Flaxseed Gum

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Contributor: František Lorenc, Markéta Jarošová, Jan Bedrníček, Pavel Smetana, Jan Bárta

FG, also known as flaxseed mucilage, is present in the outer layer of the seed coat, and its content in the whole seed ranges between 3.5–15.0%, depending on the flax variety and the planting area. The extraction method and its parameters determine the yield, purity, and properties of FG. For instance, the temperature of extraction is an essential factor affecting the chemical composition, functional properties and biological activities. Functional properties of FG can also be determined by the processing after extraction, for instance, by drying. Thus, the applied extraction method and further processing are the key factors for obtaining FG with the optimal properties according to subsequent use.

Keywords: Linum usitatissimum L. ; flaxseed ; flaxseed gum ; polysaccharides ; food hydrocolloids ; functional properties ; health benefits

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1. Methods of Extraction

Polysaccharides are easily extractable from flaxseed; it is possible to obtain them from whole seeds [1], seed hulls [2], or oilseed cake [3]. Safdar et al. [4] used four methods for the extraction of FG from whole flaxseeds with differences in the relative yield of FG from flaxseeds: hot water extraction (9.0%), ultrasound-assisted extraction (7.8%), microwave-assisted extraction (7.0%) and alkaline–acidic extraction (6.4%). For the highest yield of FG, hot water extraction is preferable, whereas, for maximal purity, it is most suitable the ultrasound-assisted extraction method. Cui et al. [5] suggested the optimal condition of aqueous extraction with respect to yield, apparent viscosity, and protein content of the final gum extract. These conditions were a temperature of 85–90 °C, a pH 6.5–7.0 and a water:seed ratio of 13. Subsequently, Kaushik et al. [1] reported that the yield, purity of carbohydrates, and protein content could be significantly affected by the extraction temperature within the aqueous extraction. They observed the increasing yield of FG from 2.1 to 8.4% with increased extraction temperature from 30 to 90 °C. They have also suggested that the longer extraction time increases the yield of FG. Fabre et al. [6] reported ultrasound-assisted extraction as the most effective method with a 6.8% relative yield, followed by hot-water extraction (6.5%) and microwave-assisted extraction (2.1%). Except for the methods and conditions of extraction, the yield of FG can vary with the type of flax cultivar, crop age, and climate [7].

2. Chemical Composition and Structure

FG is composed mainly of polysaccharides, up to 90% of relative content. Kaushik et al. [1] reported 80–90% saccharides content in FG, depending on the extraction temperature. Other studies present lower values for saccharides within FG, reaching only 68% [8] or 71% [9]. The minor part of FG represents proteins, lipids, ashes [1][10], and other compounds, such as phenolic acids [11]. However, within several studies describing the chemical composition of FG, the different values reported for saccharides, proteins, and ashes determine the wide range of their relative content in FG. The content of lipids is low compared to other constituents. The relative content of saccharides and proteins depends on the temperature of extraction, whereas increasing the extraction temperature from 50 °C to 90 °C reduces the polysaccharides yield (90.3% → 80.0%) but increases the content of proteins (4.7% → 15.1%) in FG. Conversely, there were not reported significant changes in the content of ashes and fats induced by the changes in the extraction temperature [1].

The extraction conditions may affect the ratio between the types of monosaccharides in obtained FG. Kaushik et al. [1] reported decreased ratio of neutral:acidic monosaccharides from 6.7:1 to 5.7:1 as the extraction temperature was increased from 30 to 90 °C. Troshchynska et al. [12] found that the FG of brown seed cultivars Libra Bio and Recital were more acidic (pH 5.4–5.5) compared to the yellow-seeded cultivars Amon and Raciol (pH 5.8–6.1). However, Cui and Mazza [13] reported the lower content of acidic monosaccharides (rhamnose, fucose, galactose, and galacturonic acid) and, conversely, higher content of neutral xylose within brown-seed cultivar NorMan compared to yellow-seeded cultivars Omega and Foster. Thus, the relation between cultivar type and monosaccharidic composition of FG remains unexplained.

The extraction method significantly affects the yield of polysaccharides and proteins extracted from FG. Higher content of proteins and browning in color was observed within FG extracted at higher temperatures [14]. Moczkowska et al. [15] assessed 22% of protein and only 42% of polysaccharides content extracted by the alkaline method, whereas using the enzymatic-assisted method with ultrasound allowed for the extraction of 8% of protein and 69% of polysaccharides from FG. Furthermore, microstructural differences of FG extracted from six Chinese and Mongolian flax varieties were described [16]. Differences in the structures were also found between seven Italian flax cultivars. They also differed in chemical, physicochemical, and functional properties [7]. According to the studies, it is evident that the extraction conditions have a crucial role in the monosaccharide composition of FG, mainly determined by the ratio of neutral to acidic polysaccharides in FG. This ratio then significantly determines the physicochemical properties of FG, e.g., viscosity, and thus, also other functional properties [17].

3. Functional Properties

As a soluble fiber, FG has a significant ability to bind water, reaching values of 16–30 g water/1 g FG [18]. FG is also responsible for the high-water holding capacity of flaxseed flour, reaching approximately 4.15 g of water/1 g of flaxseed flour [19]. The ability of FG to bind oil is approximately 1 g oil/1 g FG [3]. FG is generally characterized by high viscosity (rheological properties or parameters such as viscosity, shear-thinning, and Newtonian flow, as the physical characteristics, are involved within functional properties of FG due to their influence on the functioning of FG within certain applications) comparable to acacia gum and higher than guar and tamarind gums [20]. A higher proportion of neutral polysaccharides (arabinoxylans), which have a higher MW, increases viscosity and exhibits the shear-thinning flow behavior of FG. Conversely, as the abundance of lower MW acid polysaccharides increases, the viscosity decreases, and Newtonian flow behavior is exhibited. Viscosity and fluidity are also affected by the pH of FG. The lowest viscosity of FG appears at pH 2. With increasing pH, the viscosity increases up to pH 8, when the viscosity is 3-times higher than FG with pH 2. However, at a pH higher than 8, the viscosity decreases again. Different varieties exhibited wide variations in viscoelastic properties of extracted FG. At the same concentration in solution (1 to 3%), it may have a form of viscoelastic fluid or a real gel [17]. The ratio of polysaccharides also affects the related rheological properties of FG, which may form a weak gel with a higher proportion of neutral polysaccharides. At high concentrations of acidic polysaccharides, FG appears as a viscoelastic fluid [21]. The addition of FG at the concentration of 0.08% to carrageenan gel within a fixed 1% concentration of polysaccharides in the solution decreased the syneresis from 11.0% to 6.6% of FG/carrageenan gel and increased the viscosity [22]. In their research, Hu et al. [23] reported that FG extracted at a temperature of 70 °C had a higher viscosity compared to FG extracted at 98 °C (96.7 vs. 78.8 mPa·s) on the first day after extraction but lower viscosity than 98 °C (70.1 vs. 71.9 mPa·s) after storage at 4 °C for eight days. FG extracted at 98 °C had a better foaming capacity (~135 vs. ~127%) and foam stability (~88 vs. ~79%) on the first day after the extraction, but after eight days of storage, these parameters stayed comparable for both FG (foaming capacity: ~132–133%, foam stability: ~86–87%). Emulsion capacity (~43–46%) and stability (~98–100%) were comparable for both types of FGs after the first day after extraction but decreased for FG extracted at 70 °C and stayed quite constant for FG extracted at 98 °C after storage for eight days. These observations indicate changes in the functional properties of FG extracted at different temperatures by hot water extraction.

The relation between emulsion stability and pH value was observed, where the highest stability of the emulsion, in the form of model salad dressing, was observed at pH 6. FG is a comparable or better emulsifier than Tween 80, gum arabic, and gum tragacanth. An FG concentration ranging from 0.5-1.5% is suitable for stabilizing water-oil emulsions [17]. High creaming stability (creaming volume: 100%) within emulsion containing 10% olive oil (*w*/*w*) was observed for the emulsion with a high content of FG (0.4%–0.5% *w*/*w*), as well as better rheological properties of the emulsion with same addition of FG [24]. FG shows similar or even better foam stability (~41%, 1.0 *w*/*w*) than gum arabic and xanthan gum (15–27%, 0.5 *w*/*w*) [25]. Significant functional properties of FG can be affected by the extraction temperature. It has been found that the viscosity and elasticity of FG decrease with increasing temperature and is also affected by the pH values of the FG solution [11]. Fabre et al. [6] reported that ultrasound-assisted extraction decreases the intrinsic viscosity of FG extracted by hot water from 12.5 dL/g to 6.2 dL/g, and the MW of the largest polysaccharides decreased from 1500 kDa to 500 kDa. Another study reported that FG extracted at 30 °C exhibited a water absorption capacity of 25.9 g/g, comparable to that of guar gum (22 g/g). However, there was observed a deterioration in emulsifying activity (emulsion activity index: ~150→~60 m^2/g, 70→90 °C) and water absorption capacity (down to ~12 g/g, 90 °C) within FG extracted at higher temperatures. This study also stated that emulsifying activity can be affected by the content and composition of proteins in FG. Apart from that, FG extracted at higher temperatures exhibited an insignificantly increased fat absorption capacity [1].

The microstructure of FG also affects its functional properties and may vary between flax varieties [7][16]. Temperature stability is one of the properties determined by variety or its type. FG extracted from a yellow flaxseed cultivar showed higher temperature stability than FG extracted from brown flaxseeds. FG of yellow flaxseed also showed higher MW (1150–1340 kDa), higher intrinsic viscosity (6.63–5.13 dL/g), as well as viscoelastic and thickening properties [26]. The functional properties such as viscoelasticity, gelling ability, and emulsifying activity can also be influenced by phenolic compounds, especially lignans and phenolic acids, and their migration within FG. An improvement in rheological and emulsifying properties was observed when the phenolic compounds were removed, which may be caused by changes in the spatial conformation of the protein or disruption of noncovalent interactions between phenolic compounds and polysaccharide chains [27]. Unfortunately, the natural structure of FG could have inherent problems associated with its use, including uncontrolled hydration rates, solubility dependent on pH, thickening, a drop in viscosity in storage, and probable microbial contamination. Thus, the authors report that the original structure of FG can be modified by crosslinking or esterification to obtain the desired and defined properties [28].

Based on the reported findings, it is evident that the genotype and extraction conditions, determining the chemical composition and structure of FG, significantly influence the functional properties of FG, and they are crucial to obtaining FG with the desired properties. Further processing of FG, such as drying (by spray, freeze, vacuum, or oven) or ethanol precipitation, also affects some functional properties of FG, such as emulsifying activity, foaming, and gelling ability [25].

4. Biological and Physiological Activities

In addition to the functional properties, FG also shows several biological activities. FG possesses strong antioxidant activity, which has been confirmed in several studies [4][10][11][29][30]. The antioxidant activity of FG is significantly affected by the presence of some phenolic compounds easily extractable with FG, such as caffeic acid, p-coumaric acid, epicatechin, ellagic, cinnamic, and vanillic acids. Similarly, like the polysaccharides and proteins of FG, it was found that the content and composition of phenolic acids and related antioxidant activities are affected by the extraction temperature. With increasing extraction temperature (25 → 40 → 60 °C), the scavenging activity against DPPH (2,2-diphenyl-1-picrylhydrazyl) radical (4.4 → 12.3 → 29.6% radical scavenging activity) and the total content of polyphenols (12.4 → 13.0 → 18.6 mg GAE/100 g) increased. However, the content of caffeic acid (6.6 → 6.4 → 6.1 mg/L) and *p*-coumaric acid quantified together with epicatechin (1.6 → 1.4 → 1.4 mg/L) decreased slightly with increasing temperature, whereas the cinnamic acid content remained unchanged (2.3 mg/L) at all temperatures in FG solution. On the other hand, the ellagic acid content increased significantly at 60 °C (1.2 → 1.1 → 3.1 mg/L), and vanillic acid was detected only in FG extracted at 60 °C (5.4 mg/L) and was nearly comparable to the content of caffeic acid [11]. Although flaxseed contains high amounts of lignans, it remains a question whether these compounds are extracted together with FG and how much they participate in the antioxidant activity of FG.

Safdar et al. [10] report a high antioxidant potential of FG and a rise in antioxidant activity due to increasing FG concentration in an aqueous solution. The highest antioxidant activity was found at the highest measured concentration (30%) of FG expressed as total antioxidant activity [31], reaching the values of approx. 588 µg Trolox/1 mL FG. The scavenging activities reached 98% against the radical DPPH and 72% against ABTS (2,2′-azino-bis(3-ethylbenzothiazoline-6-sulfonic acid). Bouaziz et al. [29] previously assessed the antioxidant properties of FG extracted from flaxseed. They reported higher scavenging activity against DPPH (expressed as the half inhibition concentration = IC_{50}) for FG (IC_{50} = 2.5 mg/mL) compared to the antioxidant activity of polysaccharides of guara fruits (IC_{50} = 10.8 mg/mL), prickly pear peels (IC_{50} = 10.8 mg/mL) and almond juice processing by-products (IC_{50} = 2.87 mg/mL) but was lower than for polysaccharides of garlic straw (IC_{50} = 0.74 mg/mL) and pistachio juice processing by-products (IC_{50} = 1.61 mg/mL). Yang et al. [30] compared the antioxidant activities of total FG and flax oligosaccharides extracted from FG by enzymatic degradation.

Similarly, like other types of soluble fiber, FG forms a viscous or gel-like material when dissolved in water [32]. FG affects digestion in more ways. It increases food weight in the gastrointestinal tract and feces [18]. It presumably interacts with fats and sugars in the intestine and inhibits their absorption. This hypothesis is supported because fats and sugars are excreted as part of the feces when FG is consumed to a greater extent than in the case of subjects that do not ingest FG [33]. Consumption of FG also causes the prolonged feeling of satiety, accompanied by more extended inhibition of the enzyme ghrelin—a signal digestive peptide that stimulates hunger [33]. Reductions in body weight and body fat, respectively, and total triglycerides, have been confirmed in animal clinical trials due to reduced fat and energy absorption within animal subjects. This phenomenon has probably been related to the regulation of intestinal microflora as an effect of FG consumption. In particular, the inhibition of *Clostridium* bacteria from the phylum of Firmicutes was observed. Conversely, they report a slightly increased presence of bacteria from the phylum Bacteroidetes and a strong increase in the occurrence of strains from the phylum Proteobacteria [34].

5. Potential Applications

FG is a substance without taste properties, which is an essential property for its use in the food industry [7]. However, it was reported that adding FG may improve the sensory characteristics (appearance, structure and porosity, crumb color, smell, and taste) of freshly baked gluten-free bread when 1.8% or 2.4% of starch is substituted by flaxseed gum [35]. FG can replace commonly applied thickeners, emulsifiers, beverage stabilizers, and similar applications. Its presence in bread affects the baking properties, such as stickiness, rheology of dough, and baking process. In addition, it improves the texture, which is softer, makes the bread soft for longer and delays hardening during storage, probably caused by the presence of the arabinoxylan fraction. It has been suggested that 0.5% of FG (flour basis) could replace 0.1% xanthan or guar gums. FG positively affects the gluten behavior in the dough since an increase in volume was observed during leavening and baking. In bakery products and ice cream, FG can also substitute egg whites [17].

The complex viscosity of salad dressing may increase with the rising concentration of FG from 0.13 Pa·s (0% FG) to 6.61 Pa·s (0.75% FG) to finally 37.2 Pa·s (1.5% FG) and prevent flocculation and coalescence of the contained oil. The most stable emulsion was observed after the addition of 0.75% (*w*/*w*) of FG and 2.5% (*w*/*w*) of salt at pH 4 [36]. As an emulsifier, FG can also be used as a part of beverages. It can suppress creaming and increase the viscosity of fruit or vegetable juices since this phenomenon has been observed in the case of unfiltered carrot juice. At the same time, adding 0.5 g/kg of FG was most effective for stabilizing the cloudy carrot juice [37]. FG effectively improves texture characteristics and reduces the syneresis of stirred yogurt containing 0.6 g of FG per 100 mL of yogurt (14.3 → 0.1 mL). It also supports the optimal growth of starter microorganisms [38]. The 0.1, 0.2, or 0.3% concentration of FG in the heat-induced gel increased the water-holding capacity by 7.0%, 15.5%, and 25.8%, respectively, thus offering the use of FG within meat products [39]. FG, up to a content of 12%, in a mixture of carrageenan and gellan gum improved the sausage texture and color of the sausage. FG enhanced the hardness, springiness, and emulsion stability of the product [40]. In addition to the possibilities of using FG itself, it also has potential in interactions with proteins, and the possibility of applications of the complexes of these components is also studied. These heterogeneous mixtures may exhibit a combination of not only functional properties of the two components separately but also properties determined by their interaction.

A study focused on flax–protein interactions observed the formation of electrostatic coacervates consisting of whey protein and FG. These biopolymers were characterized by high viscosity and viscoelasticity, predetermining their use as a texture modifying component of food products. The maximum coacervate formation and viscosity were assessed when the mixture of whey protein isolate/flaxseed gum was prepared in water at pH 3.8, constant biopolymers concentration of 0.05% (*w*/*w*), and their ratio of 2:1 (*w*/*w*) [41]. Coacervates of FG and FPs were used as coating materials to encapsulate unstable or volatile compounds. Kaushik et al. [42] used FG and FPI crosslinked with glutaraldehyde to encapsulate flaxseed oil with three core (oil)-to-wall ratios (1:2, 1:3, and 1:4) to preserve its oxidative stability. The highest microencapsulation efficiency (87%) was observed at the spray-dried microcapsules with a surface oil of 2.8% at a core-to-wall ratio of 1:4 and an oil load of 20%. Pham et al. [43] enriched FPs-FG complex coacervates, encapsulating flaxseed oil, with flaxseed polyphenols and hydroxytyrosol to enhance the efficiency of this material against oxidation of flaxseed oil which was better than for ordinary FGI/FPI complex coacervates. The optimal protein-to-gum ratio was 6.00. The microcapsules with the lowest surface oil (1%, *w*/*w*) and highest microencapsulation efficiency (95.4%) were produced using (FPI-hydroxytyrosol)/FG complex coacervates. FG and rice bran protein coacervates were also successfully used to encapsulate vanillin to improve its thermostability and shelf-life. The optimum ratio and total concentration of rice bran protein and FG, for the maximum strength of the complex coacervate, were 9:1 and 0.4, respectively [44].

FG has been successfully used as a functional agent in edible coatings or films, protecting plant or food products against microbial spoilage and oxidative deterioration, thus preserving their sensory characteristics and safety. FG-based coatings preserved the sensory attributes, especially color, of cheese [45] and inhibited the invasion of foreign microorganisms (*Escherichia coli* and *Staphylococcus aureus*) [46]. As a part of edible coatings, FG can be used to prolong shelf-life and preserve the microbiological quality and sensory parameters of fresh fruits. The coatings containing 0.6% of FG and 500/800 ppm of essential lemongrass oil had promising effects on the sensory attributes and other overall quality parameters of ready-to-eat pomegranate arils [47]. Coating of FG with chitosan applied on pieces of fresh cantaloupe preserved sensory characteristics and increased the consumers' acceptance of the fresh-cut fruit, stored at 4 °C for 12–15 days [48]. FG combined with other polysaccharides (chitosan, pullulan, nopal, and aloe mucilages), used for a coating of fresh-cut pineapple pieces, improved the quality and prolonged the shelf-life of the fruit for 6 days compared to control samples [49]. FG was also used as a constituent of coating for yacon as the carrier of the probiotic bacteria *Lactobacillus casei,* preserving the number of viable cells throughout the storage at 8 log CFU g^{-1} [50].

Apart from the food industry, there is potential to use these mixtures in the medicine, pharmaceutical, and cosmetic industries [28]. The biological properties of FG may have a positive influence on human health, predetermining its use in the treatment of diabetes, cholesterol reduction [51], the development of obesity [34], and it can have a role in the management of hyperglycemia [52]. FG also has potential for non-food and non-health applications, such as in the printing, textile, tobacco, and paper industries [17]. In immobilized form, FG can be used to produce gel particles enabling ecological adsorption of oils from wastewater, while the adsorption properties of these particles overcome the effect of activated carbon [53]. It can also be used in the mining industry. The ability of FG in the flotation of fluorite from calcite has been demonstrated [54]. Together with cellulose nanocrystals, FG may form nanocomposite materials or biopolymers that can be used to produce bioplastics [55].

As reported in many studies, FG possesses similar properties to other plant gums, so they can successfully substitute in various food products. However, FG protein coacervates may become highly functional agents that can potentially replace commercial gums in the future. Further research should also be focused on the potential application of FG related to their unique biological properties, such as the development of new types of functional coatings to protect not only sensitive foods but also various natural products and preserve their native properties. FG may become an active constituent of encapsulating material which would serve for the transportation and protection of probiotics or drugs and other bioactive compounds within the human gastrointestinal tract to the intestines avoiding the harsh condition of the stomach. Like the other plant gums, especially gum guar, FG can be processed by hydrolysis or other treatment to produce functional and health-beneficial oligosaccharides usable in food products or pharmaceuticals. Thus, there are many directions and possibilities for future research related to FG within the food and pharmaceutical industry.

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