Black Sea Journal of Agriculture
doi: 10.47115/bsagriculture.1431076

Open Access Journal
e-ISSN: 2618 – 6578

Research Article
Volume 7 - Issue 2: 168-175 / March 2024

COMPARISON OF SOLUBLE FLAXSEED GUM EXTRACTS USING DIFFERENT AQUEOUS EXTRACTION METHODS

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Abstract: Gums and mucilages represent viable options for incorporation into food formulations owing to their numerous advantageous properties, including emulsification, thickening, and modulation of rheological characteristics within food products. Flaxseed is a material with its soluble gum that can be used for food fortification. Within the scope of the study, extracts were obtained using 16 flaxseed extraction methods in the literature and compared in terms of their general properties (color, flow behavior, total soluble solids). The method with 1% ratio, 80°C, 750 rpm and 15 minutes, with pH 5.3 was not suitable for fortified emulsion-based food another method with a 10% ratio, 90°C, 750 rpm and 240 minutes, with maximum Brix was suitable for fortified foods with soluble solid. The methods with 5% ratio, 100°C, 750 rpm and 30 minute parameters and 12% ratio, 90°C, 750 rpm and 240 minutes parameters, which have higher viscosity and lighter color, can be used for light color-fortified products. The A9 (8% ratio, 90°C, 750 rpm and 240 minutes) and A10 (10% ratio, 90°C, 750 rpm and 240 minutes) samples the highest viscosity with the darkest color, can be selected for fortified products where color is not important but needs to be improved in terms of consistency. The results indicate that method parameters in literature for soluble flaxseed gum (SFG) should be chosen according to the characteristics of the food to be fortified.

Keywords: Flaxseed, Aqueous extraction, Water soluble flaxseed gum, Functional foods

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Received: February 03, 2024
Accepted: February 29, 2024
Published: March 15, 2024
Cite as: Tok Z, Mortaş M. 2024. Comparison of soluble flaxseed gum extracts using different aqueous extraction methods. BSJ Agri, 7(2): 168-175.

1. Introduction

Flax is recommended as raw material for the textile industry (Coskuner and Karababa, 2007) and its seed can be consumed in different forms as a food ingredient or for medicinal purposes since its cultivation (Oomah and Mazza, 1998). The Latin name of it means 'very useful' because of its versatile use. In this way, flaxseed (*Linum usitatissimum L.)* can be used to describe flax when eaten by humans; on the other hand, linseed is used to describe flax when it is used for industrial purposes (Morris, 2004). In this manner, consuming of flaxseed (*Linum usitatissimum L.)* is one of the alternatives for daily nutrition. It contains high amounts of oil, protein and dietary fiber and generally, brown Canadian flaxseed composition is 41% fat, 20% protein, 28% total dietary fiber, 7.7% moisture and 3.4% ash (Morris, 2004).

Consumption of high levels of plant-derived foods can provide essential amino acids, lipids, carbohydrates, vitamins, minerals, fibers, and other phytonutrients that can be linked to lower risks of various chronic diseases (Cardosso Carraro et al., 2012; Edel et al., 2015). In literature, it is suggested that flaxseed consumption can lower the risk of cardiovascular diseases, inflammation, diabetes, cancer, kidney diseases, gastrointestinal disorders, and maintain brain health (Parikh et al., 2018; Thumann et al., 2019; Almehmadi et al., 2021; El Seedy et al., 2021; Karantonis et al., 2022). Flaxseed is one of the key sources of functional foods because of its ingredients and physical supporting properties. Ingredients isolated from flaxseed, such as oil, soluble dietary fibers, and lignans, have been incorporated into multiple food products to enhance their nutritional and functional properties (Hallund et al., 2008; Marie and Ivan, 2017; Basiri et al., 2018; Bastida et al., 2021; Kairam et al., 2021). Soluble flaxseed gum, also known as flax mucilage (SFG), is primarily found in the outermost layer of the hull. This fiber-rich hull can readily release mucilaginous material, or soluble gum, when immersed in water (Hu et al., 2020). Gums and mucilages represent viable options for incorporation into food formulations owing to their numerous advantageous properties, including emulsification, thickening, and modulation of rheological characteristics within food products (Hamdani et al., 2019; Yemencioglu et al., 2020).

In literature, the flaxseed extract was used in bread (Hao and Beta, 2012), cereal-based products (Celik and Kuzumoglu, 2020), beverages (Basiri et al., 2018), and spreads (Ghosal et al., 2022) for improving textural and rheological properties. Over the past ten years, research has predominantly concentrated on whole flaxseed-enriched food products (excluding studies on single flaxseed components in foods). Bread has been the primary focus, accounting for 44% of the studies, followed by pasta (10%), cookies (9%), and yogurt (9%). The interplay between flaxseed ingredients and substrate components varies depending on the specific fortified food matrix (Zhang et al., 2023). This fiber-rich hull can readily release mucilaginous material (soluble gum) when soaked in water. This fiber-rich hull can readily release mucilaginous material (soluble gum) when soaked in water. Previous research analyses primarily focused on the gum extracted from the whole seed (Qian et al., 2012). The properties of the SFG depend on seed types and extraction methods. It is known that the compatibility of the mucilage produced depending on different time and ratio parameters with the food to be functionalized is important and there are studies on extraction. The main problem is that it needs to be known which extraction method is suitable for the functional food to be enriched in terms of matrix, color and brix. Color change is not desired in foods that will be given functionality, but an increase in consistency is desired. In some cases, the color change is insignificant and more consistency is required. However, it has yet to be known for which food type SFG obtained by which extraction method should be used. Comparison of the extraction methods indicates the significance of choosing the right extraction temperature to align with the SFG properties for the particular application (Kaushik, 2017). In the present study, different aqueous extraction methods reported in the literature were used to extract SFG from flaxseed samples, and the effect of extraction method on the color, rheological, pH and Brix properties of extracts was determined.

2. Materials and Methods

The flaxseeds (*Linum usitatissimum*) used in this study (Fig.1) were of commercial origin with the Arifoglu brand and obtained from a local market in Türkiye. The chemicals used for analysis were Sigma-Aldrich (Germany) and Merck (Germany) brands.

2.1. Preparation Methods of SFG Aqueous Solutions

In this study, 16 different extraction methods were used to extract (flax mucilage/ soluble flaxseed gum -SFG) from brown flaxseed (Figure 1) and the methods are listed in Table 1. In general, seed ratio (%), water temperature of used and time of mixing process are three main parameters. The parameters were ranged from 1% to 12% for seed ratio, from room temperature to 100°C for temperature, from 15 minutes to one night for mixing time and from 250 rpm to 1000 rpm for mixing rpm. Firstly, whole flaxseed weighing was carried out according to the method, then water was added according to the determined seed ratio and then mixed on a heat-controlled magnetic stirrer according to different holding times (VELP Scientifica). For the next step, whole seeds were separated with a centrifuge of 5500 g and 15 minutes to get a clear extract (Hettich Universal 320R). This last process, including separating the seed from SFG, applied all the methods as a last step. The SFG samples obtained according to the methods was used in the analysis.

2.2. Proximate Analysis

In summary, 2 grams of ground flaxseed were subjected to reflux extraction with 250 mL of petroleum ether for 6 hours. The solvent was then removed using a rotary evaporation system at 50°C, and the extracted oil content of the flaxseed was determined by measuring the weight difference before and after the extraction process (Bouaziz et al., 2016). The total nitrogen content of the sample was determined according to Kjeldahl's method by determining protein content (multiplying the nitrogen content by 6.25) (Qian et al., 2012).

Table 1. Details of the methods for flaxseed aqueous extraction

Samples	Seed ratio (%)	Temperature of water (°C)	Mixing Process	References
A1	1	80	750 rpm and 15 minutes	Yesil (2020)
A2	5	100	750 rpm and 30 minutes	Erkoc et al.(2021)
A3	10	50	300 rpm and 120 minutes	Hellebois et al. (2021)
A4	5	55	250 rpm and 180 minutes	Alhssan (2021)
A5	3	80	1000 rpm and 180 minutes	Tee et al. (2016)
A6	3	100	1000 rpm and 180 minutes	Tee et al. (2016)
A7	10	85	750 rpm and 180 minutes	Kaur et al. (2018)
A8	10	25	750 rpm and 180 minutes	Wu et al. (2010)
A9	8	90	750 rpm and 240 minutes	Bostanoglu (2015)
A10	10	90	750 rpm and 240 minutes	Bostanoglu (2015)
A11	10	60	400 rpm and 300 minutes	Vieira et al. (2019) Wang et al. (2009)
A12	12	90	750 rpm and 240 minutes	Bostanoglu (2015)
A13	12	100	750 rpm and 360 minutes	Bostanoglu (2015)
A14	10	25	400 rpm and 300 minutes	Vieira et al. (2019)
A15	10	40	400 rpm and 300 minutes	Vieira et al. (2019)
A16	12	25	750 rpm and one night	Qian et al. (2012)

Figure 1. Brown flaxseed sample.

Dry matter was determined by drying the sample at 105°C in an oven (NUVE FN 500) until getting constant weight and total ash was determined after combustion of 5 g sample for four hours in a muffle furnace (Protherm Laboratory Furnace, PLF100-3, Türkiye) maintained at 550 ˝C (Qian et al., 2012).

2.4. Total Soluble Solids (TSS-°Brix)

A portable handheld refractometer (ATAGO 0-32°Brix, Japan) was used to measure the brix values of the SFG samples. Before taking measurements, the refractometer surface was cleaned with cotton and calibrated using distilled water.

2.5. pH Measurement

Before the measurements, the pH meter (EUtech 700, Singapore) was calibrated with buffer solutions (pH=4.0 and pH=7.0). After calibration, the pH measurements for all extracts were carried out in triplicated SFG samples.

2.6. Color Measurements

The color parameters L * (darkness-lightness), a * (green-redness), and b * (blue-yellowness) of the SFG samples were measured with a color measurement device (Minolta Chroma Meter, CR-400, Osaka, Japan).

Hue angel was calculated from the a* and b* parameters according to Equation 1:

$$\text{Hue angel}=180/\pi + \tan^{-1} (b^* / a^*) \quad (1)$$

Chroma (C*) values represent colorfulness and are defined as the strength or dominance of the hue. It was calculated as Equation 2:

$$C^*=\sqrt{(a^*)^2+(b^*)^2} \quad (2)$$

2.7. Rheological Measurement

Rheological measurements of the SFG samples were carried out according to Kaur's method (Kaur et al., 2018) with HAAKE MARS III device (Thermo Scientific, Germany).

2.8. Statistical Analysis

The data multiple comparison tests used the Duncan test with a 95% confidence interval, and these analyses were conducted in triplicate for each replicate. The SPSS package program (IBM SPSS Statistics 22, USA) was utilized for the statistical analysis.

3. Results

The whole flaxseed was used for the analysis and its general chemical composition of the flaxseed was determined as 7.5% moisture, 21.3% protein, 34.9% fat and 3.7% ash. In this study, it was revealed how mixing time, mixing power and temperature change the pH of the same product by applying different methods. The pH of the final extract is important for emulsion stability. All the samples were prepared with the same water pH of 7.4 but the samples had different pH values after process conditions were applied. The pH values of the samples are shown in Table 2. Although pH values of the extract samples were measured around 5-6 pH, the highest (7.4) and lowest (5.3) values belong to A1 (1% ratio, 80°C, 750 rpm and 15 minutes) and A11 (10% ratio, 60°C, 400 rpm and 300 minutes), respectively. Only three samples (A1, A2 and A3) have 7 pH values and eight samples have pH values under 6. It was criticized for emulsions in terms of emulsion stability. The pH of flaxseed gum solutions significantly impacts their physicochemical properties, encompassing flow behavior and viscosity. Total soluble solid values (Brix) of the samples were shown in the Table 2. The highest value was measured at A10 (10% ratio, 90°C, 750 rpm and 240 minutes) and A9 samples (8% ratio, 90°C, 750 rpm and 240 minutes). High ratio with high process temperature effect on getting more soluble solids from the seed. This situation is natural when general extraction parameters are considered.

Table 2. Physical properties of the samples

Samples	pH	Brix
A1	7.4±0.1^{g}	0.20±0.00^{a}
A2	7.3±0.0^{fg}	0.46±0.05^{b}
A3	6.1±0.2^{d}	0.30±0.00^{a}
A4	5.6±0.1^{b}	0.20±0.00^{a}
A5	5.7±0.0^{bc}	0.20±0.00^{a}
A6	6.5±0.2^{e}	0.66±0.05^{c}
A7	6.7±0.0^{e}	0.90±0.00^{e}
A8	6.5±0.1^{e}	0.20±0.00^{a}
A9	7.1±0.1^{f}	1.43±0.11^{h}
A10	6.8±0.0^{e}	1.70±0.10^{i}
A11	5.3±0.1^{a}	0.76±0.05^{d}
A12	5.6±0.1^{ab}	1.20±0.10^{f}
A13	5.6±0.0^{ab}	0.20±0.00^{f}
A14	5.6±0.0^{ab}	0.23±0.05^{a}
A15	5.8±0.1^{bc}	0.43±0.11^{a}
A16	5.9±0.0^{cd}	0.64±0.04^{b}

a,b= Different letters in the same column correspond to statistically different samples ($P<0.05$).

In this study, color values (L*, a*, b*, Chroma and Hue) of the samples (Figure 2) are given in Table 3. The highest L* value was measured in the A9 (8% ratio, 90 °C, 750 rpm and 240 minutes) sample, while the lowest L* value was measured in the A1 (1% ratio, 80 °C, 750 rpm and 15 minutes) sample. In addition, the highest a* and b* values of the samples were measured in A5 (3% ratio, 80 °C, 1000 rpm and 180 minutes) and A2 (5% ratio, 100 °C, 750 rpm and 30 minutes) samples, the lowest ones belong to A2 and (5% ratio, 100 °C, 750 rpm and 30 minutes) A14 (10% ratio, 25 °C, 400 rpm and 25 minutes), respectively. In the extractions at different temperatures on the samples with the same concentration percentages, it is seen that there is a statistically significant increase in the L* value as the temperature rises. The A7 and A8 samples were compared; although they have the same ratio and same mixing process with temperature differences, A7 with high-temperature water application (85°C) has a higher L* value. Table 3 indicates that the L* value increased significantly with increasing temperature ($P<0.05$). The a* and b* parameters represent red/green and blue/yellow parts of color. For a* value, the highest and lowest values were found at the A10 sample (10% ratio, 90°C, 750 rpm and 240 minutes) and A2 (5% ratio, 100 °C, 750 rpm and 30 minutes) sample. In this way, b* values were measured as 7.25 and 0.35 for the highest and lowest values at the samples shown at Table 3. The H* (hue angel) was calculated from the a* and b* parameters and the highest H* value was calculated for A16 sample (12% ratio, 25 °C, 750 rpm and one night). In addition to that the lowest one was calculated for the A1 sample (1% ratio, 80 °C, 750 rpm and 15 minutes). Generally, all the sample values were found to be different statistically ($P<0.05$). The highest Chroma value was detected in the A2 sample with a value of 11.03, and the lowest was detected in the A14 sample with a value of 0.91. The values of all samples showed statistical differences ($P<0.05$).

The samples A9 and A10 exhibited the highest viscosity values, surpassing those of A3, A7, and A8 despite having identical concentration levels. A closer examination reveals that, while these samples share the same concentration, prolonged mixing time and increased rpm led to heightened viscosity. Consequently, noticeable changes in color values were observed. Upon analyzing the color values, it was determined that the L* values of A9 and A10, characterized by the highest viscosity, were the most elevated with 26.53 and 24.89 (Pa.s) values, respectively. Properties of the extract samples according to G' and G'' were given in Table 4. The G′ and G″ values were parallel with viscosity results. The lowest values of G′ and G″ were 0.0358 Pa and 0.0461 Pa for A8 and A1, respectively. The values of tan δ are presented in Table 4, with the highest value observed in sample A8, and the lowest in sample A15.

Table 3. Color values of the samples

Samples	L*	a*	b*	C*	Hue (°)
A1	7.25±0.91^{a}	-0.60±0.15^{f}	3.29±0.39^{g}	3.35±0.07^{g}	-81.98°±0.13^{a}
A2	23.39±0.25^{h}	-2.05±0.07^{a}	10.98±0.27^{l}	11.03±0.20^{m}	-78.06°±0.06^{b}
A3	22.37±0.47^{gh}	-0.64±0.03^{ef}	1.71±0.05^{ef}	1.88±0.03^{f}	-74.27°±0.07^{d}
A4	16.45±0.05^{c}	-0.74±0.02^{de}	1.19±0.02^{de}	1.40±0.06^{d}	-74.76°±0.01^{c}
A5	17.98±0.16^{de}	-0.55±0.11^{f}	1.57±0.21^{def}	1.70±0.02^{e}	-73.09°±0.05^{k}
A6	19.63±0.22^{f}	1.91±0.06^{j}	4.97±0.08^{i}	5.17±0.03^{j}	69.51°±0.64^{f}
A7	19.59±0.28^{f}	1.33±0.04^{i}	4.36±0.09^{h}	4.54±0.02^{i}	69.84°±0.07^{g}
A8	15.55±0.30^{bc}	-0.56±0.07^{f}	0.40±0.04^{a}	0.63±0.00^{a}	73.15°±0.02^{j}
A9	26.53±0.88^{j}	2.30±0.12^{k}	6.74±0.40^{j}	7.43±0.01^{k}	70.22°±0.04^{i}
A10	24.89±0.78^{i}	2.86±0.14^{l}	7.25±0.30^{k}	7.93±0.05^{l}	69.95°±0.08^{h}
A11	19.31±0.07^{ef}	-0.89±0.03^{c}	1.80±0.05^{f}	1.93±0.08^{f}	-66.27°±0.05^{e}
A12	25.36±0.44^{ij}	0.55±0.04^{h}	4.10±0.21^{h}	4.23±0.06^{h}	83.23°±0.05^{l}
A13	21.28±0.19^{g}	0.31±0.01^{g}	3.36±0.04^{g}	3.40±0.10^{g}	83.74°±0.05^{m}
A14	14.73±0.30^{b}	-0.87±0.03 ^{cd}	0.35±0.14^{ab}	0.91±0.02^{b}	106.37°±0.02^{n}
A15	15.78±0.16^{bc}	-1.06±0.03 ^{b}	1.08±0.13^{cd}	1.34±0.06^{c}	125.98°±0.06^{o}
A16	17.76±0.12^{cd}	-0.60±0.00^{f}	0.64±0.03^{bc}	0.94±0.00^{b}	145.19°±0.02^{p}

a,b= Different letters in the same column correspond to statistically different samples ($P<0.05$).

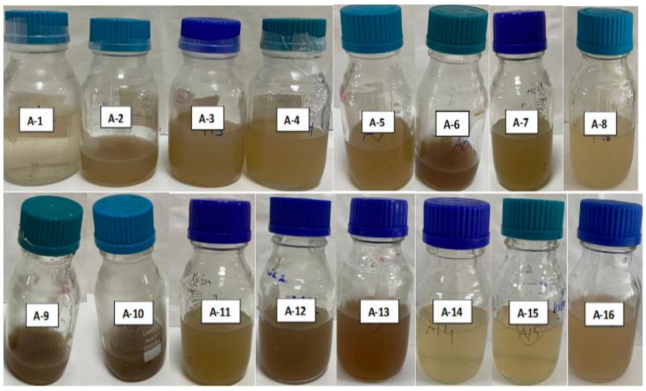

Figure 2. Samples produced by applying different methods.

Table 4. Rheological properties of the samples

Samples	μ(Pa.s)	G' (Pa)	G'' (Pa)	tan δ (G″/G′)
A1	0.0170±0.0014^{a}	0.0920±0.0005^{a}	0.0461±0.0045^{a}	0.5011±0.0009^{f}
A2	0.7849±0.0088^{h}	2.3154±0.0626^{c}	0.6843±0.0351^{d}	0.2957±0.0028^{cd}
A3	0.0586±0.0010^{d}	0.2600±0.0030^{a}	0.1322±0.0088^{ab}	0.5085±0.0015^{f}
A4	0.0308±0.0007^{c}	0.0482±0.0059^{a}	0.0946±0.0011^{ab}	1.9618±0.0008^{k}
A5	0.0357±0.0023^{d}	0.0556±0.0007^{a}	0.0583±0.0069^{a}	1.0496±0.0230^{h}
A6	0.4550±0.0345^{l}	1.6332±0.0133^{b}	0.4665±0.0857^{c}	0.2857±0.0005^{d}
A7	0.2726±0.0127^{k}	2.8915±0.0827^{d}	0.7792±0.0222^{d}	0.2695±0.0004^{c}
A8	0.0385±0.0004^{d}	0.0358±0.0041^{a}	0.1240±0.0152^{ab}	3.4665±0.0010^{l}
A9	1.1645±0.0163i	8.7954±0.1601^{g}	2.3763±0.1517^{e}	0.2702±0.0090^{c}
A10	1.2560±0.0290^{j}	6.7006±0.0475^{f}	2.3002±0.0778^{e}	0.3433±0.0004^{e}
A11	0.0757±0.0009^{f}	0.0986±0.0070^{a}	0.1405±0.0060^{ab}	1.4241±0.0010^{i}
A12	0.6949±0.0204^{h}	3.9895±0.1689^{e}	0.8378±0.0125^{d}	0.2098±0.0503^{b}
A13	0.4733±0.0309^{g}	2.5136±0.3304^{c}	0.7584±0.0043^{d}	0.3018±0.0006^{cd}
A14	0.0289±0.0019^{b}	0.1219±0.0132^{a}	0.2363±0.0030^{b}	1.9374±0.0007^{j}
A15	0.0278±0.0011^{b}	0.3514±0.4770^{a}	0.0638±0.0030^{a}	0.1816±0.0037^{a}
A16	0.0660±0.0023^{e}	0.2407±0.0311^{a}	0.2363±0.0021^{b}	0.9816±0.0004^{g}

a,b= Different letters in the same column correspond to statistically different samples (P<0.05).

4. Discussion

Flaxseed emerges as a crucial functional food, offering a range of potential health benefits. Key nutritional components in flaxseed encompass alpha-linolenic acid, protein, lignin, and dietary fiber (Jenkins et al., 1999). The average composition of flaxseed comprises 41% fat, 20% protein, 28% total dietary fiber, 7.7% moisture, and 3.4% ash (Shim et al., 2014). Similarly, the compositions of whole flaxseed were found as 30–41% fat, 20–35% dietary fiber, 20–30% protein, 4–8% moisture, and 3–4% ash (Carter, 1993; Coskuner and Karababa, 2007). Flaxseed boasts a wealth of fat, protein, and dietary fiber. However, it is essential to note that the composition of flaxseed can fluctuate based on genetics, growing conditions, and the method used for seed processing (Daun et al., 2003). Flaxseed's dietary fiber consists of 9% soluble dietary fiber and 20% insoluble dietary fiber (Cui, 2000). The soluble fiber, a viscous seed coat gum, is comprised of neutral (75%) and acidic (25%) monosaccharides (Warrand et al., 2005). This soluble fraction of SFG stands out for its nutritional and functional properties. Various studies suggest that incorporating SFG into the diet can potentially lower the risk of diabetes and coronary heart diseases, as well as contribute to the prevention of colon and rectal cancer (Thakur et al., 2009).

In acidic conditions, the gel strength of SFG diminishes with decreasing pH values, whereas in alkaline conditions, the gel strength declines with increasing pH values (Cui et al., 2006; Chen et al., 2006). The pH of flaxseed gum solutions significantly impacts on their physicochemical properties, encompassing flow behavior and viscosity. In acidic conditions, the gel strength of FG diminishes with a decrease in pH, while under alkaline conditions, the gel strength decreases with an increase in pH (Cui et al., 2006; Chen et al., 2006). Analyzing alterations in SFG solution properties during storage due to pH variations is important, as such changes may be undesirable. The optimal behavior of FG is observed within a pH range of 6.0–8.0 (Mazza and Biliaderis, 1989). On the other hand, eight samples have pH values under six value and it was critical values for emulsion stabilities.

The pH values effect the viscosity of the samples. In this way, the rheological parameters of the samples have been measured because the SFG has an important role in functional food viscosity. The SFG emulsions exhibited shear-thinning behavior, signifying a decrease in apparent viscosity with an increase in shear rate. This observation indicates that the samples displayed non-Newtonian behavior (Wang et al., 2017). Additionally, flaxseed gum exhibits notable gelling, foaming, and emulsifying capacities, offering the potential to replace gum Arabic in food emulsions (Chen et al., 2006; Wang et al., 2010).

Since SFG is expected to serve as a potential food or beverage additive or component, its color influences the visual appeal of products, particularly beverages (Hu et al., 2020). Adding SFG can affect the physical properties of the functional foods enriched with SFG. For this reason, SFG with matching colors should be added to the foods. Considering SFG's composition, which includes protein and carbohydrate, the observed darkening may be attributed to a plausible Maillard reaction between these components (Hu et al., 2020). It has been observed that the main difference between the two existing samples is the temperature difference of 75°C. It has been observed that color differences in the extraction samples occur as the temperature increases (Hao and Beta, 2012). While concentration and seed ratio were effective on the consistency differences between the samples, the temperature parameter was effective on the color differences. The reason for the darker color was the presence of tannin and the occurring Maillard reaction. In addition, soluble flaxseed gum has some monosaccharides as rhamnose (21.2–27.2%), fructose (5–7.1%), arabinose (9.2–13.5%), xylose (21.1–37.4%), galactose (20–28.4%), glucose (2.1–8.2%) (Barbary et al., 2009).

Xing et al. (2015) stated the impact of extraction temperature on the rheological properties of FG. They observed that the polysaccharide and protein content in the gel increased with temperature, peaking at 70°C. This discovery aligned with Cui et al. (1994)'s findings from a response surface analysis, which identified 70°C as the temperature for maximum gum extraction. Interestingly, there was no significant difference in viscosity between gums extracted at 70°C and 80°C (Xing et al., 2015). On the other hand, recognizing that 70°C might not sufficiently eliminate all microorganisms and inactivate all enzymes in the gum, a higher temperature (98 °C) was considered for further exploration of gum appearance and other properties (Hu et al., 2020).

The viscosity of the samples increased rapidly with an elevated concentration of SFG (Zhao, 2015; Wang et al., 2017). A similar situation was observed in the study in question, but not only the increase in concentration but also the mixing time and temperature increased the viscosity. This finding suggests that if avoiding color alterations in food products intended for use as thickeners is a priority, it is advisable to refrain from using the A9 and A10 samples. It would be more appropriate to choose a method that enables the production of a sample with higher viscosity and more transparent color, in other words, a combination that provides the production of a lighter-colored added-value product. Accordingly, the A2 and A12 samples, which have higher viscosity and lighter color, can be used and the methods in which the samples are produced can be selected. The neutural polysaccharide has a larger molecular size and shows shear thinning flow behavior in aqueous solution above 1% (w/w) flaxseed ratio (Barbary et al., 2009).

At frequencies spanning from 0.1 to 10 Hz, the storage modulus (G′) and loss modulus (G′′) were determined. G′ indicates the capacity of a viscoelastic material to store energy in one cycle during alternating stress, offering insights into the elasticity changes in the sample. Conversely, G′′ represents the energy lost as a material undergoes irreversible deformation due to viscosity, providing information about the material's viscosity magnitude (Ingrassia et al., 2019). In addition to the changes in the elastic component (G'), data for tan δ (G″/G′) can also be presented as a function of stress to interpret the contribution of the viscous component (G″) to the viscoelastic behavior (Ross-Murphy, 1994). The viscoelastic properties of polymer solutions are classified into four different categories according to the change in modules depending on the frequency: (i) "a dilute solution" if G″>G′ during frequency scanning, (ii) G″>G′ at low-frequency values, but G″< at high-frequency G′ is "high-frequency elastic character", (iii) G″<G′ throughout the whole frequency and the modules are parallel to each other at a certain angle, "weak gel" (iv) G″<G′ for "strong gel" (Sun et al., 2014). Samples produced with high temperature and high ratio have high-frequency elastic character. A tan δ value less than 0.1 indicates strong or true gel-like characteristics, while a higher value suggests weak gel properties (Ross-Murphy, 1994). For all the extraction temperatures, SFG aqueous solutions showed a shear time-independent and shear-thinning behavior. Furthermore, oscillatory measurements showed a prevailing viscous character. However, the decrease of the extraction temperature resulted in an increase of both G' and G". Therefore, SFG extracted at low extraction temperatures showed higher viscous and elastic properties. In contrast, high extraction temperatures increased the antioxidant activity.

5. Conclusion

Flax seed has been successfully used reparation of various value-added products in direct or extracted form as SFG. Flaxseed gum-containing fractions are hydrocolloid polysaccharides utilized in the food industry due to their valuable properties, which enhance both foods and solutions. These fractions are becoming increasingly popular for such applications. In this study, comparing methods in literature related to extraction of SFG was investigated. Choosing of suitable method is important for utilization of SFG preparation of various value-added products in terms of nutritional, physicochemical, phytochemical and sensory properties.

The A2 (5% ratio, 100 °C, 750 rpm and 30 minutes) and A12 (12% ratio, 90 °C, 750 rpm and 240 minutes) samples, which have higher viscosity and lighter color, can be used for light color fortified products. The A9 (8% ratio, 90 °C, 750 rpm and 240 minutes) and A10 (10% ratio, 90 °C, 750 rpm and 240 minutes) samples with the highest viscosity with the darkest color, can be selected for fortified products where color is not important but needs to be improved in terms of consistency. Another parameter to consider is pH and it is important for emulsion or emulsion-based products. A total of eight samples have lower pH value than six. The extract to be used as an additive to food should not have a negative sensory impact and should support the consistency and textural structure of the product while also contributing to its nutritional value. Therefore, this study can be useful for the further studies and sectors related to SFG-added food products.

Author Contributions

The percentage of the author(s) contributions is presented below. All authors reviewed and approved the final version of the manuscript.

	Z.T.	M.M.
C	20	80
D	10	90
S		100
DCP	50	50
DAI	50	50
L	50	50
W	20	80
CR	20	80
SR		100
PM		100
FA		100

C=Concept, D= design, S= supervision, DCP= data collection and/or processing, DAI= data analysis and/or interpretation, L= literature search, W= writing, CR= critical review, SR= submission and revision, PM= project management, FA= funding acquisition.

Conflict of Interest

The authors declared that there is no conflict of interest.

Ethical Consideration

Ethics committee approval was not required for this study because of there was no study on animals or humans.

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