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Review on starch from edible plant sources: Extraction, properties and applications

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Abstract
Starch is a major renewable biopolymer stored in cereals, roots, tubers, legumes, and emerging underutilized edible plants. Its functional versatility in food and industrial systems is influenced by granule architecture and the amylose-amylopectin ratio, which determine gelatinization, pasting behaviour, retro gradation, and digestibility. While corn, potato, wheat, and cassava dominate global starch production, growing interest in sustainability, clean-label ingredients, and supply diversification has increased focus on alternative plant sources such as water chestnut, minor millets, banana, and jackfruit seeds. Efficient starch recovery from these diverse matrices requires optimized mechanical, enzymatic, or advanced non-thermal extraction technologies to preserve native structure and enhance yield. Physicochemical diversity across botanical origins offers opportunities for tailored applications ranging from bakery, noodles, dairy, and snacks to pharmaceuticals, paper, adhesives, and emerging biodegradable packaging. Despite rapid advancements, industrial adoption of non-conventional starches continues to face challenges including inconsistent quality, limited supply chains, and the need for standardized processing protocols. Future innovation centered on green extraction methods, structure-function optimization, and integration into expanding bioplastic and functional food markets will support development of a sustainable starch economy. This review provides a comprehensive overview of edible starch sources, extraction strategies, functional attributes, and applications while identifying key research gaps and commercial opportunities.

Keywords: Starch, edible plant sources, functional properties, extraction techniques, resistant starch, food and industrial applications, sustainability

Introduction

Starch is one of the most widely occurring renewable biopolymers in edible plants, serving as the major storage carbohydrate in cereals, roots, tubers, legumes, and several underutilized species (Singh *et al*., 2003; Hoover, 2010) [12, 5]. Its significance in the global food supply chain arises from both its abundance and its multifunctional role in food formulation, nutrition, and industrial processing. Structurally, starch consists of amylose and amylopectin organized into semi-crystalline granules, and the ratio of these two polymers strongly dictates functional behaviours such as gelatinization, swelling, viscosity development, retro gradation, and digestibility under different thermal and mechanical conditions (Buleon *et al*., 1998; Tester *et al*., 2004) [3, 15]. Beyond conventional roles in texture and structure development, the nutritional relevance of starch has expanded with increasing recognition of resistant starch fractions that aidglycaemicc regulation, support beneficial gut microbiota, and reduce risk of metabolic disorders (Singh *et al*., 2010) [13].

Globally, industrial starch production has been predominantly centered on corn, potato, wheat, and cassava due to their high yield and established processing infrastructure (Liu *et al*., 2019) [7]. However, growing concerns over supply volatility, environmental stress on major crops, and rising consumer demand for sustainable ingredients are driving scientific interest toward alternative starch sources (Ai and Jane, 2015) [2]. Edible plants like water chestnut, minor millets, bananas, and jackfruit seeds represent promising substitutes owing to their regional adaptability, unique functional characteristics, and economic potential for developing agri-based industries (Makroo *et al*., 2021; Kaur *et al*., 2021; Phukan and Nongkhlaw, 2022) [8, 6, 9]. Their diverse granule morphology, thermal behaviour, and digestibility profiles broaden the possibilities for targeted technological applications.

Starch has extensive industrial utility as a thickener, stabilizer, binder, film-former, and controlled-release agent, supporting sectors such as bakery, confectionery, noodles, pharmaceuticals, adhesives, paper, textiles, and increasingly, biodegradable packaging and bioplastic production (Liu *et al*., 2019; Ai and Jane, 2015) [7, 2]. Meeting sustainability targets across industries requires advancements in starch extraction efficiency, modification techniques, and quality optimization to enhance its performance in food and non-food innovations.

Therefore, this review aims to provide a comprehensive understanding of edible plant starch sources, evaluate recent progress in extraction technologies, analyze physicochemical and functional attributes, and discuss the expanding roles of starch in diverse industrial sectors. It also highlights emerging challenges such as inconsistent quality, process scalability, and resource-efficient production that must be addressed to ensure a sustainable and economically viable starch economy in the future.

Starch Sources from Edible Plants

Edible plants constitute diverse biological reservoirs of starch, exhibiting considerable variability in concentration, granule morphology, and nutritional attributes. Cereal starches sourced from maize, wheat, and rice represent the largest share of global starch production due to high crop yield and well-established processing compatibility. These starches typically exhibit smaller granules with A-type crystalline patterns, resulting in higher gelatinization temperatures, stronger granular integrity during heating, and desirable functionality in bakery, noodle, and extruded food systems (Tester and Karkalas, 2002) [14].

Root and tuber crops, including potato, cassava, taro, yam, and sweet potato, are distinguished by their large granule sizes and B-type or mixed crystallinity, which facilitate enhanced swelling, water absorption, and paste clarity. These attributes make them highly suitable for transparent gels, gluten-free formulations, thickened sauces, and fried snack applications (Hoover, 2010; Dupuis and Liu, 2019) [5, 7]. Legume starches from peas, chickpeas, and lentils contain relatively higher amylose content, which encourages firm gel formation and slower enzymatic digestion, offering opportunities for the development of low-glycaemic and nutritionally functional food products (Singh *et al*., 2003) [12].

In recent years, emerging starch sources from underutilized edible plants such as banana, mango kernel, jackfruit seed, and water chestnut have gained substantial interest for their unique techno-functional profiles, including moderate paste viscosity, reduced retro gradation tendency, and superior film-forming ability. These properties are advantageous for biodegradable packaging, edible coatings, and specialized health-oriented formulations (Kaur *et al*., 2021; Phukan and Nongkhlaw, 2022) [6, 9]. Increasing demand for clean-label, a sustainable, and locally sourced starch ingredient highlights the importance of exploring such non-traditional botanical options, which can support agricultural diversification, rural economic development, and broader industrial innovation.

Extraction of Starch from Edible Plant Sources

Starch extraction from edible plants involves disrupting the cellular matrix to release starch granules, followed by progressive refinement to separate them from protein, fiber, lipids, and other non-starch components. Conventional wet-milling is widely adopted for cereals and tubers such as maize, wheat, and cassava, and includes steps such as washing, steeping or soaking, milling, sieving, purification through repeated washing and sedimentation, and controlled drying to stabilize the starch for safe storage (Abd Karim *et al*., 2008; Liu *et al*., 2019) [1, 7]. The botanical origin determines the extraction strategy; cereals with smaller granules require precise milling and fine sieving, whereas tubers and seed-based sources often need aggressive mechanical disruption, including peeling, grating, or hammer milling, due to the presence of robust parenchymal cell structures.

Optimizing the extraction process is critical to improve starch purity, paste clarity, and colour attributes by enabling better removal of protein-lipid complexes. Recent advancements have focused on more sustainable extraction routes. Enzyme-assisted extraction using cellulases, pectinases, and proteases enhances starch liberation by selectively degrading structural polysaccharides, lowering water demand, and maintaining granule integrity more effectively than purely mechanical methods (Rahman *et al*., 2020) [10]. Moreover, non-thermal technologies such as ultrasound-assisted and microwave-assisted extraction accelerate mass transfer, shorten processing time, and improve yield, thereby supporting eco-efficient starch recovery across various plant matrices (Zhang *et al*., 2021; Makroo *et al*., 2021) [16, 8].

Post-extraction drying also plays a decisive role in functional quality. Low-temperature drying techniques such as freeze-drying and controlled tray drying are preferred for preserving granule crystallinity, swelling ability, and rheological performance. Conversely, high-temperature rapid drying processes like spray drying may partially disrupt granule morphology, leading to lower viscosity and reduced gel strength in final applications (Hoover, 2010; Dupuis and Liu, 2019) [5, 7]. Therefore, the combined optimization of extraction and drying operations is essential for producing high-quality starch tailored to specific food and non-food industrial requirements.

Physicochemical and Functional Properties of Plant Starches

The functionality of starch in industrial applications depends on intrinsic structural attributes, such as the ratio of amylose to amylopectin, granule size, granule crystalline structure, and molecular chain distribution. Amylopectin-rich starches tend to produce soft gels with high swelling and paste clarity, suitable for sauces, desserts, and extruded snacks; by contrast, high-amylose starches yield firm, heat-reliable gels with increased retro gradation resistance, appropriate for products requiring texture stability (Buleon *et al*., 1998; Tester *et al*., 2004) [3, 15].

Granule size distribution also strongly influences pasting and rheological behaviour. For instance, tuber and legume starches with larger granules typically show higher paste viscosity and greater swelling capacity compared to small-granule cereal starches, which often exhibit lower swelling but firmer gel formation (Structural, morphological, functional and digestibility properties of starches from cereals, tubers and legumes, 2018). The crystallinity type determines gelatinization temperature and thermal resilience. Typically, cereal starches (A-type) gelatinize at higher temperatures, whereas B-type tuber starches gelatinize at lower temperatures and generate more translucent pastes (Hoover, 2010; Dupuis and Liu, 2019) [5, 7].

Digestibility is another key property. Variations in granule architecture and amylose content result in differing proportions of rapidly digestible starch (RDS), slowly digestible starch (SDS), and resistant starch (RS). Legume and high-amylose starches often yield higher SDS and RS fractions, contributing to slower glucose release and improved gut health (Singh *et al*., 2010; Ai and Jane, 2015) [13, 2]. Thus, the physicochemical diversity among plant starch sources enables tailoring of formulations for nutritional, textural, and functional needs across applications.

Applications of Starch in Food and Non-Food Sectors

Starch is widely used in the food industry as a thickener, stabilizer, emulsifier, binder, and texture modifier. Its versatility allows inclusion in soups and sauces for thickening and viscosity, bakery for crumb structure and volume, noodles and pasta for elasticity and bite, and snacks for crispiness and expansion (Liu *et al*., 2019) [7]. Modified starches—achieved via physical (heat-moisture treatment), enzymatic, or chemical (cross-linking, oxidation) methods—enhance resistance to shear, heat, and acidic conditions, making them suitable for canned foods, ready-to-eat meals, instant sauces, and frozen foods (Tester *et al*., 2004; Rahman *et al*., 2020) [15, 10].

In non-food sectors, starch plays a pivotal role as a biodegradable polymer in pharmaceutical tablets, textile sizing, paper coatings, and adhesive formulations (Ai and Jane, 2015) [2]. Beyond food, starch serves as a biodegradable polymer in pharmaceuticals for tablet binding and disintegration, in textiles for sizing, in adhesives and paper coatings, and increasingly in bio-based packaging materials. Research on starch-based films, bioplastics, and composite materials has gained momentum as global demand shifts toward environmentally friendly alternatives to petroleum-derived plastics (Zhang *et al*., 2021; Phukan and Nongkhlaw, 2022) [16, 9]. Continued innovation in nano-starch composites, edible films, and active packaging demonstrates the expanding industrial importance of starch beyond culinary applications.

Future Prospects and Challenges

Future developments in the starch industry must address the variability in functional characteristics caused by differences in crop genetics, agronomic practices, and post-harvest processing conditions. Limited technological support in developing regions hinders wider adoption of non-conventional starch sources despite their potential to enhance food security and rural economic sustainability (Makroo *et al*., 2021) [8]. There is a need for robust characterization protocols and standardized extraction/modification methods to ensure batch-to-batch consistency and reproducibility across applications.

Secondly, many underutilized starch sources like fruit seeds lack comprehensive agronomic data or consistent supply chains, limiting their commercial scalability. Investment in agronomic research, supply-chain development, and value-chain integration is therefore essential to bring these starches into mainstream industrial use.

Finally, environmental and sustainability considerations demand green extraction and modification practices. Enzyme-assisted, low-water, low-energy processes, along with eco-friendly packaging and life-cycle assessments, must be prioritized. Advancements in analytical methods to better understand starch structure-function relationships, digestibility, and biodegradability will support development of tailored starch systems optimized for both nutrition and material functionality (Rashwan, 2024; Zhang *et al*., 2021) [11, 16].

Conclusion

Starch obtained from edible plant sources continues to be a key biomaterial for both food technology and industrial innovation due to its wide availability, biodegradability, and versatile functionality. The increasing need for eco-friendly, nutrition-focused, and locally sourced materials has encouraged deeper investigation into starch from diverse botanical origins, including underutilized crops. Variations in granule structure and composition across species create unique functional properties that can be strategically applied in food formulation, pharmaceuticals, and emerging bioplastic industries. Progress in extraction and modification technologies is improving starch yield, quality, and performance while simultaneously promoting sustainable processing approaches. Nevertheless, challenges such as process standardization, property variability, and industrial scalability remain important research priorities. Strengthening technological development, optimizing valorization of non-traditional crops, and expanding application potential will ensure that edible plant starch continues to play a crucial role in future food systems and eco-friendly product development.

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