Unlocking the Potential of Chia Seed: A Comprehensive Review of its Potential Applications

Abstract

Chia, native to Mexico and Guatemala, is now cultivated worldwide and contains 25–39% oil and 16–26% protein and is rich in omega-3 and omega-6 fatty acids, tocopherols, and phytosterols, making them valuable functional foods. This review explores various methods for extracting chia oil and analyzing its composition and properties. It also highlights the potential use of chia seed by-products in food processing, such as partially defatted chia cake or meal, which can be converted into protein concentrates and phenolic compound extracts for applications in bread, cookies, and pasta. Additionally, chia cake can serve as a fat substitute and stabilize fat-free salad dressings and ice creams, while chia gum from the cake is used in biodegradable films and vegan mayonnaise. Further research is essential to expand the understanding and industrial applications of chia seeds and their derivatives.

Keywords: Chia; Seed; Oil; Application; Gum; omega-3 and omega-6 fatty acids

Introduction

Salvia hispanica, commonly known as chia, is an annual oilseed plant belonging to the Lamiaceae family. It produces small, hermaphroditic flowers that are either white or purple, measuring about 3 to 4 mm in size. [1] The plant can grow to a 60 to 180 cm height and features petiolate leaves with serrated edges ranging from 4 to 8 cm in length and 3 to 5 cm in width.[2] Chia plants typically yield between 500 and 600 kg of seeds per acre, although some studies have reported yields varying from 120 to 930 kg per acre.[3]Chia seeds are small, oval-shaped, and measure approximately 2 mm in length, 1 to 1.5 mm in width, and less than 1 mm in thickness. They come in a range of colors, including black, gray, black-speckled, and white. Historically, the Aztecs and Mayans valued chia alongside amaranth, beans, and corn for both dietary and medicinal purposes.

Agronomic research has identified three chia varieties—Tzotzol, Iztac 1, and Tliltic—each exhibiting growth cycles of 125 to 160 days when cultivated in different regions of Ecuador's Inter-Andean valleys, such as Patate (2,042 m), Guayllabamba (2,200 m), and Salinas (1,621 m). Studies have also highlighted the high nutritional value of chia seeds, which contain 25% to 39% oil and 16% to 26% protein.[6-8,11-13,34]

Table 1: Oil and protein levels in various oilseeds.

Oil Seed	Yield (%)	Protein content (%)

Chia	25-39	16-26
Canola	44-54	17-27
Flax	37-49	19-24
Soybean	19-22	39%-49
Sunflower	20-43	15-22

Adapted from : Mondor and Hernández-Álvarez [34].

Chia seeds' oil content is comparable to sunflower seeds (*Helianthus annuus* L.). However, it is generally lower than that in canola (Brassica napus L.) and flax (Linumusitatissimum L.), while it exceeds that of soybeans (*Glycine max* L.).[15-20]Chia seeds have a higher protein content than sunflower seeds and are comparable to soybeans in this regard. They are also a rich source of essential fatty acids, including omega-3 and omega-6, as well as tocopherols, phytosterols, and phenolic compounds. As shown in Table 2, the saturated fatty acid content in chia seeds is similar to that of flaxseed but lower than in soybeans and sunflower seeds. Among the five oilseeds listed in Table 2, chia seeds have the lowest content of monounsaturated fatty acids and the highest level of polyunsaturated fatty acids.[21-25,34] Additionally, chia seeds generally have a lower total tocopherol content than the other four oilseeds. This pattern is also observed for total phenolic content, with flax showing a similar phenolic content to chia seeds.[26-33,34]

Table 2. Fatty acid profiles, total tocopherol levels, and total phenolic contents in various oilseeds.

Oilseed	**SFA content (%)**	**MUFA content (%)**	**PUFA content (%)**	**Total tocopherol content (mg/kg)**	**Total phenolics content (mg/100 g)**
Chia	8.7–10.0	7.3–11.0	80.4–82.7	143-164	53-164
Canola	5.5–8.3	60.1–78.0	15.1–31.0	166-526	756-1324
Flax	7.9–9.9	13.3–20.1	71.7–78.5	92.6–311.6	88-156
Soybean	16.4–19.3	17.5–23.1	60.1–64.3	114.0–361.1	183-554
Sunflower	10.7	27.5	61.8	153.5–513.3	1800–7200

Source: [34]

Ciftci et al. [15] identified 16 distinct fatty acids in chia seeds, with α-linolenic acid (59.76% ± 0.13%), linoleic acid (20.37% ± 0.19%), and oleic acid (10.53% ± 0.17%) being the most prominent [33, 35, 36]. These findings align with other studies that also highlight α-linolenic and linoleic acids as the primary fatty acids in chia seeds, along with significant levels of palmitic acid. The fatty acid composition is influenced by temperature fluctuations during the growing season, with higher temperatures leading to a reduction in linoleic and palmitic acids and an increase in linolenic and stearic acids [37–40]. Ayerza and Coates, along with Ayerza, observed that factors such as geographic location, temperature, light exposure, and soil type significantly impact the fatty acid profile of chia seeds [6-8, 35, 36, 47]. The health benefits of these fatty acids are well-documented, including their roles in maintaining membrane structure and function, regulating intracellular signaling, influencing transcription factors and gene expression, and producing bioactive lipid mediators. Fatty acids from chia seeds are beneficial for cardiovascular health and may offer advantages for managing metabolic conditions such as type 2 diabetes, inflammatory diseases, and cancer.

In addition to fatty acids, 19 polyphenols have been identified in chia seeds, including apigenin, caffeic acid, chlorogenic acid, daidzin, epicatechin, ferulic acid, gallic acid, genistein, genistin, glycitein, glycitin, kaempferol, kaempferol 3-O-glucoside, myricetin, p-coumaric acid, protocatechuic acid ethyl ester, quercetin, rosmarinic acid, and rutin. Chia proteins are classified into several fractions: albumins, globulins, glutelins, and prolamins, each with unique solubility characteristics. Segura-Campos isolated these protein fractions from chia meal using the method developed by Vázquez-Ovando et al. [39, 46]. The predominant fraction was glutelins (42.94%), followed by albumins (20.81%), globulins (17.3%), and prolamins (5.81%). The functional properties of these protein fractions were evaluated, including their water-holding capacity, oil-holding capacity, water-absorption capacity, organic molecule absorption capacity, emulsifying capacity, stability, and foam capacity and stability. Glutelins exhibited the highest water-holding and water-adsorption capacities, albumins were most effective in organic molecule absorption, globulins had the greatest oil-holding capacity, and prolamins demonstrated the highest water-adsorption capacity. Emulsifying capacity was highest for glutelins at pH 2, 4, and 6, and for prolamins at pH 8 and 10. Globulins showed the greatest foam capacity at pH 8, while the other fractions exhibited the highest foam capacity at pH 2. The stability of foaming and emulsifying properties was significantly influenced by pH. Additionally, chia proteins contain bioactive peptides with potential antidiabetic, anticancer, antimicrobial, antibiofilm, and antioxidant activities.

Chia seeds are a valuable source of dietary fiber, which can be divided into soluble and insoluble types. The soluble fiber, also known as mucilage, can be extracted using water. Dietary fiber has prebiotic properties and is associated with a lower risk of various health issues, including coronary heart disease, stroke, hypertension, diabetes, obesity, and gastrointestinal disorders. The total dietary fiber content in chia seeds ranges from 24.56 g/100 g to 56.46 g/100 g, with insoluble fiber being the predominant type. Klason lignin is identified as the primary component of the insoluble dietary fiber in chia seeds, recognized for its cholesterol-lowering effects. Both soluble and insoluble fiber fractions also contain neutral sugars.[47]

In addition to fiber, chia seeds are rich in bioactive compounds such as phytic acid, trypsin inhibitors, saponins, and tannins. The phytic acid content in chia seeds has been reported to range from 0.96 to 1.16 g/100 g, while other studies have found it to be 0.2341 g/100 g. [48,84] A trypsin inhibitor with a molecular weight of 14.4 kDa has been isolated from chia seeds,[50] showing 60% inhibition of trypsin activity. Saponin levels in chia seeds have been reported at 0.616 g/100 g, and tannin levels at 0.23 g/100 g.[49] While these compounds can negatively affect protein digestibility and amino acid bioavailability, they may also offer health benefits, such as anticarcinogenic and cholesterol-lowering effects. Various processing methods can reduce the levels of these compounds.[49] For instance, boiling, autoclaving, and roasting chia seeds have been shown to decrease phytic acid content by 49.94%, 48.27%, and 36.18%, respectively. Saponin levels decreased by 9.90%–62.27% with boiling, 29.11% with autoclaving, and 15.75%–21.59% with roasting. However, these treatments also resulted in an increase in tannin content, with boiling leading to a 78.84%–96.48% increase.[49]

Chia oil is produced from seeds on an industrial scale, but until recently, the by-product—partially defatted chia cake or meal—was often discarded. However, recent research has explored the potential of chia seeds and their oil by-products as functional foods to enhance the nutritional value of various products. This review examines the methods of chia oil extraction and processing, its uses in edible applications, and potential future research directions for utilizing chia by-products.

Extraction and Processing of Chia Oil

There are a few methods to extract chia oil, but the most prevalent forms of extraction are through solvent and mechanical pressing. While "cake" is the term for the partially defatted by-product from mechanical pressing, solvent extraction yields a defatted by-product termed as meal. The literature points to some confusion regarding these terms. In the solvent extraction method, chia seeds are ground into flour and then soaked to mix with a low-boiling-point solvent such as hexane or acetone for extracting oil. It can be either continuous or in batch mode. The extraction efficiency relies on several factors, such as contact time, moisture content, temperature, sample size, and the kind of solvent used. The solvent must be evaporated with heat to retrieve the oil, and the defatted meal needs dehydration prior to more usage.[55] With high efficiency, simplicity, and low cost-effectiveness, hexane is widely used in industrial solvent extraction. Notwithstanding, it carries flammability risks and may be harmful when solvents are not completely removed. Extraction time had a noticeable effect on the oil yield, and in general, hexane resulted in richer oils than acetone. Using the Soxhlet method with acetone, one study reported that hexane produced 36.1% oil compared to only around 33.53% (4 h) and was not significantly different from 33.73% after 8 hours, respectively.[57] However, the total amount of phenolics and antioxidant activity were higher by extraction using acetone than hexane, with a maximum value for acetone (4 hours) of 75.13 mg GAE/g oil. At the same time, it was only 14.44 mg GAE/g oil for hexane extract. Furthermore, acetone (8 hours) was higher in carotenoids, with 3.51 mg/kg oil being its best source.[34,35,36,37]

Pressing extraction, a standard method, involves several steps, including seed pre-treatment and oil extraction. To enhance oil extraction efficiency, the pre-treatment process consists of cleaning, grinding, breaking, and heating the seeds at temperatures between 90°C and 115°C. The pre-treated seeds are then processed through a screw press, which extracts the oil and results in a partially defatted cake as a by-product. This method produces high-quality oil without solvent contamination and poses lower risks, although it yields less oil than solvent extraction.

Supercritical fluid extraction, a green technology, is gaining popularity for extracting chia oil. This method uses a fluid at its critical state to extract the oil, which is then separated by returning it to its gaseous phase. Supercritical solvents such as carbon dioxide, acetone, ethanol, and methanol are used in this process. It minimizes the degradation of sensitive compounds and avoids solvent contamination, but it is more expensive than traditional methods. Guindaniet al.[58] utilized supercritical CO_2 to extract residual oil from chia seed cake, exploring the effects of pressure, temperature, and co-solvents. Without co-solvents, oil yields ranged from 5.0% ± 0.3% at 150 bar/50°C to 10.6% ± 0.2% at 300 bar/50°C. The highest total phenolic content of 34 mg CAE/g ± 3 mg CAE/g was achieved at 300 bar/50°C, comparable to hexane Soxhlet extraction.

Dąbrowski et al.[59] evaluated different extraction methods for chia seed oil recovery, comparing Soxhlet extraction with acetone and hexane, screw pressing at room temperature and 110°C, and supercritical CO2 extraction at 70°C and 90°C. Recovery rates varied from 69.6% ± 5.4% for supercritical fluid extraction at 90°C to 94.8% ± 1.1% for Soxhlet extraction with acetone. Fernandes et al.[60] further examined the effects of different extraction processes on chia oil yield and composition. Supercritical CO2 extraction, both with and without ultrasound and ethanol as co-solvents, yielded between 0.57% and 33.90%. In comparison, Soxhlet extraction with hexane provided a yield range of 13.56% ± 0.59% to 19.28% ± 0.74%, with the highest yield obtained after a 15-minute ultrasound pre-treatment. The optimal supercritical CO2 extraction yielded 25.10% at 25 bar/40°C/75 minutes with 30% ethanol co-solvent and a 15-minute ultrasound pre-treatment. Despite its higher peroxide value, screw pressing produced oil with the best chemical quality.[50,60,55,54]**(Table 3)**

Table 3: Extraction Techniques for Different Methods

Method of Extraction	**Solvent**	**Extraction Yield% (Black Chia Seeds)**	**Fatty acid content % black chia seed ω-3**	**Fatty acid content % black chia seed ω-6**
Ultrasonic extraction	Hexane, ethyl acetate, isopropanol	25.6	62.9	19.8
	Hexane	ND	46.4	19.5
	Hexane ethyl acetate	10.6	59.6	22.1
	ethanol	11.3	ND	ND
Cold pressing and DCS	ethanol	ND	ND	ND
Ultrasound extraction	acetone	ND	ND	ND
Ultrasound liquid-liquid extraction	methanol-water solution	ND	ND	ND
Supercritical fluid extraction	CO2	88.1	63.4	35.8
		7.2	66.0	18.2
		10.6	62.3	19.7
		27.8–31.8	52.5–55.9	19.8–20.9

		17.5	ND	ND
	ethanol	64.5–90.3	65.0–68.0	17.0–23.0
	CO_2	24.6	68.3	18.6
	n-propane	ND	46.2	17.5
Pressing	-	20.3–24.8	64.5–69.3	16.6–17.5
Pressurized liquid extraction	ethanol	17.7–19.9	65.0–68.0	17.0–23.0
	Hexane	ND	65.5	18.1
Screw pressing	Hexane	9.0	3.5	2.97
Soxhlet extraction	Hexane ethyl acetate	13.8 12.10	ND	ND
	ethanol	15.4	64.1	19.9
	Hexane	ND	48.66	17.98
		10.9	ND	ND
		35.6	3.5	2.97
		25.7–32.2	54.4–54.4	20.2–21.8
		ND	ND	ND
		26.7–33.6	65.6–69.3	16.6–19.7
Cold solvent extraction	Hexane	30.0	3.5	2.97
		42	ND	ND
		19.3	67.9	17.6

Oil Composition, Characteristics, and Health Attributes

Chia oil is abundant in fatty acids, tocopherols, and phytosterols. Key fatty acids in chia oil include α-linolenic acid, linoleic acid, oleic acid, and palmitic acid. Ciftci et al.[15] identified 21 triacylglycerides in chia seed lipids, with LLnLn (21.8%±2.1%), LnLnLn (21.3%±1.6%), and OLnLn (11.3%±1.4%) being the most prevalent. The oil also contains three tocopherols (α-, γ-, δ-), with γ-tocopherol accounting for about 95% of the total tocopherols. Four phytosterols were identified—campesterol, stigmasterol, β-sitosterol, and Δ5-avenasterol—with β-sitosterol being the most abundant at 2057 mg/kg of lipids ±110 mg/kg.

Ixtainaet al.[54] noted that chia oil, whether extracted by pressing or solvent extraction, contains significant phenolic compounds, including chlorogenic acid, caffeic acid, myricetin, quercetin, and kaempferol. Chlorogenic acid and the total polyphenol content were higher in chia oil obtained through pressing extraction compared to solvent extraction.[74,75,76]

Dąbrowski et al.[59] compared various extraction methods (Soxhlet with acetone and hexane, screw pressing at room temperature and 110°C, and supercritical CO2 at 70°C and 90°C). They found that Soxhlet extraction with acetone was the most effective for preserving bioactive components, yielding the highest phenolic content (172.4 mg D-catechin/kg ±5.7 mg D-catechin/kg) and carotenoid content (8.4 mg lutein/kg ±0.4 mg lutein/kg), resulting in oil with superior oxidative stability.**(Table 4 and 5)**

Chia seed oil is recognized as a functional food due to its rich content of essential fatty acids (α-linolenic and linoleic acids), tocopherols, and antioxidants, which are vital for health. It is noted for its anticancer, antioxidant, antihyperlipidemic, and antiviral properties. Tak et al.[61] highlighted its benefits for skin health, anti-inflammatory effects, antihypertensive properties, and potential to combat obesity-related diseases. These attributes have heightened interest in chia seed oil as a valuable functional food.[79,80,81-90]

Table 4: Comparison of chemical composition between Chia and Flax Seed

Fatty Acids	**Chia**	**Flax**
Saturated Fats (SFA) (g/100g)		
Lauric acid (12:0)	0.03	0.03
Myristic acid (C14:0)	0.06	0.04
Pentadecanoic acid (C15:0)	0.04	0.05
Palmitic acid (C16:0)	7.1	5.39
Margaric acid (C17:0)	0.06	0.08
Stearic acid (C18:0)	3.24	3.17
Arachidic acid (20:0)	0.24	0.15
Behenic acid (22:0)	0.08	0.14
Lignoceric acid (24:0)	0.1	0.09
Monounsaturated Fats (MUFA) (g/100g)		
Palmitoleic acid (C16:1)	0.2	0.02
Margaric acid (C17:0)	0.06	0.08
Oleic acid (C18:1 – ω-9)	10.53	18.7
Eicosenoic acid (20:1)	0.16	0.2
Polyunsaturated Fats (g/100g)		
Linoleic acid (C18:2 – ω-6)	20.37	16.13
Linolenic acid (C18:3 – ω-3)	59.76	56.37
Eicosadienoic acid (20:2)	0.08	n.e.

Summary (g/100g)		
SFA	9.99	8.78
MUFA	7.33	18.72
PUFA	82.68	72.5
Ratio n-6/n-3	0.3	0.29

Table inspired by cift et al. [15]

Table 5: Amino acid composition between Chia Seed

Essential amino acids content in (g/100g)		**Non-essential amino acids** content in (g/100g)	
Arginine	2.14	**Cystine**	0.41
Histidine	0.53	**Tyrosine**	0.56
Isoleucine	0.80	**Alanine**	1.04
Leucine	1.37	**Aspartic acid**	1.69
Lysine	0.97	**Glutamic acid**	3.50
Methionine	0.59	**Glycine**	0.94
Phenylalanine	1.02	**Proline**	0.78
Threonine	0.71	**Serine**	1.05
Tryptophan	0.44		
Valine	0.95		

Table inspired by cift et al. [15]

Quantity of Chia Seed Oil By-Product

Due to limited data, estimating the quantity of chia seed oil by-products in the industrial process is challenging. However, based on the oil extraction yield from cold pressing reported by Fernández-López [62], approximately 72% of the seed weight remains as residual chia cake. With an import of 1200 tonnes of chia oil, it is estimated that about 2830 tonnes of chia cake were produced during the same period.

Edible Applications of Chia Seed Oil By-Product

Chia cake and meal are valuable protein and fiber sources, comparable to other oilseeds, although soybeans generally have higher protein content. Silva et al.[73] observed that chia meal (fine fractions: 100 mesh) has functional properties that are either comparable to or exceed those of full-fat flour. For example, while the water-holding capacity was similar for both chia meal and full-fat flour (9.2 ± 0.37 g/g vs. 10.13 ± 0.08 g/g), chia meal exhibited superior oil-holding capacity and emulsification activity. The oil-holding capacity for full-fat flour was 1.94 ± 0.09 g/g, whereas it ranged from 2.75 ± 0.01 g/g to 3.07 ± 0.35 g/g for chia meal fine fractions.

Additionally, emulsification activity was 66.6% for full-fat flour compared to 100% for chia meal.**(Table 6)**

Given their composition and functional properties, chia seed oil by-products are highly valuable for various food applications. They can be used to produce protein ingredients (concentrates and isolates), extract phenolic compounds, and enhance the nutritional profile of products such as bread, cookies, muffins, pasta, and meat products. These by-products also serve as fat replacers and stabilizers in low-fat salad dressings and ice cream.

Table 6. Composition of some oilseeds cake and meal.

Oilseed	Lipids content	Protein content	Fibers content
Chia cake	6.0%-12.4%	21.6%-36.5%	21.4%-59.7%
Chia meal	0.3%	38.0%-41.5%	32.5%
Canola cake	16.7%-21.5%	27.7%-33.3%	ND
Canola meal	2.0%-3.8%	34%-40%	9.7%-12.8%
Flax cake	4.8%-12.0%	32.7%	66%
Flax meal	1.9%	34.1%	ND
Soybean cake	1.2%	44.5%-49.3%	45.8%
Soybean meal	3.2%	44%-53.2%	4.3%-6.1%
Sunflower cake	11.0%-30.3%	23.6%-29%	8.6%-32%
Sunflower meal	1.2%-2.0%	15%-48%	13.2%-28.9%

Inspired by papers [40-72]

Production of Chia Protein Ingredients and Extraction of Phenolic Compounds

By 2027, the global market for plant-based proteins is projected to reach $17.4 billion, driven by an annual growth rate of 7.3%. This surge is fueled by increasing consumer demand for alternatives to animal proteins and a growing emphasis within the food industry on plant-based products. While traditional plant protein sources such as soybeans, wheat, and corn have long dominated the market, chia seeds are gaining attention as a promising alternative due to their exceptional nutritional composition and functional properties.

Chia seeds are rich in protein, containing approximately 16% to 26% protein content, and offer a well-balanced amino acid profile. Their protein fraction is known for its bioactive properties, including anti-inflammatory and antioxidant effects, making them a valuable addition to functional food formulations. Research on chia protein extraction methods has yielded diverse findings, with various approaches optimizing yield, purity, and functionality.

Timilsena et al. [76] extracted proteins from defatted chia meal by first removing mucilage using sodium carbonate, followed by alkaline extraction at pH 12. Their resulting protein isolate exhibited a purity of 90.5% to 91.2% and demonstrated superior solubility across different pH levels when spray-dried. Similarly, Cárdenas et al. [78] conducted alkaline extraction at pH 8 and found that the highest protein yield and content were achieved using water at pH 4, which also exhibited notable anti-inflammatory activity.

Comparative studies on extraction techniques have provided additional insights. Coelho et al. [65] evaluated dry fractionation versus wet extraction methods and found that while dry fractionation resulted in a moderate protein yield of 49.7%, wet extraction significantly increased protein purity, yielding between 70.9% and 74.1%. However, wet extraction also led to diminished functional properties, such as reduced water-holding capacity and lower emulsifying stability. López et al. [80,81] further investigated pH-dependent protein recovery and reported the highest extraction efficiency at pH 12, with optimal protein content observed at pH 10.

As the plant-based protein market continues to expand, chia seed proteins present a promising and sustainable alternative. Ongoing research into optimized extraction methods and functional applications will be crucial for maximizing their potential in various food and nutraceutical formulations.

The variability in protein content across studies is partly due to the different pH levels used during extraction. Generally, higher pH levels enhance protein yield but may lead to the formation of undesirable compounds like lysinoalanine. Therefore, exploring extraction methods at pH 11 and alternative approaches could be beneficial. Conventional alkaline extraction methods, though effective, may affect protein functionality and generate environmental waste.**(Table 7)**

Research on phenolic compounds from chia by-products is still limited. Capitani et al.[88] identified chlorogenic and caffeic acids as the main phenolics in chia meal and cake, respectively. Fernández-López et al.[80,81,62] reported multiple phenolic acids and flavonols in chia cake, with rosmarinic acid being the most prevalent. Oliveira-Alves et al.[86] used methanol extraction combined with ultrasound to identify phenolic compounds with high antioxidant activity in chia cake. Given their health benefits, such as antioxidant and anti-inflammatory properties, extracting phenolic compounds from chia by-products for use in food and pharmaceutical applications shows great promise.

Table 7. Phenolic compounds in chia cake and meal.

		Meal	Cake
Phenolic acids (μg/g)	Caffeic	~3.86	128.66 ± 1.36
	Chlorogenic	~124.01	ND
	Ferulic	ND	37.04 ± 0.36
	Gallic	ND	43.87 ± 0.16
	p-Coumaric	ND	26.41 ± 0.39
	Rosmaniric	ND	669.88 ± 23.98
Flavonols (μg/g)	Kaempferol	~4.09	ND
	Myricetin	~9.10	29.41 ± 0.36
	Quercetin	~23.75	298.96 ± 1.56
	Rutin	ND	101.45 ± 0.98
Isoflavones (μg/g)	Daizdin	ND	463.88 ± 4.87
	Genistein	ND	55.69 ± 0.31
	Genistin	ND	19.58 ± 0.09

Abbreviations: ND: not detected. Inspired by Capitani et al.,[88] Fernández-López et al.[62]

Supplementation/Formulation of Food Products

General Overview

Recently, partially defatted chia cake and defatted chia meal have been integrated into a variety of food products, such as breads, cookies, muffins, pasta, and meat items. Incorporating these chia by-products can boost the protein content, antioxidant levels, and dietary fiber of these products, potentially offering additional health benefits. Furthermore, chia gum or mucilage extracted from chia cake has been utilized to create low-fat vegan mayonnaise and edible biodegradable films.[71,72,73]

Bread

Bread, a staple in many diets worldwide, has increasingly included chia cake or meals. Guiottoet al.[66] experimented with partially defatted chia cake and defatted meal, replacing 5% and 10% of wheat flour with these chia by-products. The resulting bread had a higher protein content (13.5% - 15.25%) compared to the control (11.2%). While the specific volume remained unaffected at the 5% substitution level, it decreased significantly to 10%. Texture was generally stable, though firmness increased at the higher substitution rate. The study concluded that a 5% substitution improves the nutritional profile without compromising bread quality. Sayed-Ahmad et al.[94] tested defatted chia cake in whole wheat bread at 2%, 4%, and 6% substitution levels, noting slight increases in protein content and significant antioxidant activity at 6%. Higher substitution levels also improved moisture content and reduced hardness. Zdybel et al.[67] incorporated partially defatted chia cake into both wheat and gluten-free breads. A 5% substitution increased the protein content and specific volume in wheat bread but reduced the specific volume in gluten-free varieties. Both bread types saw enhanced polyphenol and antioxidant levels without deteriorating sensory attributes. Ewerlinget al.[95] optimized gluten-free bread formulations using defatted chia cake, hydroxypropylmethylcellulose gum, and xanthan gum, achieving a balanced formulation with good sensory acceptance. These studies suggest that chia cake or meal can enhance bread's nutritional profile, though specific volume and texture may vary depending on the substitution level.

Cookies and Muffins

Chia cake or meal has also been used to fortify cookies and muffins. Lucini Mas et al.[96,99] replaced wheat flour in cookies with 5%, 10%, or 20% defatted chia cake. The substitution increased hardness and polyphenol content, with 10% being the preferred level in sensory tests. Martínez et al.[85,97] used chia cake in cookies, resulting in higher protein, fiber, and fat content but reduced elasticity compared to control cookies made with wheat flour. These chia cookies were more prone to crumbling and received lower sensory scores. Aranibar et al.[53,64,98] added 2.5%, 5%, and 10% semi-defatted chia cake to wheat muffins. The chia muffins had increased protein, fiber, polyphenol content, and antioxidant capacity, with minimal impact on sensory properties up to a 5% substitution. While chia cake can enhance the nutritional profile of cookies and muffins, higher substitution levels may affect textural and sensory attributes.

Pasta

Pasta formulations have also been improved with chia cake or meals. Aranibar et al.[53,64,98] incorporated 2.5%, 5.0%, and 10.0% defatted chia cake into pasta. This substitution reduced whiteness and cooking time while increasing phenolic content and antioxidant capacity. Sensory evaluations indicated that although the supplemented pasta was acceptable, the control pasta was preferred.

Meat Products

In response to health and environmental concerns, chia cake and meals have partially replaced meat in various products. Souza et al.[95] added semi-defatted chia cake and textured soy proteins to hamburgers. This substitution significantly affected lipid, protein, and ash content, with higher chia cake levels leading to reduced lipid content. Rabadánet al.[97] replaced corn starch with chia cake in lamb burgers, increasing fiber content and altering texture parameters. Sensory evaluations showed similar acceptability between chia and control burgers. Fernández-López et al.[80,81,62] added chia cake to frankfurters, resulting in lower moisture content and higher fiber content. This addition improved oxidative stability and did not affect microbial load or most texture parameters, although general acceptability was slightly lower than the control. These findings highlight chia cake's potential to enhance meat products' nutritional profile while maintaining acceptable sensory qualities.

Low-Fat Salad Dressing and Ice Cream

Chia cake and mucilage have been used as fat replacers in low-fat salad dressings and ice creams. One study developed a low-fat salad dressing using semi-defatted chia cake, xanthan gum, oil, and egg yolk powder, resulting in a product with comparable properties and high stability to commercial samples. Hijazi et al.[91,94] extracted mucilage from chia cake for use in low-fat vegan mayonnaise, achieving desirable rheological and microstructural properties. Additionally, they formulated a low-fat ice cream with chia cake, xanthan gum, and reduced fat content, which had similar sensory properties to full-fat ice cream and improved emulsion stability.

Edible Films

Chia mucilage has also been employed to produce edible biodegradable films. Muñoz-Tebar et al.[92,93] developed chia mucilage films with good mechanical properties and water vapor permeability, and the addition of oils enhanced the film's antifungal activity.

Conclusion and Future Perspectives

Partially defatted chia cake and meals, which are rich in nutrients such as protein and antioxidants, offer significant potential as value-added ingredients in a range of food products. Although conventional extraction methods have been widely utilized, there is a growing need to explore more environmentally sustainable and efficient techniques. Additional research is essential to optimize the use of chia by-products in innovative food applications and to fully comprehend their health benefits.

Disclaimer (Artificial intelligence)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

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