustrates the objectives of each starch esterification reaction.
Fig. 10. Diagram illustrates the objectives of each starch etherification, oxidation and Schiff base reaction.

3 Application

3.1 Film

Starch, widely found in nature at a low cost, offers substantial benefits as an alternative to plastic films derived from petroleum. However, native starch is constrained by its low solubility in organic solvents, film brittleness, and susceptibility to water absorption \[66\]. Furthermore, native starch does not exhibit a visible glass transition temperature \(T_g\) without any plasticizer, making it extremely challenging to process \[67\].

The study utilized oleic acid and 10-undecanoic acid to esterify different types of starch, including corn, tapioca, potato, and waxy potato starch. These esterification reactions achieved maximum degrees of substitution of 2.4 and 1.9, respectively. The study concentrated on examining the thermal and mechanical characteristics in relation to amylopectin content, starch molecular weight, and the specific fatty acid employed. Findings revealed that regardless of their botanical source, all starch esters demonstrated improved degradation temperatures. The glass transition temperature \(T_g\) showed a rise with increased amylopectin content and molecular weight, while it decreased with longer fatty acid chain lengths. Various casting temperatures were employed to generate films with different optical properties. The dialdehyde starch/Polyvinyl alcohol film exhibits effective UV barrier, antioxidant, and antibacterial properties. The tensile strength of the dialdehyde starch/PVA (5:1) film was improved by 123.7% compared to the pure PVA film. Examination through scanning electron microscopy and polarized light microscopy unveiled that films cast at \(20°C\) showcased porous structures and internal stresses, a departure from those cast at higher temperatures. Tensile tests demonstrated a rise in Young's modulus with increasing starch molecular weight \(M_w\) and amylopectin content. Moreover, starch oleate films demonstrated superior ductility in comparison to starch 10-undecenoate films. Notably, all films maintained water resistance for at least a month, with certain films undergoing light-induced
crosslinking. Remarkably, starch oleate films exhibited antibacterial properties against Escherichia coli, which were absent in native starch and starch 10-undecenoate film [68].

### 3.2 Adsorption

The pollution of water resources by hazardous substances like heavy metals, organic compounds, and pharmaceuticals (Table 1) poses a significant environmental and health concern [69]. Adsorption is recognized as one of the most practical and extensively researched methods for wastewater treatment among various approaches available [70]. There is also significant interest in utilizing biomaterials derived from renewable sources in this regard [71, 72]. Polysaccharides are attracting increased interest due to their significant adsorption capacity, biodegradability, biological compatibility, and relatively low cost [73].

Specifically, the existence of ionic functional groups within the polymeric structure of polysaccharides provides a unique adsorption mechanism and selectivity [74]. These characteristics, combined with increased surface area, have motivated several studies investigating the adsorption behavior as well as the efficacy of modified polysaccharides.

<table>
<thead>
<tr>
<th>Adsorbent</th>
<th>Adsorbate</th>
<th>Adsorption capacity and efficiency</th>
<th>Reference</th>
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<tbody>
<tr>
<td>Starch modified with citric acid</td>
<td>Crystal Violet d</td>
<td>The equilibrium adsorption capacity reached 731.66 mg g⁻¹, while the monolayer adsorption capacity per unit mass was 833.3 mg g⁻¹.</td>
<td>[75]</td>
</tr>
<tr>
<td>Starch modified with sodium hypochlorite</td>
<td>Pb²⁺ and Cu²⁺</td>
<td>The specific monolayer adsorption capacities for Pb²⁺ and Cu²⁺ were 94.5 mg g⁻¹ and 81.0 mg g⁻¹, respectively.</td>
<td>[76]</td>
</tr>
<tr>
<td>Surface-modified starch with methacrylic acid grafting.</td>
<td>Methylene blue dye</td>
<td>The absorption of dye achieves 65% when using 2.0 grammes of the adsorbent</td>
<td>[77]</td>
</tr>
<tr>
<td>Succinic anhydride modified starch</td>
<td>Phenol</td>
<td>Succinic anhydride-modified starch has an adsorption efficiency of 189mg/g for phenol.</td>
<td>[35]</td>
</tr>
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### 3.3 Water-resistant adhesive

The widespread use of starch lies in its contribution to the design and manufacture of adhesives based on natural polymers. This popularity stems from its wide range of raw material sources, as well as its renewable and biodegradable attributes [78].

Starch-based adhesives encounter significant constraints related to bond strength and water resistance, constraining their potential utilization within the wood processing sector [79]. To improve the effectiveness of starch-based adhesives, different methods of modifying starch molecules have been explored, such as oxidation and esterification [80], as mentioned above the modification of starch by ammonium dihydrogen phosphate to form an ester provides a strength exceeding 1.2 MPa, a significant application of starch modification involves creating a renewable, environmentally friendly adhesive through the oxidation of starch with NaIO4 and subsequent reaction with hexane diamine. This innovative glue exhibits superior sticking characteristics, largely attributed to the creation of Schiff bonds between the oxidised starch and hexane diamine. The adhesive, when made with an oxidation period of 12 hours and a concentration of NaIO4 at 11% (w/w, in relation to dry starch),
displays remarkable efficacy in terms of both bonding power and resistance to water. Plywood that is joined using this adhesive attains a dry strength of 1.87 MPa, a 24-hour cold water resistance of 0.91 MPa, and a hot water resistance (at 63°C) of 0.96 MPa [60].

In a separate study, a new environmentally friendly adhesive has been developed for wood bonding. The method involves the combined reaction of citric acid resins with 1,6-hexane-diamine to give hexamethylene diamine and a NaIO4-oxidized glucose solution to synthesize adhesives, without the use of formaldehyde. To evaluate the performance of the newly synthesized resin, we conducted laboratory-scale plywood production. The adhesive exhibited impressive bonding strength and excellent water resistance when oxidation was not applied during the process, and the molar ratio of oxidized glucose to hexamethylene diamine remained at 1:1.6. Plywood bonded with this formulation displayed dry strength, 24-hour moisture resistance, and resistance after immersion in hot water at 63°C, measuring 1.36 MPa, 1.60 MPa, and 1.49 MPa, respectively [81]. In summary, the assessment results are in accordance with the specifications set forth in the Chinese national standard GB/T 9846-2015 (≥0.7 MPa) for both research endeavors [82].

3.4 Nano-particles (NPs):
Starches undergo processes that reduce their size, resulting in various nanoparticles that expand their versatility and potential applications. Nanostructured starches are essential components in drug delivery systems, purification agents, blocking agents, and stabilizers, serving vital functions in these applications [83].

Starch nanoparticles were developed through ball milling by [84]. The study revealed that ball milling offers a physical approach to reducing starch particle size, proving to be more cost-effective, stable, and less time-consuming compared to chemical methods. Furthermore, researchers noted enhanced antioxidant properties resulting from the cleavage of glycosidic bonds and the formation of carbonyl groups during the ball milling process. As a result, there was increased exposure of free hydroxyl (−OH) groups in starch, as confirmed by FTIR analysis. Rheological assessments indicated a transition to a more viscoelastic behavior in the nano-reduced starch particles, suggesting their suitability for food products that do not require high viscosity. Additionally, there was an improvement in antioxidant activity, with radical scavenging increasing from 9.29% to 39.17% (PMS) to 12.18%–43.21% (nano-PMS), making it a valuable functional food ingredient and bioactive carrier with enhanced commercial viability [85].

3.5 Pharmaceutical and medicinal use
In pharmaceutical applications, starch serves several vital roles, including functioning as a binder, disintegrant, and diluent. In particular, as a disintegrant, it is incorporated into oral tablets or capsules to hasten the release and absorption of the active drug by aiding in the breakdown of hard shells and tablets into smaller fragments. The effectiveness of the disintegrant depends on factors like its water absorption capacity, particle size, concentration in the formulation, and the wetting characteristics of other components in the tablet. Comparison was made between the dissolution rates of active ingredients in starch granules or tablets containing organic drugs and those in corn starch. Acid-modified starches demonstrate various enhancements, including improved bond strength, heightened dissolution rates ranging from 65% to 80%, and reduced disintegration time from 400 to 82 seconds and the dialdehyde starch DAS can act as a binding agent in the production of pharmaceutical tablets, thereby enhancing their cohesion and maintaining their structural integrity. Its reactivity with the functional groups of drugs and excipients improves tablet cohesion. Additionally, the DAS can be incorporated into controlled-release formulations to regulate the release rate of active ingredients. Its ability to interact with the functional groups of drugs provides modulation of the release kinetics of active substances, which can be advantageous for extending the duration of drug action [86]. Embedded within diclofenac sodium tablets, acid-modified starch demonstrated a disintegration time of 82 seconds and
an accelerated dissolution rate, releasing 80% of the drug within 30 minutes, surpassing the performance of native starch [87]. They utilized acid-modified PMS as a binding agent in both paracetamol granules and tablets. Their results suggested the possibility of replacing maize starch with modified starch because of its improved disintegration properties. Acetylated starches with low DS (0.01–0.2) showed encouraging potential as binding agents [85].

Fig. 11. Applications of starch [60, 88-91].

4 Conclusion

In summary, the modification of starch through processes like esterification, etherification, oxidation, and Schiff base formation presents a broad spectrum of potential applications across diverse domains. The methods of starch modification allow for adjusting its physicochemical properties to meet the specific needs of each application. In the field of adsorption, modified starch can effectively be used to remove pollutants from the environment. As an adhesive agent, it provides excellent bonding in a variety of industrial products. In the pharmaceutical sector, modified starch derivatives can serve as valuable excipients in drug formulations. Furthermore, the ability of modified starch-based films to form protective coatings or biodegradable packaging makes them promising candidates for sustainable use in various applications. By combining starch modification chemistry with a deep understanding of the specific requirements of each application field, it is possible to develop innovative and environmentally responsible products that address the current challenges facing society.

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