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Konjac: A Versatile Plant for Utilization in Nutrition, Health and Environmental Sustainability

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Abstract

This review aims to furnish a thorough examination of konjac (*Amorphophallus* spp.) and its derivative glucomannan (KGM), emphasizing its production, functional characteristics, and applications in food technology, healthcare, and environmental sustainability. Konjac and KGM have gained attention as natural, biologically active substances with excellent biocompatibility and harmless characteristics. Globally, konjac is produced in significant quantities, with major cultivation occurring in China and Japan, and its production is expanding into other Southeast Asian countries. The corms and stems of edible konjac are consumed as vegetable ingredients in Asian cuisines. Konjac flour and KGM have been registered as food additives being used as a gelling agent, thickener, film former, and emulsifier. Deacetylated KGM is made by taking off the acetyl groups from the molecular chains of KGM. When heated and mixed with an alkaline coagulant, it turns into a thermos-irreversible gel that can be used in more ways. KGM has the potential to be used as a fat replacer and biofilm component. As a soluble dietary fiber, KGM is beneficial to the digestive system. KGM exhibits many health benefits, such as exerting anti-diabetic effects, reducing triglycerides, cholesterol, blood glucose, and weight, regulating the gastrointestinal tract, and improving immunity. KGM applications also expand to biomedicine, including drug delivery and wound healing. In addition, konjac can be promoted to be planted in community forests for environmental conservation and deforestation concerns, being considered as non-timber forest products. In conclusion, konjac and KGM demonstrate multifunctional attributes. They have demonstrated widespread applications. This review article highlights the potential of konjac as a sustainable, health-enhancing resource, providing insights into future research and industrial applications

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Introduction

Konjac, a vegetable species belonging to the genus *Amorphophallus* within the Araceae family, comprises approximately 200 species, predominantly distributed across southern, southeastern, and eastern Asia, with a limited number found in Africa. While konjac is cultivated extensively in Southeast Asia, its primary demand stems from the Chinese and Japanese markets (Srzednicki & Borompichaichartkul, 2020).

The global konjac market has experienced significant growth, driven by the increasing consumer demand for natural and health-conscious food ingredients. Valued at USD 3.54 billion in 2023, the market is expected to expand at a compound annual growth rate (CAGR) of 10.5% in the coming years. The Asia-Pacific region, which includes China, Japan, and South Korea, remains the dominant market for konjac, due to its long-standing integration of konjac in various food products. Additionally, North America has emerged as one of the fastest-growing regions, fueled by rising consumer interest in plant-based and gluten-free products, as well as konjac's endorsement as a sustainable and environmentally friendly ingredient. Despite the growing demand, challenges remain in terms of the limited geographical availability of konjac, with most production concentrated in Asia, leading to supply chain constraints and higher transportation costs (SkyQuest, 2025).

Certain *Amorphophallus* species, particularly those with underground tubers, contain significant amounts of glucomannan (Shenglin et al., 2020a), a water-soluble polysaccharide known for its remarkable swelling and viscosity properties (Sun et al., 2023). The dietary fiber extracted from konjac tubers is referred to as konjac glucomannan (KGM) (Fang & Wu, 2004).

In recent years, there has been a surge in interest surrounding konjac, primarily due to the health benefits associated with its primary dietary fiber, glucomannan (Behera & Ray, 2017). The demand for natural health products has steadily increased, and KGM is extensively studied for its potential as a biologically active compound. Its exceptional biocompatibility, along with its non-toxic and harmless properties, makes it suitable for a wide range of applications, including in food, medicine, and biological fields (Du et al., 2021).

Moreover, konjac crops are characterized by their shade tolerance, ease of cultivation, high yield potential, and minimal susceptibility to pests and diseases. As a result, the expansion of konjac cultivation has been observed across several regions, particularly in Asia (Nurshanti et al., 2022). Konjac can be cultivated as a secondary crop within an intercropping system, thriving under the canopy of forests or in shaded environments provided by communal woods and shrubs. This practice has been particularly advocated for highland communities in Tak province, Thailand, where konjac cultivation in community forests has been promoted as a means to address environmental conservation and deforestation concerns (Suksard et al., 2019). This review aims to highlight the importance of konjac and konjac glucomannan (KGM) in dietary, biomedical, and bioenvironmental contexts, offering a synthesis of recent developments in the field.

Konjac cultivations

Plants belonging to the genus *Amorphophallus* are perennial species distinguished by their underground corms and deeply dissected, umbrella-shaped leaf blades. These species are primarily distributed in tropical regions, extending from West Africa to Polynesia (Hetterscheid et al., 2020). *Amorphophallus* species are classified into two main types based on their predominant component: starch type and konjac glucomannan (KGM) type. The starch type species are characterized by corms composed almost entirely of starch, with little to no glucomannan content. The presence of a toxic alkaloid in the corm of starch-type species has led to their neglect in human use (Shenglin et al., 2020a). In contrast, only the KGM-type species have been widely cultivated and further developed for commercial purposes. Konjac can be cultivated in association with forests or on agricultural lands. However, much of konjac cultivation continues to occur in semi-wild environments, with many production areas relying on unimproved, original genetic material (Shenglin et al., 2020a). The konjac corm reaches a commercially viable size after 2-3 annual cycles of alternating wet and dry cultivation. The plant is propagated through one of three methods: seed, bulbil, or corm (Nurshanti et al., 2022). As a native plant of tropical rainforests, konjac thrives in shaded conditions, preferring well-draining, humus-rich soils with a pH range of 6.5–7.5 (Li et al., 2018). The cultivation practices in major konjac-producing countries are summarized in Table 1.

Table 1 Konjac cultivation practices in major producing countries

Countries	Varieties	Ecological adaptability	References
China	*A. konjac* (majority) and *A. albus*.	*A. konjac* grows well at an altitude of 800-2,500 m while *A. albus* can grow at an altitude of 800 m. Shading and temperature not higher than 35°C are optimal.	Shenglin et al. (2020a)
Japan	Only *A. konjac* Koch is used for industrial production.	Konjac is typically grown from small corms or tubers, which are planted in well-drained soil during the spring months. The plant requires a warm and humid climate to thrive.	Kurihara (1979); Shenglin et al. (2020a)
Southeast Asia	*A. muelleri* is the most important variety for industrial application.	Growing well in moderate shading, warm, and moist conditions with consistent temperatures. Southeast Asia commonly grows konjac as intercrop plant.	Follett et al. (2002); Shenglin et al. (2020b)
India	*A. paeoniifolius* and *A. konjac* are commercially cultivated.	It is cultivated in plain areas under sunshine. In hilly areas, it is grown as a rainfed crop. The ideal temperature is 15-30°C. Well distributed rainfall of 1000-1500 mm or above, high humidity, adequate soil moisture are needed.	Misra (2013)

China is the primary producer of konjac, operating around 400 factories dedicated to the manufacture of konjac flour and associated products (Chua et al., 2010). Yunnan is the most affluent province regarding *Amorphophallus,* hosting 15 of the 22 indigenous species exclusive to this region (Long et al., 2003). In response to the rising demand for konjac flour, the Chinese government has classified konjac as an agronomically significant crop with substantial potential in both domestic and international markets (Chua et al., 2010). Nine *Amorphophallus* species, i.e., *A. albus* P.Y. Liu & J.F. Chen, *A. corrugatus* N.E.Br., *A. kachinensis* Engl. & Gehrm., *A. konjac* K. Koch ex N.E.Br., *A. krausei* Engl., *A. nanus* H. Li & C.L. Long, *A. paeoniifolius* (Dennst.) Nicolson, *A. yuloensis* H. Li and *A. yunnanensis* Engl. have been used as food, medicine, fodder, and for wine production in China (Shenglin et al., 2020b). One of the most widely utilized species is *A. konjac,* from which the common name of this crop "konjac" originates (Behera & Ray, 2017).

Japan ranks as the second largest producer of konjac. Five varieties of konjac are cultivated: Zairai (originating from Japan), Shina (originating from China), Haruna-kuro, Akagi-ohdama, and Miyogi-yutaka. The final three are hybrids produced from the cross-fertilization of Zairai and Shina. The Haruna-kuro and Akagi-ohdama cultivars account for over 90% of total konjac corm production in Japan (Shenglin et al., 2020b).

Southeast Asia comprises Burma, Laos, Vietnam, Thailand, Indonesia, and Malaysia, serving as the center of origin for konjac, which is consequently widely distributed throughout the region (Shenglin et al., 2020a). The rainy season constitutes the growing season for *Amorphophallus* species in Southeast Asia. The *A. muelleri* Blume and yellow konjac groups possess significant economic value, making them the most harvested species (Nurshanti et al., 2022; Shenglin et al., 2020a). Over the past decade, the cultivation of konjac in Southeast Asian countries has gradually developed, driven by demand from the Chinese market (Lontoh et al., 2019). The cultivation of *A. muelleri* Blume is being promoted in many parts of Thailand (Wongpinta et al., 2024). The Indonesian Ministry of Agriculture has developed a roadmap for the cultivation and processing of konjac to meet the significant demand in international markets (Rafani et al., 2021). Konjac plantations are being promoted in North Sumatra, South Sulawesi, and East Java (Sjah et al., 2021).

Several varieties of the konjac are growing in India. In contrast to other regions, only the starch type, *A. paeoniifolius,* is cultivated and consumed on a large scale. The main cultivated variety is Kavvor. The other variety is the *A. paeoniifolius* var. hortensis Backer (Shenglin et al., 2020a).

Additionally, konjac is under investigation as a prospective new crop in Western Europe and New Zealand (Follett et al., 2002). The collaboration project within the European Union was conducted in France to create methodologies for the production, processing, and application of konjac for both food and non-food purposes. It aimed to establish an integrated konjac glucomannan (KGM) production chain in Europe by enhancing local konjac availability and processing capabilities (Alonso-Sande et al., 2009).

Konjac as food

There are several culinary ways to consume konjac (Fig. 1). The corms and stems of edible konjac species are used as vegetable ingredients in many Asian dishes. The Joint FAO/WHO Expert Committee on Food Additives (JECFA) developed the standards for konjac flour (INS 425), which state that it is an unprocessed raw product made from the corms of various *Amorphophallus* species. Konjac flour has been categorized by the US Food and Drug Administration as generally recognized as safe (GRAS). The corms are ground to various levels

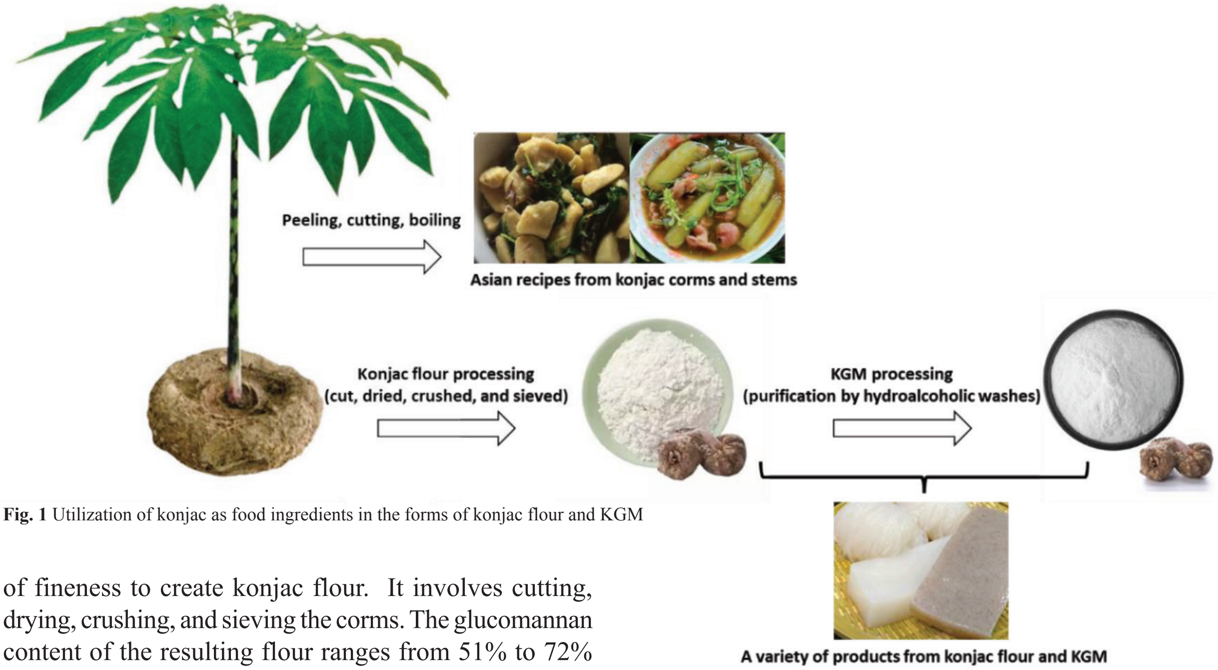

Fig. 1 Utilization of konjac as food ingredients in the forms of konjac flour and KGM

of fineness to create konjac flour. It involves cutting, drying, crushing, and sieving the corms. The glucomannan content of the resulting flour ranges from 51% to 72% by dry weight (Fang & Wu, 2004). The dried crude konjac flour is poor in vitamins and fats and contains roughly 10–30% carbohydrate, 2-5% fiber, 5–14% protein, 3–5% reducing sugars, and 3.4–5.3% ash, depending on the species. A purification process utilizing hydroalcoholic washes is essential to achieving refined flour (KGM) with over 95% glucomannan on a dry basis (Le Bail et al., 2020).

1. Fresh consumption of konjac

Fresh konjac corm comprises carbohydrates, including glucomannan, insoluble starch, cellulose, proteins, lipids, and some impurities, like calcium oxalate, which must be removed for safe ingestion. Many species possess substantial levels of acridity and/or oxalate (Kumar et al., 2017). Konjac products, including konjac flour and KGM, undergo multiple processing processes that remove acridity and/or oxalate. The calcium oxalate content may differ across several konjac cultivars and within distinct portions of the same konjac plant (Aprilia et al., 2023). Acridity manifests as an irritating feeling (itching, stinging, burning) in the oral cavity and pharynx, maybe accompanied by edema. Contact with external skin may also provoke itching, indicating the severity of irritation. The bitterness is attributed to needle-shaped oxalate crystals known as raphides (Lewu et al., 2010). In addition to being irritant, oxalate is regarded as anti-nutritional and poisonous (Guil-Guerrero, 2014). Consumption of elevated levels of oxalate (2 g) can be lethal to humans (Li et al., 2022). Oxalates can chelate minerals such as iron, calcium, zinc, and magnesium, rendering them inaccessible to the body. Consequently, the ingestion of oxalate-containing meals may lead to a deficit of vital minerals in the body. Oxalate crystals may accumulate in the kidneys, resulting in renal stones and potentially causing renal failure (Geraghty et al., 2020). Minimizing dietary oxalate is essential to avert oxalate-related disorders. Patients with kidney stones should limit their dietary oxalate intake to 40–50 mg per day (Kumar et al., 2017). Consequently, the elimination of acridity and oxalate will enhance the usage of konjac in food applications. Soaking and/or boiling in water as a food processing method can effectively reduce oxalate levels to a safe level. It is well recognized that boiling significantly reduces oxalate content (both soluble and total) and lowers the sensory acridity score. Boiling for ten minutes effectively reduced the oxalate content to levels well below the established safe threshold of 71 mg/100g (Kumar et al., 2017; Kumoro et al., 2014).

It should be noted that oxalate content is a concern when consuming fresh konjac. Heating methods, particularly boiling and steaming, easily eliminate oxalate. Proper pretreatments and processing of fresh konjac can ensure a safe level of oxalate content. Commercial products such as konjac flour and KGM must meet the standard for food additives, in which the maximum oxalate content must be well below 3 g/100 g dry solid (Chinese standard). Modern processing of konjac flour and KGM usually leaves behind oxalate levels between 0 and 1 g/100 g dry solid (Aprilia et al., 2023).

The corms, stalks, and blooms of edible konjac species are consumable as a vegetable in numerous Asian dishes. In Thailand, the konjac leaf or young stem is utilized for culinary purposes, such as *A. Paeoniifolius.* The konjac with immature stems and blossoms are utilized for culinary purposes, such as *A. Elatus, A. longituberosus* and *A. Macrorhizus*. The prevalent Thai meal is the soup using young stems and/or flowers (Fig. 2).

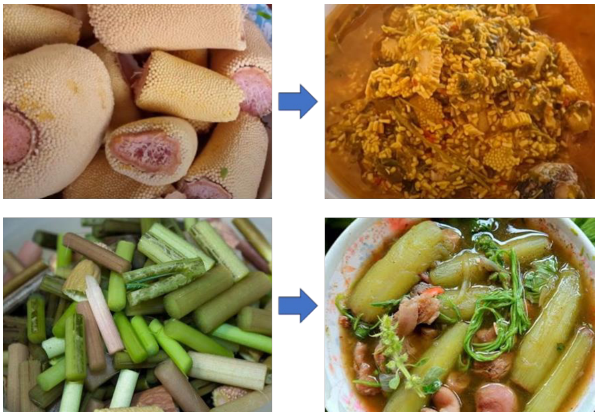

Fig. 2 Thai soups prepared with flowers and/or young stems

2. Konjac flour and KGM

Generally, konjac flour is an unpurified raw product from the corms while KGM is the more purified form of konjac flour. Other names include konjac gum, konjac mannan, konjac, and konnyaku. As defined by JECFA, konjac flour (INS 425) is the hydrocolloidal polysaccharide obtained from the tubers of various species of *Amorphophallus*; principal component is a high molecular weight, slightly branched, non-ionic glucomannan consisting of mannose and glucose, connected by ß-1,4 linkages, at a respective molar ratio of approximately 1.6-4:1; acetyl groups along the glucomannan back-bone contribute to solubility properties and are located, on average, every 9 to 19 sugar units (Fig. 3).

In the EU, konjac gum (E 425 i) and KGM (E 425 ii) are also authorized as food additives. According to the regulations, there are distinct specifications konjac gum and KGM. JECFA has one specification for konjac flour. However, konjac gum and KGM are distinguished by

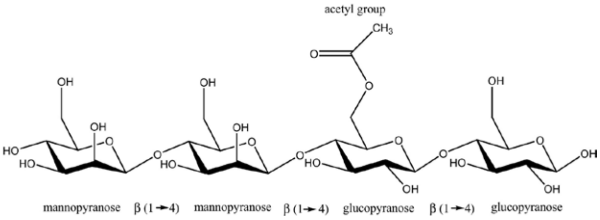

Fig. 3 Structural formula of the repeating unit of konjac glucomannan
Source: EFSA Panel on Food Additives and Nutrient Sources added to Food (ANS) et al. (2017)

their grade of purity. The JECFA specification for konjac flour covers both EU specifications. Both konjac gum and KGM are defined as water soluble hydrocolloid obtained from konjac flour. Konjac gum is obtained by aqueous extraction, while KGM ii is obtained by washing with water-containing ethanol (EFSA Panel on Food Additives and Nutrient Sources added to Food (ANS) et al., 2017).

In China, the China's Agricultural Standard for konjac divides konjac flour into four categories based on their particle size and KGM concentration. These include common konjac fine flour (particle size: 90% 0.125–0.335 mm), common konjac particulate flour (particle size: 90% ≤0.125 mm), purified konjac fine flour (particle size: 90% 0.125–0.335 mm and KGM ≥ 85%), and purified konjac particulate flour (particle size: 90% ≤0.125 mm and KGM ≥ 85%) (Shenglin et al., 2020a).

The processing of konjac corms into flour is the key step in the utilization of konjac. The processing methods can be divided into dry and wet processing methods (Fig. 4).

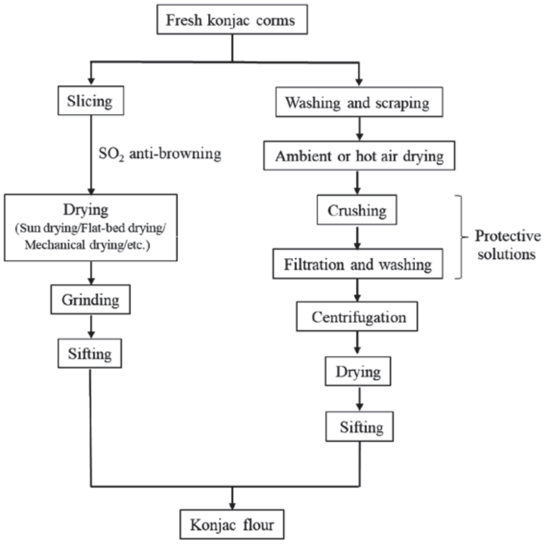

Fig. 4 The processing methods of konjac flour

The dry process commences with the slicing and desiccation of konjac corms. The desiccated chips are pulverized into a powder and screened to remove contaminants. Wet processing encompasses crushing, grinding, centrifugation, and drying. A protective solution is employed for immersing the freshly crushed corms, preventing the konjac flour from swelling or discoloring. Modern processing incorporated both wet and dry methods to achieve high-efficiency results (Zhao et al., 2010). The initial stage involves submerging the pulverized corms in a sequence of protective solutions at a precise concentration that allows the macromolecules to swell without dissolving and becoming amorphous. The macromolecules can be systematically and effectively disintegrated, allowing for the separation of their components. The wet processing stage involves the purification of KGM granules by the elimination of alkaloids, tannins, starch, sulfur, and other contaminants. The second phase, the dry processing stage, involves grinding and sifting the konjac flour acquired in the initial phase according to the application standards for its intended purpose. At this point, a further separation of starch from the surface of the KGM granules transpires (Impaprasert et al., 2020).

Because KGM is highly hydrophilic, it readily disperses in water to form a sol, a colloidal suspension of solid particles. To regulate the solubility of KGM during the wet process, ethanol solutions of varying concentrations are frequently employed as protective agents. As the weight ratio of ethanol to fresh corms increases (ranging from 1 to 3), the ethanol concentration correspondingly decreases (Tatirat et al., 2013; Zhao et al., 2010).

3. Utilizations of konjac flour and KGM in food products

Konjac flour and KGM are highly flexible biomaterials with extensive applications in food preparation. As previously stated, they are listed as food additives utilized as a gelling agent, thickening, film forming, and emulsifier (EFSA Panel on Food Additives and Nutrient Sources added to Food (ANS) et al., 2017). Consequently, several KGM-based food products and functional foods have been commercially introduced.

3.1 Traditional applications of konjac flour

Konjac flour has been used as an important food ingredient for more than a thousand years in China and Japan. With the addition of a mild alkali such as calcium hydroxide, konjac flour aqueous solution (approximately 3% concentration) changes to a strong, elastic and irreversible gel. KGM is usually used to prepare thermal irreversible gel by heating in a certain concentrated alkaline suspension with a temperature higher than 70°C and does not melt even above 100°C (Miwa et al., 1994). The alkali-treated konjac gel is a widely recognized traditional delicacy in Chinese and Japanese cuisine. Traditionally, corms are cleaned, peeled, cut, dried, and crushed to yield konjac flour, which is consumed as cake (or gel) after being boiled with plant ash (a natural alkali). Konjac flour is utilized as a functional meal in several forms, including noodles, tofu, and snacks, or as konjac curd, which is flavorless and typically cooked with meat in traditional cuisines (Chua et al., 2010).

In Japanese cuisine, konjac flour is pounded with lime and water into a gelatinous grey cake, a key ingredient in Japanese noodles (shirataki) and cuisines such as sukiyaki and gyudon. Outside Asia, konjac is also grown as an ornamental due to its beautiful compound foliage and marbled petioles (Follett et al., 2002).

The development of commercial konjac processing technologies originated in Japan. Nakajima (1745–1826) developed a technique to produce konjac flour by pulverizing dried chips of the corm. This was further improved by Mashiko (1745–1854) who developed the methodology to produce purified konjac flour (KGM). Originally this purified flour was used in food production and was later also used as a food additive (Chua et al., 2010; Shenglin et al., 2020b).

3.2 Deacetylated konjac glucomannan

Referring to the structure of KGM (Fig. 4), acetyl groups attached to the saccharide units are scattered randomly along the molecule, with an occurrence of approximately 1 per 19 sugar residues at C-6 position. It is well-known that the removal of acetyl groups on the molecular chains of KGM upon addition of an alkaline coagulant and heating results in the formation of a thermos-irreversible gel (Du et al., 2012).

To date, the deacetylation of KGM has been conducted in homogenous systems, primarily in water, using alkali treatment. Nevertheless, the KGM solution at elevated concentrations cannot be executed using this method due to its significant viscosity and the intricate procedures involved. The aforementioned drawbacks have significantly constrained the use of homogenous deacetylation. The recent focus on solid-phase reactions by mechanochemical treatment has intensified due to increasing economic and ecological demands (Pan et al., 2008). Nonetheless, given that the solid-phase reaction rate is theoretically very slow, the increased degree of deacetylation may be attributed to ethanol washing in the subsequent step rather than the elimination of the acetyl group. Recent reports indicate that heterogeneous deacetylation can be utilized on KGM to achieve deacetylated KGM with a precise and controllable degree of deacetylation (Li et al., 2014). The efficient techniques for making deacetylated KGM are ongoing, and further research is required (Wang et al., 2024; Ye et al., 2022). Notwithstanding the manufacturing difficulties, deacetylated KGM food possesses significant market potential. A diverse array of deacetylated KGM gel foods is commercially accessible, including konjac vermicelli, konjac "tofu," and bionic foods (Song et al., 2022).

3.3 Food additives

KGM functions as a hydrocolloid that enhances the texture of food products. KGM possesses advantageous physicochemical characteristics, including neutral flavor, swelling ability, and capability for gel formation. KGM possesses additional advantageous qualities, including enhanced viscosity and water retention capacity. The characteristics of KGM are contingent upon pH levels. It exhibits water retention, suspension, and stability characteristics at a pH below 10 (Zhang et al., 2005). It has been utilized in jelly to enhance gel strength, in yogurt to improve fruit suspension and gelation, in pudding for mouthfeel and thickening, in pasta to augment water retention, in beverages for mouthfeel, among other applications (Takigami, 2009). KGM has been utilized to enhance the texture and rheological characteristics of starch-based products. The products can be adjusted to exhibit increased viscosity and experience reduced syneresis. KGM decreased the syneresis and moderately enhanced the gel hardness in rice starch gel exposed to freeze-thaw cycles (Charoenrein et al., 2011). Moreover, KGM diminishes starch retrogradation and enhances gel stability in frozen starch gel systems (Lee et al., 2002). The presence of KGM may influence the gelatinization, retrogradation, and complexation processes of starch. The addition of KGM can suppress the retrogradation of starch gel during freeze-thaw treatment, leading to reduced pore size in the composite gel (Charoenrein et al., 2011). The pasting and rheological characteristics of the corm starch were dramatically altered, mostly due to the robust interaction between the corm starch and KGM in the composite system (Ma et al., 2019).

Recently, KGM has been utilized in conjunction with several hydrocolloids, including agarose (Yuan et al., 2018), carrageenan (Penroj et al., 2005), gum Arabic (Li et al., 2021a), and xanthan (Brenner et al., 2015), to enhance gel performance or establish a cohesive network through synergistic interactions (Wang et al., 2023a). The utilization of KGM as a food additive has garnered the attention of researchers owing to its cost-effectiveness, ease, and pronounced impact on preservation.

3.4 Fat replacer

The utilization of fat replacers in low-fat or fat-free products is a prevalent approach to enhance their physicochemical and nutritional attributes. The efficacy of carbohydrate-based fat replacers stems from their capability to enhance gel formation and viscosity, impart flavor and texture, and augment water retention (Dai et al., 2018). The incorporation of KGM enhanced the rheological and textural characteristics of low-fat processed cheese (de Silva et al., 2016). KGM served as a fat substitute in low-fat/skimmed yogurt, enhancing the textural properties and structure of the yogurts through its incorporation (Dai et al., 2016). KGM has been extensively utilized as a fat replacer in the formulation of reduced or low-fat meat products, which are typically influenced by cold storage and freezing/thawing processes. Cold-set konjac gels have been utilized as fat substitutes in the development of reduced or low-fat meat products, including lamb sausages (Osburn & Keeton, 2004), pork meat batters (Fernández-Martín et al., 2009), frankfurters (Jiménez-Colmenero et al., 2010), and fresh pork sausages (Jiménez-Colmenero et al., 2012).

Furthermore, KGM composite has been documented to surpass the textural limitations of KGM alone and offers enhanced nutritional characteristics. The sensory qualities of the complex are more akin to those of actual fat than the gel generated just by protein or polysaccharide (Wei et al., 2024). KGM/oat β-glucan composite gel was utilized to substitute pig back fat in emulsified sausage, resulting in a denser microstructure that enhanced water retention, emulsion stability, and reduced cooking loss in low-fat emulsified sausage (Geng et al., 2023). The KGM/soy protein isolate composite enhanced the texture and rheological characteristics of emulsion gels, facilitating the creation of three-dimensional, plant-based cubic fat substitutes (Ran & Yang, 2022). KGM content enhanced the hardness, springiness, and chewiness of the cubic fat substitutes, hence improving texture and flavor while inhibiting lipid oxidation (Huang et al., 2023).

3.5 Biofilms

Although films derived from petrochemical sources fulfill certain requirements of the food business, they present significant risks, including pollution and food safety concerns. A polysaccharide film serves as an appropriate alternative to address this issue. KGM exhibits superior film-forming capabilities, biodegradability, biocompatibility, and physicochemical stability (Ni et al., 2021). Nonetheless, pure KGM films exhibit numerous drawbacks, including inadequate mechanical characteristics and insufficient stability. To address this issue, various ways are employed to enhance mechanical strength, stability, and other features (Wang et al., 2014). It can be integrated with various polysaccharides, proteins, metal nanoparticles, and reinforcing fibers (including glass fibers, cellulose nanocrystals, and cellulose nanofibers) to enhance performance (Haruna et al., 2019). Nonetheless, the extensive utilization of metal nanoparticles and chemically synthesized fibers has raised concerns regarding the environmental contamination generated by metal nanoparticles. Certain natural biological polymers and their derivatives may be utilized in an environmentally beneficial manner due to their propensity for aggregation, hence mitigating pollution issues (Kaczmarek-Szczepańska et al., 2024; Xu & Pang, 2021).

Recently, KGM composite film has been engineered to improve its functional attributes. The KGM/sodium lignosulfonate/ε-polylysine composite film was observed to improve mechanical strength and exhibit consistent antibacterial properties (Xu & Pang, 2021). A synergistic strategy combining photodynamic and photothermal methods was employed in KGM-based films to provide broad-spectrum antibacterial activity (Ni et al., 2021). The incorporation of 2% carvacrol showed significant antibacterial efficacy against prevalent food spoilage bacteria (Peng et al., 2022).

Health benefits of KGM

KGM, a soluble dietary fiber, offers notable benefits for the digestive system and is classified as a non-caloric fiber due to its resistance to hydrolysis by digestive enzymes (Pichaiyongvongdee et al., 2023; Xiong et al., 2009). In addition to its physicochemical properties, KGM exhibits several functional health-promoting effects, including anti-diabetic activity and the ability to reduce triglyceride levels, cholesterol, blood glucose, and body weight (Chen et al., 2019). It also plays a role in regulating gastrointestinal (GI) function and enhancing immune response (Mao et al., 2022).

The prospective preventive and therapeutic capabilities of KGM in metabolic syndrome are associated with its diverse biological properties, including its anti-diabetic and anti-obesity actions, as well as its capacity to reduce blood pressure and blood lipids (Jian et al., 2024).

1. Anti-diabetic activity

KGM can alleviate certain symptoms of type 2 diabetes mellitus (T2DM) and diminish the necessity for diabetes medications. Clinical studies indicate that KGM effectively lowers cholesterol levels, blood sugar, and glucosamine in individuals. The elevated viscosity of KGM impedes food digestion and extends gastric emptying, thus diminishing the diffusion capacity of glucose across the colon (Guo et al., 2021). KGM may also provide protective effects against lipid metabolic disorders, pancreatic damage, oxidative stress, and insulin resistance, while additionally enhancing hypoglycemic effects (Deng et al., 2020). KGM improves insulin sensitivity by upregulating the gene and protein expression of insulin signaling pathways (Li et al., 2021b). Moreover, KGM may enhance the metabolism of branched-chain amino acids (BCAAs) by modulating the intestinal microbiota, hence contributing to the anti-diabetic effects of glucomannan (Chen et al., 2021).

2. Anti-obesity activity

Numerous research has demonstrated that KGM is equally efficacious in lowering weight and body fat while simultaneously enhancing hunger. A recent investigation indicated that KGM may mitigate obesity caused by a high-fat diet by augmenting thermogenesis in inguinal white adipose tissue through β-adrenergic mediation (Hong et al., 2023).

KGM may mitigate obesity caused by high-fat meals by enhancing insulin sensitivity and averting hepatic injury; it also regulated the release of proteins linked with adipogenesis and adipocytokines (Zhai et al., 2018). A recent experiment of KGM-enriched meals demonstrated that KGM consumption resulted in a substantial reduction in waist circumference (Fernandes et al., 2023), as well as decreases in BMI and total body fat concentration (Kardum et al., 2014).

KGM not only ameliorated hepatocyte hyperplasia in liver tissue and curtailed fat droplet accumulation and lipid peroxidation, but also enhanced energy metabolism and diminished fat accumulation by influencing the gene expression related to lipid metabolism (Shang et al., 2019). Fat accumulation in adipose tissues was significantly inhibited in rats using a KGM-enriched diet, which improved its physical qualities (Xu et al., 2023a). The subcutaneous fat mass of the mice was dramatically diminished due to the consumption of KGM (Liu et al., 2023).

3. Lowering blood pressure and blood lipids

Polysaccharides, such as KGM, are advantageous for reducing blood pressure and cholesterol levels (Jing et al., 2022). KGM dietary supplements successfully decrease cholesterol levels (Arvill & Bodin, 1995), dramatically diminish the ratio of total to HDL-cholesterol, systolic blood pressure, and serum fructosamine (Vuksan et al., 1999). This may be associated with reduced insulin sensitivity, which influences sodium absorption in distal renal tubules, enhances sympathetic nervous system activity, and diminishes peripheral vascular resistance (Vuksan et al., 2001).

4. Meta-analyses and systematic reviews

Meta-analyses and systematic reviews could enhance the creditability of health claims mentioned above. Hence, we summarized the recent meta-analyses and systematic reviews related to KGM. It should be noted that most articles were obtained from glucomannan studies, with very few articles that solely investigated KGM.

In a recent systematic review, a total of 129 participants were included from six trials that met the eligibility criteria, with ages ranging from 25-75 years and duration of KGM intervention lasting from 2-12 weeks. They found that KGM can reduce post-prandial glucose (PPG), fasting blood glucose (FBG), glycated hemoglobin (HbA1c), and homeostatic model assessment of insulin resistance (HOMA-IR) in T2DM patients (Febrinasari et al., 2024).

A recent meta-analysis evaluated the effects of glucomannan supplementation on T2DM in humans. From six randomized controlled trials (RCTs), they found that glucomannan not only reduced the total cholesterol (TC) and low-density lipoprotein (LDL) levels compared with the control group but also reduced the fasting blood glucose (FBG), 2 h postprandial blood glucose (P2hBG), fasting insulin (FINS), and serum fructosamine (SFRA) levels. However, it had no reducing effect on triglyceride (TG) (Zhang et al., 2023). Similarly, a meta-analysis from six RCTs, consisting of 124 participants, found that glucomannan supplementation significantly reduced FBG. However, it had no significant impact on PPG (Mirzababaei et al., 2022).

In addition, a total of 334 participants were divided into either a glucomannan intervention group or a control group. Among the trials, one was conducted exclusively with women, two with men, and eight with both genders. The mean age of participants ranged from 32 to 64 years. The trial durations varied from 3 to 12 weeks. The study found that glucomannan supplementation had a beneficial effect on the level of TC and LDL (Musazadeh et al., 2024). A current systematic review and meta-analysis from 11 RCTs revealed that KGM supplementation positively influenced TC and LDL levels. They also concluded that supplementation with KGM, particularly in older individuals and at higher doses (exceeding 4000 mg/day), demonstrated greater efficacy in improving lipid profiles (Haijan et al., 2024).

Biomedical applications of KGM

Numerous materials derived from KGM are considered superior options in biomedicine due to their exceptional biocompatibility and nontoxicity (Li et al., 2024; Zhuang et al., 2024). These materials are used in drug delivery, wound healing, tissue engineering, antibacterial applications, and anti-inflammatory treatments.

1. Drug delivery

KGM has achieved notable progress in targeted drug delivery and the sustained release of pharmaceuticals (Zhou et al., 2022). KGM gels, in contact with water, serve as an optimal material for matrices that regulate the sustained release of pharmaceuticals. This decreases the frequency of drug delivery and enhances patient adherence, which is beneficial for treatments that need to maintain therapeutic levels in the body for prolonged durations. Moreover, the mucoadhesive characteristics of KGM have been examined in relation to drug delivery. Certain tissues, including the gastrointestinal tract, may maintain extended contact with the polymer due to its propensity for mucosal surface adherence, hence enhancing targeted administration to specific sites and augmenting medication absorption (Kapoor et al., 2024).

A more effective modulation of blood calcium levels has been enhanced by the KGM-based gastric floating delivery system (Ai et al., 2019). The subcutaneous or intravenous injections have been assisted using KGM-based composite materials (Tong et al., 2021). The KGM-based amphiphilic polymers were created and used as a pH-sensitive nano-micelle system for intracellular drug delivery (Luan et al., 2017).

2. Wound healing

KGM has become an ideal choice for wound dressing material due to its excellent biocompatibility, gel formation ability, water absorption, promotion of gas exchange, stimulation of fibroblast proliferation, ease of removal from the wound surface, and enhancement of tissue regeneration (Xu et al., 2023b). KGM-based wound dressings exhibited a unique ability to absorb and retain moisture, forming a protective barrier that sustains wound hydration and promotes healing (Xu et al., 2024). Furthermore, wound dressings made from KGM can act as carriers for various bioactive agents (polysaccharides, proteins, growth factors, pharmaceuticals, and nanoparticles), enabling the incorporation of multiple functionalities (such as antimicrobial and antioxidant properties, extracellular matrix mimicry, sustained drug release, and photothermal therapy) (Su et al., 2024; Tang et al., 2024; Xu et al., 2024; Zong et al., 2024).

The limitations of the mechanical properties of pure KGM material hinder its applicability as a wound dressing (Zhou et al., 2020). Combining KGM with other polymers to attain certain biological functions is an effective strategy for improving the reparative effectiveness of KGM-based wound dressing materials (Genevro et al., 2019). KGM and polyvinyl alcohol fibrous wound dressings exhibited superior moisture retention, air permeability, and a high specific surface area (Yang et al., 2020). A new dressing with superior moisturizing and antibacterial properties was developed using the synergistic combination of cellulose, KGM, and AgNPs (Yuan et al., 2021). A multifunctional and conductive hydrogel, made from polymerized ionic liquids and KGM, was developed for wound dressing, demonstrating enhanced mechanical properties, biocompatibility, and a robust, effective sterilization capability (Liu et al., 2021).

KGM was conjugated with gallic acid (GA) by esterification to prepare a material for skin repair. It was proposed that KGM-GA could significantly upregulate M2 macrophage polarization and eliminate excess reactive oxygen species (ROS), exhibiting efficient dressings for improving the wound healing process (Li et al., 2023) (Fig. 5). Macrophages, which help repair tissue, are highly plastic and can be polarized into classic M1 (inflammatory phenotype early on) and M2 (anti-inflammatory mid-stage) phenotypes. Under certain conditions, they can switch between phenotypes. M2 macrophages release anti-inflammatory and healing factors that reduce inflammation, increase angiogenesis, and establish a regenerative milieu (Gan et al., 2018).

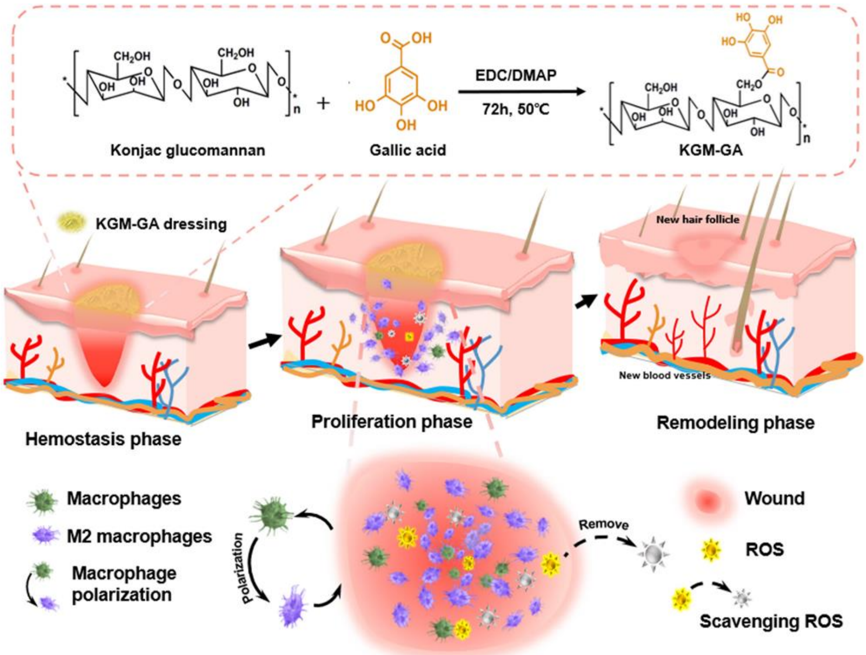

Fig. 5 The synthesis of konjac glucomannan–gallic acid (KGM-GA) and KGM-GA dressing for accelerating wound healing through M2 macrophage polarization and scavenging reactive oxygen species (ROS).
Source: Li et al. (2023)

Tissue repair and skin healing depend on M1-to-M2 shift control. The wound surface also releases copious ROS after skin injury, which helps fight bacterial infections. However, elevated ROS levels can cause oxidative stress and other injury, inhibit angiogenesis, causing endothelial dysfunction (Zhao et al., 2010).

3. Tissue engineering

Tissue engineering aims to replace or regenerate damaged or lost tissues by employing biomaterial scaffolds to include cells and growth factors (Eivazzadeh-Keihan et al., 2024). KGM-based composite materials are efficiently employed in tissue engineering owing to its biocompatibility, non-toxicity, gel properties, and biodegradability (Redondo et al., 2023; Thangavel et al., 2023; Xiao et al., 2024; Yang et al., 2023). A hydrogel demonstrating superior mechanical properties and recoverability was created using Schiff base crosslinking of gelatin and oxidized KGM. The consistently porous structure and advantageous biocompatibility of gelatin-oxidized KGMs hydrogels can promote the proliferation of human umbilical vein endothelial cells (Jiang et al., 2021). Additionally, novel KGM-based microfibre scaffolds were created by combining KGM, polyvinylpyrrolidone, and epigallocatechin-3-gallate, providing enhanced antioxidant capabilities to mitigate ocular fatigue (Ni et al., 2019).

4. Antibacterial activity

Because pure KGM lacks bactericidal characteristics, it is typically used as a composite carrier for antibacterial active ingredients in the production of antibacterial products (Lin et al., 2019; Ni et al., 2021). Various natural antibacterial agents (including curcumin, epigallocatechin-3-gallate, gallic acid, and nisin) are integrated into KGM-based substrates to confer antibacterial characteristics (Du et al., 2019; Pan et al., 2024a; Wang et al., 2019; Wang et al., 2023b). Composite materials made from the combination of KGM with an antibacterial agent are extremely important for effectively treating foodborne diseases (Yang et al., 2022).

The incorporation of metal nanoparticles (e.g., Ag, Au, ZnO, and TiO_2) into KGM-based materials has improved their antibacterial properties (Llorens et al., 2012; Sun et al., 2020). KGM/chitosan hydrogel dressings loaded with Ag nanoparticles exhibit strong antibacterial activity (Jiang et al. 2020). Duan et al. (2021) produced nanocomposite films containing KGM, κ-carrageenan, and TiO_2 nanoparticles to enhance their antifungal properties and efficacy.

5. Tumor and anti-inflammatory

Radiotherapy and chemotherapy are the most often used cancer treatment options (Dash et al., 2024). Natural biopolymers such as KGM, chitosan, starch, and sodium alginate have been widely used as anticancer drug carriers due to their low toxicity, high biocompatibility, and biodegradability (Tören et al., 2024). A previous study has demonstrated that KGM can be used as both an anticancer drug and a component in the creation of composite materials for anticancer medication administration (Li et al., 2019).

Furthermore, KGM-based materials have been used to treat inflammatory diseases (Gu et al., 2023). A Previous studies have looked into the effect of pulverized KGM on the intestinal immunity of mice with oxazolone (OXA)-induced colitis. The findings suggested that PKGM could be used to purposefully treat OXA-induced colitis (Onitake et al., 2015). Because of its specific affinity, KGM can cause macrophages to secrete pro-mitogenic, pro-angiogenic, and anti-inflammatory chemicals (Wang et al., 2020). Binding to mannose receptors on macrophage surfaces promotes M2 polarization, releases anti-inflammatory molecules, and reduces inflammation (Deng et al., 2023; Pan et al., 2024b).

Konjac for bioenvironment conservation

Given that konjac can be cultivated in an intercropping arrangement beneath forest canopies or in the shade of community forests and shrubs, its promotion for planting in community forests could be advantageous for environmental conservation and addressing deforestation issues (Suksard et al., 2019). Konjac cultivation in community forests can be classified as a non-timber forest product (NTFP). The global recognition of NTFPs has emerged as a crucial strategy for sustainable forest management, ecological conservation, and regional economic growth (Baumgartner, 2019). This is especially crucial for underdeveloped areas (Lepcha et al., 2019), where NTFPs can convert resource advantages into economic gains, alleviate poverty, and enhance local living conditions (Belcher & Schreckenberg, 2007), thereby attaining equitable economic, social, and ecological benefits (Mon et al., 2023; Shackleton & de Vos, 2022). Consequently, the ongoing promotion of NTFPs is highly significant.

This case study highlights the promotion of konjac cultivation in Tak province, Thailand, an area confronting deforestation and wildfire issues. The villagers and hill tribes are permitted to cultivate konjac on specific lands within the National Parks, in accordance with official rules (Choonim et al., 2022; Suksard et al., 2019). The villagers must establish the group and subsequently register with the Royal Forest Department of Thailand. The authorized group is permitted to cultivate solely inside their assigned zones, adhering to the plantation regulations established by the department. Upon harvesting, they must report to the agency for authorization prior to transporting the product from the area for sale to cooperatives or konjac processing facilities. The province hosts multiple konjac processing facilities supported by the Department of Industrial Works of Thailand. Fig. 5 illustrates the supply chain. It functions effectively and can enhance the villagers' income while mitigating the spread of deforestation. The financial analysis included three indicators: benefit-cost ratio (BCR), net present value (NPV), and internal rate of return (IRR), assessed at a discount rate of 7%. They found that B/C > 1, NPV > 0, and IRR > the determining discount rate (Choonim et al., 2022).

The local factories in Tak province generally process dried konjac chips and konjac flour, and products are mostly exported to China. Villagers only sell fresh corms. No high-value products undergo processing in these areas. There are promotions from the government to process konjac into high-value products, such as noodles, konjac tofu, etc.

The konjac agroforestry system has also been adopted in Indonesia, particularly within state-owned industrial forest areas in Central and East Java. In this system, konjac is cultivated as an intercrop beneath the canopy of hardwood trees. Local communities participate in konjac farming, contributing to forest maintenance while simultaneously generating significant income through the sale of konjac corms (Hermudananto et al., 2019). This model underscores the potential of konjac cultivation to support sustainable agriculture, especially within community-managed woodlands aimed at environmental conservation. Furthermore, it highlights konjac's role in promoting rural economic development and alleviating poverty.

Additionally, konjac is a prevalent plant in various regions of China. It has been advocated for agrobiodiversity conservation in Yunnan Province, China, owing to its several advantages (Long et al., 2003). However, the sustainable development of the NTFPs faces challenges in several aspects. Factors such as the development of the industry chain and the low level of marketization affect the economic sustainability of the NTFPs. Additionally, the absence of policy support may hinder the social sustainability of the NTFPs (Pandey et al., 2016; Qiao et al., 2024). It should be noted that the excessive cultivation of konjac in forest areas may pose a threat to biodiversity and hinder the growth of indigenous plant species (Wahidah et al., 2021).

Konjacs are planted in the shade of the forests (designated areas)

↓

Reporting and inspection of areas and quantities to be taken out for selling

↓

Selling to the factory

Fig. 5 The supply chain of konjac in Tak province of Thailand

Conclusion

There is no doubt that konjac and its derived functional glucomannan or KGM, have garnered interest as natural, biologically active compounds with exceptional biocompatibility and innocuous properties. They have exhibited extensive applications in the domains of food, health, and bioenvironmental sciences. Konjac flour and KGM have been registered as food additives for food texture improvement and emulsifiers. KGM also possesses the ability to serve as a fat substitute and a component of biofilms. Prospective investigations of KGM in nascent sectors such as biodegradable polymers or plant-based food products are required.

As a soluble dietary fiber, KGM demonstrates numerous health advantages. Owing to its superior biocompatibility and nontoxicity, KGM applications extend to biomedicine. Furthermore, konjac can be advocated to address environmental conservation and deforestation issues, as it is classified as the NTFP that provides socio-economic benefits to society.

Although konjac has been cultivated and consumed for centuries in various regions of China, Japan, and Southeast Asia, it is still often grown under semi-wild conditions in many production areas. In most regions, the crop is cultivated using unimproved genetic material, which limits its capacity to meet the demands of industrial-scale production. Therefore, the development and implementation of efficient cultivation and management practices are essential. Moreover, advanced genetic improvement of konjac varieties tailored to industrial applications may offer viable solutions. Attention should also be given to the promotion of konjac cultivation in additional countries, with careful consideration of supply–demand dynamics and potential impacts on biodiversity.

In terms of the application of KGM, recent research focuses on its synergistic effects with other polysaccharides to enhance their functional properties. The synergistic effects of KGM with other active compounds also enhance their health benefits. The KGM composites could exhibit excellent choices for use in drug delivery, wound healing, tissue engineering, antibacterial activity, and anti-inflammatories. Furthermore, there is also a need for clinical trial research to confirm the health benefits of KGM and their composites.

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