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REVIEW ARTICLE

Benefits of Chia Seeds as a Functional Food for Cardiovascular Diseases Prevention: A Review

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A B S T R A C T

In order to increase overall health while maintaining a healthy lifestyle, the interest in consuming lipid-based food or lipid-modifying foods is growing. The aim of this paper is to review the morphology, composition, and benefits of chia seeds in the prevention of cardiovascular diseases. Chia seed is an annual herbaceous plant that is rich in lipids (30-33%), carbohydrates (2-41%), dietary fibre (18-30%), and protein (15-25%). Chia seeds also contain high amounts of bioactive compounds, such as omega-3 fatty acids, antioxidants, and polyphenols, to prevent some chronic diseases. Its rate of consumption has grown over the years due to its health benefits for chronic conditions such as obesity, cardiovascular disease, diabetes, and cancer. Some studies have been done to prove the benefits of consuming chia seeds. Although future clinical research is still required, previous research showed that regular chia seed consumption had been related to reduced risk of cardiovascular disease, obesity, and other chronic diseases with a balanced nutritional profile.

K E Y W O R D S

Chia seeds, Functional food, Lipid, Cardiovascular disease

H I G H L I G H T S

- Chia seeds are rich in nutrients, including omega-3 fatty acids, fibres, proteins, and antioxidants, which may contribute to cardiovascular health.
- Several studies have associated regular consumption of chia seeds with improved blood pressure control, reduced oxidative stress, and better lipid profiles.
- More comprehensive clinical trials are needed to establish clear guidelines for chia seed consumption in cardiovascular disease prevention.

INTRODUCTION

Lipid-based food or lipid-modifying food remains a growing interest due to achieving low-density lipoprotein cholesterol (LDL-C) goals and statin-induced myopathy that leads to risks of cardiovascular disease. Most worldwide guidelines have approved and encouraged the use of nutraceuticals and functional foods to supplement conventional medication, including the National Cholesterol Education Program and

European guidelines. In addition, nutraceuticals can be an advantage for safety and tolerance when recommending a patient's diet to improve the lipid profile. Moreover, many nutraceuticals have demonstrated positive effects in lowering cholesterol and reducing the risk of cardiovascular disease (Sahebkar *et al*., 2016).

Chia is an annual herbaceous plant of the Lamiaceae family that was first grown in high tropical and subtropical areas. Chia seeds are rich in lipids (30–33%), carbs (2–41%), dietary fibre (18–30%), protein (15–25%), vitamins, minerals, and free radicals (Lopez *et al*., 2023). Aztecs of ancient Mexico cultivated this desert plant with the Latin name *Salvia hispanica L.* as their daily diet. Furthermore, in California, Nevada, Arizona, and New Mexico, a similar plant named Salvia *columbariae was found*. It is used as a source of food and medicinal purposes because of the nutritional benefits discovered (Franklin & Hongu, 2016).

Caffeic acid, chlorogenic acid, ferulic acid, p-coumaric acid, 7-hydroxycoumarin, catechol, quercetin, quercetin-3-glucoside, and kaempferol are among the phenolic chemicals abundant in chia seeds (Romankiewicz *et al*., 2017). Phenolic compounds can be found in many plants, such as soybeans, canola, and other edible plants. It plays an important role as an antioxidant to protect the human body against chronic diseases (Coelho & Salas-Mellado, 2014). Additionally, chia also has a gum-like property in which a fibre-rich fraction of 56.4 g/100 g of dietary fibre, of 53.45 g/100 g, is insoluble, and the remaining is soluble. Hence, chia seeds are suitable for desserts or cookies (Ding *et al*., 2018).

Chia consumption has increased over the years due to its health benefits for chronic conditions such as obesity, cardiovascular disease, diabetes, and cancer. As mentioned, chia seeds are high in bioactive compounds such as omega-3 fatty acids, antioxidants, polyphenols, dietary fibre, and proteins. Chia seed oil has been shown to be high in fatty acids, particularly polyunsaturated fatty acids (PUFA), with around 19.5% alpha-linoleic acid (omega 3) and more than 5.2% alpha-linoleic acid (omega 6) (Grancieri et al., 2019). Both omega-3 and omega-6 are essential to the human body since they cannot be synthesized. Moreover, omega-3 fatty acids contained in chia seeds have been demonstrated to decrease inflammation, enhance heart health, and lower the risk of some chronic illnesses (Ghafoor et al., 2020). According to studies, oil produced from chia seeds contains many phenolic components such as tocopherols, phytosterols, and carotenoids, all of which have antioxidant activity and play a key role in the degradation of the oil related to lipid oxidation (De Falco et al., 2017).

Furthermore, the antioxidant and polyphenol content of chia seeds may aid in the prevention of oxidative damage and cancer. Additionally, the high content of dietary fibre in chia seeds could enhance satiety and reduce hunger, which may aid in weight loss. However, some environmental factors, including climate, soil, geographic location, pre-harvest, and post-harvest processing, could contribute to the chemical compound contained in chia seed (Katunzi-Kilewela et al., 2021). Besides its nutritional content and health benefits, adding chia to food products could also improve their physicochemical and sensory characteristics.

MATERIAL AND METHODS

This review paper was made by compiling information from a variety of research papers found in several search engines, namely Google Scholar, PubMed, and ScienceDirect. First, the insertion of the phrases “chia seeds," “bioactive compounds," “cardiovascular disease," "health," "processing," “clinical trial," and “shelf life” into the search engines specified the sources that cover the objective of the research paper. The papers were then selected according to the validity criteria, which included publications published in the last 11 years (2012-2023).

International studies addressing the general nutritional profile and health benefits of chia seeds, as well as lipid-related advantages of chia seeds in cardiovascular disease prevention, were eligible for inclusion. Studies that were not specific to chia seeds and their nutritional content, as well as health benefits, were excluded. Papers that did not provide full text were also excluded. Titles and abstracts were then checked for relevance, followed by a full-text review to confirm inclusion, with disagreements handled by discussion.

51 papers were then selected and reviewed in this paper based on the inclusion criteria. The study's characteristics, methodology, sample size, nutritional profile, and health outcomes of chia seeds were all gathered. Relevant information, including the nutritional content (macro- and micronutrients), its relevance to human health specifically related to cardiovascular disease, dosing, and toxicology, as well as its utilization in the food industry as functional ingredients, was then reviewed and summarized from the papers in this review paper.

NUTRITIONAL CONTENT OF CHIA SEEDS

Table 1. Nutritional components of whole chia seeds and different fractions

Nutritional Properties (g/100g)			Reference
Protein	**Lipids**	**Fibre**	
18.18-19.72	30.17-32.16	33.37-37.18	Silva et al., 2017
22.7	32.5	33.5	Sandoval-Oliveros & Parades-Lopez, 2012
19.6	34.4	23.7	Coelho & Mellado, 2014

With regards to the nutritional content of chia seeds, the main components that can be abundantly found within chia seeds include lipids, proteins, amino acids, dietary fibres, vitamins, minerals, and antioxidant compounds. Nonetheless, their nutritional content is still heavily influenced by the climate, geographical location, and the development of the plant itself. For example, as the plant ages, fibrous content within chia seeds will increase as protein content decreases (Melo et al., 2019).

Table 2. Fatty acid contents in whole chia seeds

Fatty Acids (% of Total Fat Content)							FA Ratios		Reference
C16:0	**C18:0**	**C18:1**	**C18:2 n-6**	**C18:3 n-3**	**SFA**	**PUFA**	**n-6:n-3**	**PUFA:SFA**	
6.69	2.67	10.55	17.36	62.02	9.74	79.47	0.28	8.16	Coelho & Mellado, 2014
1.82-1.85	0.90-1.03	1.43-1.67	5.09-5.69	18.74-20.37	2.73-2.88	25.73-27.75	0.27-0.28	9.42-9.64	Silva et al., 2017
5.857	2.498	6.161	17.473	54.485	8.355	71.958	0.32	8.613	Sargi et al., 2013

Lipids play a significant role in one’s diet as energy sources, providing viable sources of essential fatty acids and fat-soluble vitamins (Field & Robinson, 2019). Within chia seeds are 25-40% of oils, constituting polyunsaturated essential fatty acids (PUFA), in which 60% makes up omega-3 alpha-linolenic acid (ALA) while 20% makes up omega-6 linoleic acid (LA) (see **Table 2**). PUFA is vital in lipid homeostasis, where it regulates cell membrane fluidity and function throughout cell signalling and also promotes transcriptional regulation during gene expression (Kuznetcova et al., 2020). Not naturally synthesized in organisms, ALA is known to lower blood sugar levels by encouraging nitric oxide-mediated endothelium-dependent vasodilation, hence improving microcirculation in patients with diabetic polyneuropathy (Nguyen & Gupta, 2022). Moreover, ALA is also a strong antioxidant that restores the intrinsic antioxidant systems, supporting cell accessibility (Salehi et al., 2019). On the other hand, the eicosanoids derived from LA are effective against cardiovascular diseases and cancer as they decrease total cholesterol concentrations and are essential in forming prostaglandins and thromboxanes (Froyen & Whitmore, 2020).

Table 3. Protein fractions in chia seeds. Values represent the mean $\pm$ SD of three replicates

Protein	g/100g protein*	Reference
Albumins	17.3 ± 0.8	Sandoval-Oliveros & Parades-Lopez, 2012
Globulins	52.0 ± 1.0	Sandoval-Oliveros & Parades-Lopez, 2012
Prolamins	12.7 ± 0.2	Sandoval-Oliveros & Parades-Lopez, 2012
Glutelins	14.5 ± 0.2	Sandoval-Oliveros & Parades-Lopez, 2012

Table 4. Thermal characterization of chia protein isolates and fraction

Protein Fraction	T_d (°C)	ΔH_d (J g^{-1})	ΔT_d (°C)	Reference
Albumins	103.6 ± 0.7	12.6 ± 0.8	96.0-118.8	Sandoval-Oliveros & Parades-Lopez, 2012
Globulins	104.7 ± 0.2	4.7 ± 0.9	94.3-116.6	Sandoval-Oliveros & Parades-Lopez, 2012
Prolamins	85.6 ± 0.6	2.3 ± 0.2	72.1-93.2	Sandoval-Oliveros & Parades-Lopez, 2012
Glutelins	91.3 ± 0.8	6.8 ± 0.1	76.0-104.9	Sandoval-Oliveros & Parades-Lopez, 2012

Proteins found in chia seeds constitute about 16–26% of their entire nutritional value, whereas prolamins, glutelins, globulins, and albumins can be found (see **Table 3**). The denaturation temperature ranges, denaturation peak temperatures, and denaturation enthalpies of the mentioned lyophilized extracts of protein fractions of chia seeds were previously obtained through differential scanning calorimetry (DSC), where results reveal single peaks for each fraction, indicating refined single and diverse protein fractions (see **Table 4**). In the case of albumins and prolamins, both fractions were discovered to produce more refined peaks than other protein fractions (Sandoval-Oliveros & Paredes-Lopez, 2013).

Table 5. Amino acid profile of chia seeds

Amino Acid	g/100g protein	Reference
Alanine	1.05	Ullah et al., 2016
Arginine	2.14	Ullah et al., 2016
Aspartate	7.64	Ullah et al., 2016

Amino Acid	**g/100g protein**	**Reference**
Glutamate	3.50	Ullah et al., 2016
Glycine	0.95	Ullah et al., 2016
Histidine	0.53	Ullah et al., 2016
Isoleucine	0.80	Ullah et al., 2016
Leucine	1.37	Ullah et al., 2016
Lysine	0.97	Ullah et al., 2016
Methionine & Cysteine	-	Ullah et al., 2016
Phenylalanine & Tyrosine	-	Ullah et al., 2016
Proline	0.77	Ullah et al., 2016
Serine	1.05	Ullah et al., 2016
Threonine	0.71	Ullah et al., 2016
Valine	0.95	Ullah et al., 2016
Phenylalanine	1.016	Ullah et al., 2016
Methionine	0.59	Ullah et al., 2016
Asparagine	1.69	Ullah et al., 2016
Cysteine	0.45	Ullah et al., 2016
Tyrosine	0.56	Ullah et al., 2016
Tryptophan	0.44	Ullah et al., 2016

* Essential amino acids

Additionally, a good balance of eight essential amino acids can be detected, including histidine, isoleucine, leucine, lysine, methionine, cysteine, phenylalanine, tyrosine, threonine, and valine. Nonetheless, the most abundant amino acid found within chia seeds is glutamic acid (see **Table 5**). However, unlike adults, it should be taken into consideration that chia seeds are not able to provide sufficient threonine, lysine, and leucine for preschool children (Melo et al., 2019).

The dietary fibers found in chia seeds can be classified into soluble and insoluble fractions. In total, dietary fibres comprise 23–41% of chia seeds, 85% of which is attributed to the insoluble fraction, while the remaining 15% is attributed to the soluble fraction. The fibres that can be detected include cellulose, hemicellulose, lignin, pectin, gums, mucilage, and other polysaccharides or oligosaccharides (Melo et al., 2019). Since the majority of dietary fibres found in chia seeds are insoluble, this augments the feeling of satiety, allowing proper bowel movement as it is unable to undergo fermentation in the large intestine. Aside from aiding weight loss, dietary fibres are also strongly associated with the reduced risk of coronary diseases and diabetes as they decrease cholesterolemia, increase insulin sensitivity, and improve the glycemic index of lipid profiles (Barber et al., 2020).

Table 6. Vitamin B in chia seeds (mg/100g)

Vitamin B	mg/100g	Reference
Thiamine	0.6	Kulczynski et al., 2019
Riboflavin	0.2	Kulczynski et al., 2019
Niacin	8.8	Kulczynski et al., 2019

Table 7. Macrominerals in chia seeds (mg/100g)

Macroelement	mg/100g	Reference
Calcium	456-631	Kulczynski et al., 2019
Potassium	407-726	Kulczynski et al., 2019
Phosphorus	860-919	Kulczynski et al., 2019
Magnesium	335-449	Kulczynski et al., 2019

Table 8. Recommended dietary allowance of macrominerals for adults (mg/day)

Macroelement	mg/day
Calcium	1000
Potassium	4.7
Phosphorus	700
Magnesium	420, 320 (males, females)

Chia seeds are widely acknowledged as an affluent source of vitamin B, namely thiamine, riboflavin, and niacin (see **Table 6**). Moreover, it is also recognized for its copious amounts of macrominerals such as calcium, potassium, phosphorus, and magnesium (see **Table 7**) (Kulczynski et al., 2019). Both vitamins and minerals are indispensable in the human body as they sustain numerous basic metabolic pathways, playing key roles in metabolism, DNA synthesis, oxygen transport, and neuronal functions (Tardy et al., 2020). Furthermore, based on the recommended dietary allowance of macrominerals for adults, chia seeds provide sufficient amounts of phosphorus and magnesium, as well as about half of the required calcium. Unfortunately, the same cannot be said for potassium (see Table 8) (Melo et al., 2019).

Antioxidant compounds are also known as the first line of defense for protecting cells, maintaining cell integrity, and regulating the physiological processes of living systems. It functions to neutralize free radicals, mitigating stress and its succeeding consequences (Kurutas, 2015). Thus, chia seeds may enhance anti-inflammatory affairs within the body. Following consumption, chia seeds will be degraded and oxidized, and metabolites and digestive products will be released, encouraging anticancer and antithrombotic activities. These metabolites include tocopherols, sterols, chlorogenic acid, caffeic acid, quercetin, and kaempferol (Melo et al., 2019). One of the many studies supporting chia seeds as a potent antioxidant is Martínez-Cruz & Paredes-Lopez (2014), where they discovered that the phenolic compounds extracted from chia seeds—including rosmarinic acid, protocatechuic ethyl ester, caffeic acid, gallic acid, and daidzin—possessed a 69% inhibition rate against DPPH radical scavenging activity.

BENEFITS AND EFFICACY OF CHIA SEEDS

Health benefits

Several health benefits can be maneuvered from the consumption of chia seeds. As mentioned earlier, chia seeds contain a considerable amount of essential fatty acids, protein, dietary fibre, vitamins, and minerals. This balanced nutritional profile provides several health benefits in normal physiology, such as reducing blood cholesterol levels and maintaining body weight. Therefore, regular consumption of chia seeds can support overall health and well-being by providing essential nutrients and promoting various physiological functions.

Additionally, it featured anticarcinogenic and antiradical properties. Moreover, chia seeds also offer ample protection for one's cardiovascular system. Alongside chia seeds' anticarcinogenic properties, this feature is also closely accompanied by its antineoplastic, antiproliferative, and apoptotic properties. In an experiment with mice, several findings were concluded, further corroborating the aforementioned characteristics. The experimental mice were fed either 6% fat of chia seed oil or 6% safflower oil, and after three months, a murine mammary gland adenocarcinoma with moderate metastatic ability was implanted subcutaneously. Findings indicate a significant tumour weight decrease with the use of chia oil, as well as apoptosis encouragement and dampened mitosis. Higher EPA (eicosapentaenoic acid) was also detected in membranes, suggesting the occurrence of apoptotic effects through the activation of caspase activity and programmed cell death (Melo et al., 2019). This may be the effects produced from the isoflavones present in chia seeds: 0.0066 of daidzin, 0.0014 of glycitin, 0.0034 of genistin, 0.0005 of glycitein, and 0.0051 mg g^{-1} of genistein. The presence of alpha-linolenic acid in chia seeds can also help to neutralize the free radicals and may regenerate the presence of various antioxidants and maintain its barrier, which may inhibit the growth of cancer cells, such as vitamin C, vitamin E, and glutathione (Durand et al., 2013; Maciejczyk et al., 2022).

Chia seeds also boast a range of protection against cardiovascular diseases through their control of hypertension, hypotensive properties, vasodilation, and dyslipidemia. These aspects were all observed in the experiment of Valenzuela et al. (2014), where 60 male Wistar rats were given some types of oils, including *Rosa canina*, sunflower, sacha inchi, chia, and canola for twenty days. Other than that, as one of the major causes of death and one of the most expensive treatment costs, prevention of cardiovascular diseases, including controlling the presence of obesity, dyslipidemia, and hypertension, must be conducted. A study by Poudyal et al. (2012) reported evidence of chia seeds' anti-obesity activity in animals, which can occur due to its low carbohydrate and high fibre content that may increase the satiety feel and allow chia seeds to have a lower calorie density (Zagorski et al., n.d.). The supplementation of chia seeds was also found to be effective in reducing inflammation, hepatic steatosis, and the level of adipose tissue in the body since chia seeds contain various antioxidants and anti-inflammatory compounds, such as chlorogenic acids and caffeic acids, that can be beneficial for inhibiting the production of pro-inflammatory enzymes and cytokines in the body (Cisternas et al., 2024). The presence of ALA in the chia seeds also allowed the various anti-inflammatory compounds to regenerate and maintain their barrier in the body, as mentioned by Durand et al. (2013) and Maciejczyk et al. (2022), which can be effective in lowering the risk of obesity and cellular lipid accumulation.

Moving on to chia seeds' antioxidant and antiradical activity, Ullah et al. (2017) discovered that the hydrolysis of chia protein enhances antioxidant activity and the inhibitory potential of ACE (angiotensin-converting enzyme). The experiment was conducted with 100% milk fat as the control, along with evaluating the antioxidant potentials of different chia olein fractions: 5%, 10%, 15%, and 20%. Results reveal 5.61%, 17.43%, 36.84%, 51.17%, and 74.91% values for the control group and the four different fractions, respectively. Hence, advancements in 2,2-diphenyl-1-picrylhydrazyl free radical scavenging activity are reported. Furthermore, it was also proposed by Parker et al. (2018) that chia seeds can behave as electron donors and scavengers for free radicals. This was concluded based on their experiment observing the inhibitory effects of chia protein isolates towards ACE that were significantly more potent than lima beans (*Phaseolus lunatus* L.) and common beans (*P. vulgaris* L.). Supporting both aforementioned experiments above, Orona-Tomayo et al. (2015) successfully demonstrated how prolamins and globulin were able to effectively chelate *in vitro* ferrous ions (Fe^{2+}) in the gastrointestinal tract. Following this finding, they also determined the potency of the antiradical activity of chia against 2,2'-azinobis (3-ethylbenzothiazoline 6-sulfonic acid), 2,2-diphenyl-1-picrylhydrazyl, and ACE.

Dosing and toxicology

The general dosing of chia seeds, according to the United Kingdom (UK) Advisory Committee for Novel Foods and Processes, should be approximately 2.1g day^{-1} with a maximum of 12.9 g day^{-1} for adults; this is estimated to be equivalent to a tablespoon and contains more than 2500 mg of omega-3 fatty acids and 4.5 g of dietary fibre. For children between the ages of 1.5 and 4.5 years, the average consumption should be 1.1 g daily, with a maximum of 3.2 g daily. On the other hand, children between the ages of 4.5 and 19 should only consume 1.4 g day^{-1} with a maximum daily intake of 4.3 g (Melo et al., 2019).

Table 9. Authorized use of chia seeds and its products

Specified Food Category	Maximum Levels	Reference
Bread Products	5% (whole/ground chia seeds)	Turck et al., 2019
Baked Products	10% whole chia seeds	Turck et al., 2019
Breakfast Cereals	10% whole chia seeds	Turck et al., 2019
Fruit, Nut & Seed Mixes	10% whole chia seeds	Turck et al., 2019
Fruit Juice & Fruit/Vegetable Blend Beverages	15g/day for the addition of whole, mashed, or ground chia seeds	Turck et al., 2019
Pre-packaged Chia Seed as Such	15g/day whole chia seeds	Turck et al., 2019
Fruit Spreads	1% whole chia seeds	Turck et al., 2019
Yoghurt	1.3g whole chia seeds per 100g of yoghurt or 4.3g whole chia seeds per 330g of yoghurt (portion)	Turck et al., 2019
Ready to Eat Meals	5% whole chia seeds	Turck et al., 2019

Table 9 summarizes the authorized use of chia seeds within specified food categories based on the EFSA NDA Panel (Turck et al., 2019). As long as individuals do not exceed maximum levels, the consumption of chia seeds should not compromise biological safety. Nonetheless, it has also been proven by the European Parliament that the approved novel food does not cause allergic, anti-nutritional, or toxic effects in organisms. Hence, how the oil is extracted from chia seeds is now applied in the design of omega-3 supplements in capsules (Melo et al., 2019). Though there were reported cases of immunoglobulin E (IgE) mediated anaphylactic reactions back in 2015 and 2018 by Jimenez et al. and Perez et al., there are no other reported allergic reactions that have yet to be published in the literature to date. Furthermore, the patients who experienced these anaphylactic reactions also have personal histories of tenacious allergic rhinitis, making the said cases not generalizable to the global population.

Although no allergenicity of Chia seeds was reported in the present literature, there have been some cases reported regarding the cross-reactivity of Chia seeds in patients with food allergies, especially peanut and sesame allergies, where IgE-binding to proteins from chia were detected in patients sensitized to peanut and sesame. Therefore, the recommended approach is to label foods containing chia seeds (EFSA, 2009).

For the toxicology of chia seeds, a number of toxicological studies were performed by Shu-Qin et al. (2013), which were conducted according to the National Standards of the People's Republic of China for the toxicological assessment of food. An acetone extract of chia seeds was tested for the presence of gene mutations through the plate incorporation method with four *Salmonella typhimurium* tester strains. Results showed that there were no significant differences in the number of revertant colonies at doses of 5 mg/plate in the absence and presence of a metabolic activation system in comparison to the control. Another toxicological experiment involved the *in vivo* micronucleus test using bone marrow, where the chia seeds were ground into a powder. Subsequent to oral administration to Kunming mice, no enhancement in the frequency of micronucleated polychromatic erythrocytes (PCE) was observed. No cytotoxicity of the test material was observed as well (Hayashi, 2016).

Regarding potential drug-nutrient interactions, the omega-3 fatty acids in chia seeds may interact with anticoagulant and antiplatelet medications due to their blood-thinning properties (Carrillo, 2022). Patients taking these medications should consult healthcare providers before consuming large quantities of chia seeds. Moreover, the high fibre content of chia seeds may interfere with the absorption of certain medications, potentially reducing their effectiveness (Jeelani et al., 2023).

Chia seeds for cardiovascular disease

The mechanism of chia seeds in preventing cardiovascular diseases (CVD) is still not well understood, as there are limited clinical trials and evidence that show the direct effect of consuming chia seeds on preventing CVD. However, some in vivo and in silico studies, like the one conducted by Elebeedy et al. (2022) and Toscano et al. (2014), showed that chia seeds have anti-obesity effects that could lower oxidative stress and LDL cholesterol in the body. The action of chia seed hydrolysate could reduce oxidative stress as it acts as an electron donor to scavenge free radicals. Another activity done by angiotensin-converting enzyme inhibitors is also beneficial in enhancing vasodilation and arterial compliance, which later could reduce the blood pressure and risk of CVD. In their studies, it is also mentioned that the combination of chia seeds with other high-antioxidant foods like green tea chitosan could significantly lower the body weight gain and liver weight of rats, preventing the rats from obesity, which then could lower the risk of cardiovascular diseases. Ali et al. (2012) also mentioned that fortifying chia seeds could lower triglyceride and cholesterol levels due to omega 3 and omega 6 in chia seeds.

Numerous studies have demonstrated the health advantages of chia seeds and chia seed oil. In rats given a high-fat diet, chia seeds reduce oxidative stress and inflammation, which improves lipid profiles, insulin resistance, and BMI, according to mechanistic research by Aref et al. (2024). Furthermore, in animal models with hypercholesterolemia and metabolic syndrome, chia seed oil lowers triglyceride levels and improves vascular function, as observed in the experimental investigation conducted by Jerez et al. (2021). Additionally, an epidemiology study by Enes et al. (2020) observed that a higher intake of ALA from chia seeds is associated with a reduced risk of ischemic heart disease in large cohort studies.

Not only in vivo studies but also reviews of some clinical trials that have been conducted in the past years show the benefits of lowering cardiovascular disease in humans. As written by Ali et al. (2012) paper, 25 grams per day for 7 weeks could improve the cardiovascular disease eicosapentaenoic acid (EPA) and alpha-linolenic acid (ALA), which is beneficial to prevent blood clotting and reduce the level of triglycerides in the blood. Another clinical trial was performed by Alowasais et al. (2021), where adults with type II diabetes mellitus were split into 2 groups, treatment and control, and the treatment group was told to consume 40 grams of chia seeds for 12 weeks. The results showed that the treatment group had lower systolic blood pressure compared to the control group, meaning that the treatment group had a lower risk of getting cardiovascular diseases. But, in contrast with Ali et al. (2012) findings, there was no significant difference in the treatment group's body weight, glycemic control, lipid profile, or body weight. It discusses how the difference with previous findings was caused by the small sample size, which makes the result unable to represent the population of people with type 2 diabetes. Moreover, a study by da Silva et al. (2016) mentioned that chia seed consumption could lower the glucose level presence in the blood.

Other than improving the overall lipid profile in the human blood, Ayaz et al. (2017) explained the role of chia seeds in maintaining the satiety level of a healthy individual. Satiety maintenance is crucial in the prevention of overeating and obesity prevention. As mentioned by Hetherington et al. (2013), the ability to regulate the satiety level will prevent the individual from having obesity, diabetes, and cardiovascular diseases due to high body weight and high body fat percentage.

In addition to those benefits, chia seed consumption could also improve aortic relaxation (Sierra et al., 2015). According to Cecelja and Chowienczyk (2012), arterial stiffness could increase the risk of CVD since, during the cardiac cycle, the aorta and major arteries often function as a buffer, absorbing the force of blood ejected from the heart (during systole) and gradually releasing it (during diastole). When the aorta stiffens and relaxes inefficiently, it loses its ability to absorb this strain. This leads to greater systolic blood pressure.

On top of all these benefits, an experimental study done by Fernandez et al. in 2008 mentioned that the consumption of chia seeds could improve the immunity system by increasing the immunoglobulin E (IgE) of rats. Immunoglobulin E (IgE) is an important antibody that fights against allergic reactions and defends against parasitic infections (Amarasekera, 2011). With a high immune system, the inflammation inside the body could be reduced, hence lowering the risk of CVD.

Table 10. Potential effects of chia seeds on cardiovascular risk factors: evidence from multiple studies

Study Type	**Cardiovascular Risk Factor**	**Key Findings**	**Reference**
Mechanistic Study	Oxidative stress, inflammation	Chia seeds alleviate oxidative stress and inflammation within rats that were fed a high-fat diet—improved BMI, lipid profile, and insulin resistance.	Aref et al., 2024
Mechanistic Study	Arterial stiffness	Adding chia seed oil to rabbits' diets improved aortic relaxation, which was activated by acetylcholine.	Sierra et al., 2015
Experimental Study	Hypercholesterolemia, metabolic syndrome	Chia seed oil dampens triglyceride levels and simultaneously improves vascular function in animal models.	Jerez et al., 2021
Epidemiological Study	Ischemic heart disease	A higher intake of alpha-linolenic acid (ALA) from chia seeds was observed to have a reduced risk of ischemic heart disease in large cohort studies.	Enes et al., 2020
Experimental Study	Blood pressure, platelet aggregation	Chia seed components were discovered to reduce cholesterol, oxidation, platelet aggregation, and blood pressure.	Khalid et al., 2023

Experimental study	Blood lipid profile	Chia seed consumption could improve the blood lipid profile by reducing the total cholesterol and VLDL-c (Very Low-Density Lipoprotein Cholesterol) and increasing HDL-c (High-Density Lipoprotein Cholesterol).	Ali et al., 2012 Elebeedy et al., 2022 Toscano et al., 2014
Experimental study	Blood glucose level	Chia seed consumption could lower the presence of glucose levels in the blood.	da Silva et al., 2016
Experimental study	Low immunity system	Chia seed consumption could significantly increase immunoglobulin E (IgE) in rats.	Fernandez et al., 2008

Chia seeds utilization

As a functional food, chia seeds can be eaten directly or included in numerous foods and recipes, as it could increase the palatability of the food itself. Some findings prove that the hydrophobicity of the chia seeds could be utilized to replace eggs and oil in baked goods and cake products. Not only does it enhance the protein, fibre, and omega-3 fatty acids, but the substitution of the egg also increases the sensorial acceptability of the baked goods in terms of colour, texture, and taste (Kulczyński et al., 2019). It must be taken into consideration that chia seeds could lower the yield volume of the cake, which makes it become less airy and denser (Fernandes & Mellado, 2017). Kulczyński et al. (2019) mentioned that substituting 50%-75% of the total egg with chia seeds reduces the acceptability of the cake. Other than baked goods, the utilization of chia seeds as an egg replacer in making pork patties also shows positive results, as it improved the texture and slowed down the oxidative changes during storage.

Many studies have also stated that the utilization of chia seeds as flour replacements is beneficial for increasing both the nutritional values and sensorial properties of several food products. Pasta made with chia seed flour proved to have higher protein, mineral, and dietary fibre contents compared to regular wheat flour pasta (Olivera et al., 2015). Another report from Coelho and Mellado (2015) mentioned that a fortification of 7.8 grams per 100 grams of flour could increase the amount of polyunsaturated fatty acids (PUFA) in the bread. For chip products, Coorey et al. (2012) mentioned that rice and potato flour substitution with chia seed flour could increase the palatability of the chips. In terms of sausage, the mixture of chia seed flour with olive oil increases the total dietary fibre and minerals while also lowering the fat and energy content of the chia seed-fortified frankfurters (Pintando et al., 2016). As the chia flour has low water activity, it could be stored at room temperature inside an airtight container to prevent exposure to both air and water.

CONCLUSION

Chia seed is an annual herbaceous plant that is rich in lipids, carbohydrates, dietary fibre, protein, vitamins, and minerals. Chia seeds also contain high amounts of bioactive compounds, such as omega-3 fatty acids, antioxidants, and polyphenols, to prevent some chronic diseases, such as cardiovascular disease, obesity, diabetes, and cancer. Previous studies show that regular chia seed consumption could reduce the risk of cardiovascular disease. Since chia seeds contain a lot of antioxidants, they can neutralize the free radicals and may have control over hypertension, hypotensive properties, vasodilation, and dyslipidemia. Chia seeds also have an anti-obesity effect, which allows them to lower oxidative stress and LDL cholesterol levels due to the presence of omega 3 and omega 6 in the chia seeds. Even though there is a recommended intake of chia seeds mentioned by Melo et al. (2019), which is 1.1-3.2 grams/day for children and 2.1 grams/day for adults, some clinical trials are still needed to prove the direct correlation between chia seeds in preventing cardiovascular diseases, as there is only limited evidence with contrast findings found till this day.

While current research shows promise for chia seeds in cardiovascular health, more comprehensive studies are needed to establish clear consumption guidelines and health benefits. For future research, researchers can focus on large-scale and long-term clinical trials to determine the optimal dosage and duration of chia seed consumption for preventing cardiovascular diseases. These studies can also look into how chia seeds affect different cardiovascular risk factors across various demographics, including people who already have heart problems as a positive control. Furthermore, more investigation can be done on any possible interactions between chia seeds and popular heart medications.

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