

Review Article

The Promising Future of Chia, *Salvia hispanica* L.

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With increasing public health awareness worldwide, demand for functional food with multiple health benefits has also increased. The use of medicinal food from folk medicine to prevent diseases such as diabetes, obesity, and cardiovascular problems is now gaining momentum among the public. Seed from *Salvia hispanica* L. or more commonly known as chia is a traditional food in central and southern America. Currently, it is widely consumed for various health benefits especially in maintaining healthy serum lipid level. This effect is contributed by the presence of phenolic acid and omega 3/6 oil in the chia seed. Although the presence of active ingredients in chia seed warrants its health benefits, however, the safety and efficacy of this medicinal food or natural product need to be validated by scientific research. *In vivo* and clinical studies on the safety and efficacy of chia seed are still limited. This paper covers the up-to-date research on the identified active ingredients, methods for oil extraction, and *in vivo* and human trials on the health benefit of chia seed, and its current market potential.

1. Introduction

Salvia hispanica L. (Figure 1), a biannually cultivated plant, is categorized under the mint family (*Labiatae*), superdivision of *Spermatophyta*, and kingdom of *Plantae*. Prominently grown for its seeds, *Salvia hispanica* also produces white or purple flowers. The seed (Figure 2) contains from 25% to 40% oil with 60% of it comprising (omega) ω -3 alpha-linolenic acid and 20% of (omega) ω -6 linoleic acid. Both essential fatty acids are required by the human body for good health, and they cannot be artificially synthesized. Chia can grow up to 1 m tall and has opposite arranged leaves. Chia flowers are small flower (3-4 mm) with small corollas and fused flower parts that contribute to a high self-pollination rate. The seed color varies from black, grey, and black spotted to white, and the shape is oval with size ranging from 1 to 2 mm [1-4]. Wild and domesticated chia differs little. Currently, only *Salvia hispanica* but not other species of the genus *Salvia* can be grown domestically. To

prevent the misidentification of *Salvia hispanica* and other species of *Salvia*, clear understanding of the morphological and genotypical differences among them had been proposed as solutions [4, 5]. Locally known for its medicinal uses, *Salvia hispanica* L. acquired the common name chia from the indigenous South American people of the pre-Columbian and Aztec eras [6]. Owing to the fact that it can grow in arid environments, it has been highly recommended as an alternative crop for the field crop industry [7].

Chia seed is composed of protein (15-25%), fats (30-33%), carbohydrates (26-41%), high dietary fiber (18-30%), ash (4-5%), minerals, vitamins, and dry matter (90-93%). It also contains a high amount of antioxidants [8]. Heavy metal analysis showed that chia seed contains them at safe levels, not exceeding the maximum metal levels for food safety, and the seed is also free from mycotoxins [1]. Another key feature of chia seed is that it does not contain gluten [9]. Recent studies on chia seeds have focused on phytochemicals and their extractions from the seed. Only very little studies



FIGURE 1: *Salvia hispanica* L. plant with purple flower and large leaves [10].

have focused on *in vivo* or clinical bioactivities and the safety aspects of chia seed. The aim of this paper is to critically evaluate the health benefits, phytochemical contents, methods of oil extraction, and the current market potential of chia seed as a health food supplement.

2. Phytochemicals in Chia Seed

Various active ingredients including essential fatty acids and phenolic compounds have been identified in chia seed. These active compounds which contribute to the health benefits of chia seeds are summarised in Table 1.

There are many factors that may cause variations in the concentrations of the active compounds in chia seed. One of them is the cultivation area of the plant itself. Differences in the environment, climate changes, availabilities of nutrient, year of cultivation, or soil conditions play crucial roles to the variations [17, 22]. For example, the protein content tends to decrease as the temperature increased [23]. Furthermore, an inverse relationship between altitude and the content of saturated fatty acids (SFAs) had been observed whereby, at low elevation, an increase in fatty acid saturation was noted in areas where the temperature was high [7, 24]. In Argentina, Ayerza [25] demonstrated that temperature largely contributed to the type of fatty acid found in the oil. They found that, during seed development from April to May, an increase in the temperature of the environment brought about a decrease in the polyunsaturated fatty acid (PUFA) content.

Another factor that may contribute to differences in the chemical compositions of chia seed is the developmental stage of the plant. It was shown that the (α -linolenic acid) ALA content decreased by 23% from the early stage to the matured stage of the seed. This concurrently resulted in the increase of linolenic acid (LA) and lignin content [7].

3. Health Benefits of Chia Seed-Animal Studies

Several crops have been commercially recognized as being good sources of oil for dietary use including flaxseed,

rapeseed, sunflower seed, soybean seed, maize, evening primrose, and chia seed. A comparative study using flaxseed, rapeseed, and chia seed as chicken feed had been conducted. Eggs from hens fed with chia had the highest ω -3 ALA content as compared to hens fed with flaxseed or rapeseed [26]. Due to the easier availability and lower price of flaxseed over chia, an attempt to replace chia with flaxseed in laying hen's feed was carried out. The incorporation of flaxseed in the diet resulted in a slight decrease of the ω -3 ALA content of egg yolk [27]. However, the high antinutritional content of flaxseed affected the poultry meat quality.

Besides the utilization of chia in poultry animal targeted for human consumption, it had also been used for animal nutrition by itself. Other than chia seed oil, studies had been done using other grain oil such as flaxseed in broiler feed which also resulted in an increase of fatty acid quality level in broiler's meat [16].

Ayerza and Coates [28] and Fernandez et al. [29] conducted studies concerning the effects of chia seed feeding on rat plasma. Their findings indicated that serum triglycerides (TG) and low-density lipoprotein (LDL) were significantly decreased whereas high-density lipoprotein (HDL) and ω -3 PUFA levels were increased. They also noted that no adverse effects were observed on the rat's thymus and IgE serum level. Furthermore, chia seed feeding was tested in pigs and rabbits, which resulted in an increase of PUFA in meat fats as well as aroma and flavor [30–32]. These are desirable characteristics of human food. In summary, the incorporation of chia seed into animal feed results in an increase of ALA and a decrease of cholesterol levels in meat and eggs. Hence, it is a good substitute source of PUFA to fish and other seed oils. Moreover, atypical organoleptic characteristics such as flavor and smell from marine sources were not found in chia [33]. This showed the superiority of chia seed against other nutritional sources.

4. Health Benefits of Chia Seed-Human Clinical Trials

Correlation between high SFA and low PUFA intake with diseases such as cardiovascular diseases, diabetes, and metabolic syndrome were widely reported [20, 34]. Besides, the additive effect of ALA and n-3 long chain PUFA was observed to exhibit cardioprotective effects in women [35], which led to consequent human clinical studies of chia on disease risk factors. To date, four clinical trials have been carried out, and the details are summarised in Table 2. Among these trials, only that of Nieman et al. [19] showed no health benefits from chia seed. This difference could be due to the treatment durations employed and also the actual biochemical components of the dietary chia seed used in the various studies. Nevertheless, later studies [18, 20, 21] demonstrated well the benefits of chia on human health. However, studies of chia's intake in human diet which take into consideration factors such as lifestyle and genetic variations are still limited. Hence, studies which target these factors should be done in the future.

TABLE 1: Active compounds identified in *Salvia hispanica* L. and their chemical structure.

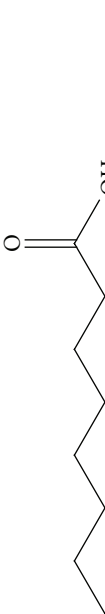

Active compounds in <i>Salvia hispanica</i> L.	Chemical structure	Activities
<p data-bbox="406 457 510 672">Omega 3 alpha-linolenic acid; ω-3 ALA (18 : 3) (<i>PUFA fatty acids</i>)</p>		<p data-bbox="406 1281 510 1323">Essential fatty acid</p> <p data-bbox="406 1323 510 1365">Benefits:</p> <p data-bbox="406 1365 510 1503">(1) lowering TG and cholesterol levels, which in turn results in low blood pressure and heart-related diseases [11]; (2) anti-inflammatory activity [12, 13]; (3) cardioprotective and hepatoprotective activities by redistributing lipid away from visceral fat and liver [14, 15]; (4) antidiabetic action; (5) protection against arthritis, autoimmune disease, and cancer [13].</p>
<p data-bbox="526 457 630 672">Omega 6 linoleic acid; ω-6 LA (18 : 2) (<i>PUFA fatty acids</i>)</p>		<p data-bbox="526 1281 630 1323">Essential fatty acid</p> <p data-bbox="526 1323 630 1503">This FA has inflammatory, hypertensive, and thrombotic activities. Eicosanoid produced from LA has been associated with CVD and cancer [16]. It works inversely with ALA; thus a balanced ratio of ALA to LA is important in maintaining good health [15, 17].</p>

TABLE 1: Continued.

Active compounds in <i>Salvia hispanica</i> L.	Chemical structure	Activities
Myricetin (flavonols and phenolic acids)		
Quercetin (flavonols and phenolic acids)		Antioxidant, anti-inflammatory, anticancer, and antithrombotic activities [12].
Kaempferol (flavonols and phenolic acids)		

TABLE 1: Continued.

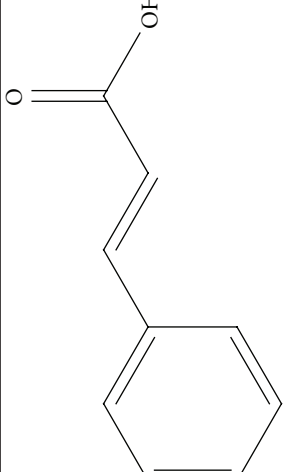
Active compounds in <i>Salvia hispanica</i> L.	Chemical structure	Activities
Caffeic acid (flavonols and phenolic acids)		



FIGURE 2: *Salvia hispanica* L. seeds with brown stripes color [10]. They can also be found having white and dark seed coat colors [8].

TABLE 2: Human clinical trials of chia seed.

Duration	Mode of trial	Formulation	Results	Ref.
7 weeks	10 postmenopausal women	25 g chia seed/day	Polyunsaturated fatty acid content particularly ALA, and eicosapentaenoic acid (EPA) was elevated after supplementation with milled chia. The result was in agreement with previous studies conducted in hens, rats, and rabbits.	[18]
12 weeks	Single blinded with 76 subjects (placebo 37; chia seed 39)	25 g chia seed in 250 mL water twice/day	Although Nieman et al. have hypothesized that the high dietary fiber and ALA content in chia can promote human weight loss and reduce disease risk factors related to heart disease and obesity, no significant results on weight loss and disease risk factors even though the plasma level of ALA increased.	[19]
2 months	Randomized trial, with control diet (500 kcal for 2 weeks), 67 metabolic syndrome subjects (placebo 35; beverage 32)	Beverage of 235 kcal that contains soy protein, nopal, chia seed, and oat	Body weight loss and reduction of triglyceride and blood glucose levels.	[20]
120 minutes	Randomized, double-blind trial on 11 healthy subjects	50 g white bread containing either 0, 7, 15, or 24 g of chia seed	Reduced postprandial glycemia.	[21]

TABLE 3: Extraction of oil from chia seed.

Methods of extraction	Details
Seed compression	(i) Cold pressing technique and storage at low temperature (4°C) in dark [36]. (ii) Komet screw press at 25–30°C using electrical resistance heating. (1) Pro: better preservation of antioxidant contents (quercetin and myricetin) than solvent extraction [37]. (2) Con: only partial recovery of oil yield [38].
Solvent	(i) Soxhlet method using n-Hexane (less preferable than other methods). (1) Pro: it favors the functional characteristics of the oil such as water holding and absorption capacity, organic molecule absorption, and emulsifying stability. (2) Con: it causes slight loss of antioxidant content [37] and health and environment safety issues of using hexane [38].
Supercritical fluids	(i) Use of carbon dioxide at optimum pressure $P = 408$ and 80°C (more preferable method). (1) Pros: better purity and higher ALA/LA content of the final products [39, 40]. The oil yield can be increased with pressure enhancement, but high temperature will slightly affect it [40].

TABLE 4: Commercial usage of chia seed.

Chia seed usage	Products	Remarks
Animal feed	Chicken	(1) Increased ω -3 alpha-linoleic acid and ω -6 linoleic acid of egg and yolk [26]. (2) Increased ω -3 alpha-linoleic acid and decreased palmitic fatty acid of meat. (3) Taste, sensory evaluation, and production of eggs and broilers were not affected [34, 45–47].
	Pigs and rabbits	Increase of PUFA in meat fats as well as improved aroma, flavor, and digestibility of meat [2, 30, 46–49].
Food formulation	Composite flour (15–20% of chia with corn flour)	Increased total dietary fiber and a decrease in Glycemic Index [41].
	Ingredient for cookies, cereal bars, chips, desserts, breads, jellies, and emulsions	Improved water holding, absorption capacity, and emulsifying stability [1, 37, 50].
Health supplement	Chia seed oil	Topical application for skin diseases such as pruritus and xerotic especially in diabetic and renal dysfunction patients [12].
	Carbohydrate-loading drinks	Enhanced athletes' sports endurance by more than 90 minutes but not athletes' performance [51].
	Supplement for postmenopausal women	Enhanced the levels of ALA and eicosapentaenoic acid (EPA) [18].

5. Extraction of Chia Seed Oil

Chia seed is mainly valued for its oil. Thus, many oil extraction methods had been utilized. Differences in the extraction methods caused variations in the oil yield, quality of fatty acids, fatty acid contents, total dietary fibers, and also antioxidant content. Table 3 summarises the current methods used in the extraction of chia seed oil.

6. Market Potential and Commercial Application of Chia Seed

Functional foods have gained tremendous attention worldwide over the past few years due to the wave of healthy lifestyle changes. One of the reasons for the interest to shift to a healthier lifestyle is the increasing number of people suffering from cardiovascular diseases (CVDs), high blood pressure, obesity, diabetes, and other related diseases. These conditions are commonly due to inactive lifestyle and poor diet where the food consumed daily contains high amounts of saturated fatty acids (SFAs). There are numerous studies which reported on the correlation between high SFA, particularly palmitic acid, and low PUFA intakes with CVD [34]. Traditionally, the now so-called functional foods have been consumed based on their availabilities as daily staple foods. At present, many studies have been done to increase their functionality as high nutrient food supplements. The benefits of functional foods primarily come from the presence of active ingredients and bioactivities of compounds originally present in the plant being still present in the food products after they have been processed to make them suitable for human consumption.

Recently, chia has regained its popularity by becoming one of the main oil sources that contains high levels of PUFA. Chia, which used to be the major food crop of the indigenous peoples of Mexico and Guatemala, is now widely cultivated and commercialized for its (omega) ω -3

alpha-linolenic acid (ALA) content and antioxidant properties. Today, its cultivation is not only limited to the Americas but is also extended to other areas such as Australia and Southeast Asia [6].

At present, chia seed is used as a healthy oil supplement for humans and animals. Table 4 presented a summary of the current commercial usages of chia seed. Human consumption of chia in diet is mainly from the extracted oil through its incorporation into cooking oil, confections, or supplements. In 2000, the US Dietary Guidelines recommend that chia seed can be used as a primary food not exceeding 48 g/day. Chia is commonly consumed as salad from chia sprout, in beverages, cereals, and salad dressing from the seed, or it is eaten raw [41, 42]. The European Commission approved the use of chia seed in bread products with a limit of not more than 5%. Other than bread, the food industry of various countries around the world including US, Canada, Chile, Australia, New Zealand, and Mexico has widely used chia seeds or its oil for different applications such as breakfast cereals, bars, cookie snacks, fruit juices, cake, and yoghurt [43, 44].

Despite of its well-known antioxidant activities and healthy fatty acid profile, consumers are not very aware of chia's benefits until recently. Chia seed production is a major contributor to the Argentine economy being responsible for 24% of its agricultural industry. In 2008, Argentina contributed approximately 4% of the world grain production [52]. Although chia seed has been commercialized for a long time in Argentina, however, due to the comparatively small-scale production there, problems in its availability and sustainability as an edible oil source in the global market exist. The current planting and production of chia seed oil are yet to fully meet the world market demand [17, 53, 54].

7. Summary

Based on the current research findings, chia seed is a good choice of healthy oil to maintain a balanced serum lipid

profile. However, unlike vitamin E and coenzyme Q₁₀, *in vivo* clinical bioactivity and safety evaluation of chia seeds are still limited. Furthermore, details on the mechanisms of chia seed's hypolipidemic effects need to be studied and compared with those of the isolated omega 3 and omega 6 fatty acids.

References

- [1] J. L. Bresson, A. Flynn, M. Heinonen et al., "Opinion on the safety of "Chia seeds (*Salvia hispanica* L.) and ground whole Chia seeds" as a food ingredient," *The European Food Safety Authority Journal*, vol. 996, pp. 1–26, 2009.
- [2] P. G. Peiretti and G. Meineri, "Effects on growth performance, carcass characteristics, and the fat and meat fatty acid profile of rabbits fed diets with chia (*Salvia hispanica* L.) seed supplements," *Meat Science*, vol. 80, no. 4, pp. 1116–1121, 2008.
- [3] E. Reyes-Caudillo, A. Tecante, and M. A. Valdivia-López, "Dietary fibre content and antioxidant activity of phenolic compounds present in Mexican chia (*Salvia hispanica* L.) seeds," *Food Chemistry*, vol. 107, no. 2, pp. 656–663, 2008.
- [4] J. P. Cahill and M. C. Provance, "Genetics of qualitative traits in domesticated chia (*Salvia hispanica* L.)," *Journal of Heredity*, vol. 93, no. 1, pp. 52–55, 2002.
- [5] A. Reales, D. Rivera, J. A. Palazón, and C. Obón, "Numerical taxonomy study of *Salvia* sect. *Salvia* (Labiatae)," *Botanical Journal of the Linnean Society*, vol. 145, no. 3, pp. 353–371, 2004.
- [6] W. Jamboonsri, T. D. Phillips, R. L. Geneve, J. P. Cahill, and D. F. Hildebrand, "Extending the range of an ancient crop, *Salvia hispanica* L.—a new ω 3 source," *Genetic Resources and Crop Evolution*, vol. 59, no. 2, pp. 171–178, 2012.
- [7] P. G. Peiretti and F. Gai, "Fatty acid and nutritive quality of chia (*Salvia hispanica* L.) seeds and plant during growth," *Animal Feed Science and Technology*, vol. 148, no. 2–4, pp. 267–275, 2009.
- [8] V. Y. Ixtaina, S. M. Nolasco, and M. C. Tomás, "Physical properties of chia (*Salvia hispanica* L.) seeds," *Industrial Crops and Products*, vol. 28, no. 3, pp. 286–293, 2008.
- [9] M. Bueno, O. di Sapio, M. Barolo, H. Busilacchi, M. Quiroga, and C. Severin, "Quality tests of *Salvia hispanica* L. (Lamiaceae) fruits marketed in the city of Rosario (Santa Fe province, Argentina)," *Boletín Latinoamericano y del Caribe de Plantas Medicinales y Aromáticas*, vol. 9, no. 3, pp. 221–227, 2010.
- [10] O. di Sapio, M. Bueno, H. Busilacchi, M. Quiroga, and C. Severin, "Morphoanatomical characterization of *Salvia hispanica* L. (LAMIACEAE) leaf, stem, fruit and seed," *Boletín Latinoamericano Y Del Caribe De Plantas Medicinales Y Aromáticas*, vol. 11, no. 3, pp. 249–2268, 2012.
- [11] B. Heuer, Z. Yaniv, and I. Ravina, "Effect of late salinization of chia (*Salvia hispanica*), stock (*Matthiola tricuspidata*) and evening primrose (*Oenothera biennis*) on their oil content and quality," *Industrial Crops and Products*, vol. 15, no. 2, pp. 163–167, 2002.
- [12] S. K. Jeong, H. J. Park, B. D. Park, and I. H. Kim, "Effectiveness of topical chia seed oil on pruritus of end-stage renal disease (ESRD) patients and healthy volunteers," *Annals of Dermatology*, vol. 22, no. 2, pp. 143–148, 2010.
- [13] A. P. Simopoulos, "Omega-3 fatty acids in inflammation and autoimmune diseases," *Journal of the American College of Nutrition*, vol. 21, no. 6, pp. 495–505, 2002.
- [14] H. Poudyal, S. K. Panchal, J. Waanders, L. Ward, and L. Brown, "Lipid redistribution by α -linolenic acid-rich chia seed inhibits stearoyl-CoA desaturase-1 and induces cardiac and hepatic protection in diet-induced obese rats," *Journal of Nutritional Biochemistry*, vol. 23, no. 2, pp. 153–162, 2012.
- [15] A. P. Simopoulos, "The omega-6/omega-3 fatty acid ratio, genetic variation, and cardiovascular disease," *Asia Pacific Journal of Clinical Nutrition*, vol. 17, no. 1, pp. 131–134, 2008.
- [16] M. Betti, T. I. Perez, M. J. Zuidhof, and R. A. Renema, "Omega-3-enriched broiler meat: 3. Fatty acid distribution between triacylglycerol and phospholipid classes," *Poultry Science*, vol. 88, no. 8, pp. 1740–1754, 2009.
- [17] V. Dubois, S. Breton, M. Linder, J. Fanni, and M. Parmentier, "Fatty acid profiles of 80 vegetable oils with regard to their nutritional potential," *European Journal of Lipid Science and Technology*, vol. 109, no. 7, pp. 710–732, 2007.
- [18] F. Jin, D. C. Nieman, W. Sha et al., "Supplementation of milled chia seeds increases plasma ALA and EPA in postmenopausal women," *Plant Foods For Human Nutrition*, vol. 67, pp. 105–110, 2010.
- [19] D. C. Nieman, E. J. Cayea, M. D. Austin, D. A. Henson, S. R. McAnulty, and F. Jin, "Chia seed does not promote weight loss or alter disease risk factors in overweight adults," *Nutrition Research*, vol. 29, no. 6, pp. 414–418, 2009.
- [20] G. C. Martha, R. T. Armando, A. A. Carlos et al., "A dietary pattern including Nopal, Chia seed, soy protein, and oat reduces serum triglycerides and glucose intolerance in patients with metabolic syndrome," *Journal of Nutrition*, vol. 142, no. 1, pp. 64–69, 2012.
- [21] V. Vuksan, A. L. Jenkins, A. G. Dias et al., "Reduction in postprandial glucose excursion and prolongation of satiety: possible explanation of the long-term effects of whole grain Salba (*Salvia hispanica* L.)," *European Journal of Clinical Nutrition*, vol. 64, no. 4, pp. 436–438, 2010.
- [22] R. Ayerza and W. Coates, "Influence of environment on growing period and yield, protein, oil and α -linolenic content of three chia (*Salvia hispanica* L.) selections," *Industrial Crops and Products*, vol. 30, no. 2, pp. 321–324, 2009.
- [23] R. Ayerza h and W. Coates, "Protein content, oil content and fatty acid profiles as potential criteria to determine the origin of commercially grown chia (*Salvia hispanica* L.)," *Industrial Crops and Products*, vol. 34, no. 2, pp. 1366–1371, 2011.
- [24] R. Ayerza, "Effects of seed color and growing locations on fatty acid content and composition of two chia (*Salvia hispanica* L.) genotypes," *Journal of the American Oil Chemists' Society*, vol. 87, no. 10, pp. 1161–1165, 2010.
- [25] R. Ayerza (h) R., "Oil content and fatty acid composition of chia (*Salvia hispanica* L.) from five northwestern locations in Argentina," *Journal of the American Oil Chemists' Society*, vol. 72, no. 9, pp. 1079–1081, 1995.
- [26] A. Antruejo, J. O. Azcona, P. T. Garcia et al., "Omega-3 enriched egg production: the effect of α -linolenic x-3 fatty acid sources on laying hen performance and yolk lipid content and fatty acid composition," *British Poultry Science*, vol. 52, no. 6, pp. 750–760, 2011.
- [27] R. Ayerza and W. Coates, "Omega-3 enriched eggs: the influence of dietary α -linolenic fatty acid source on egg production and composition," *Canadian Journal of Animal Science*, vol. 81, no. 3, pp. 355–362, 2000.
- [28] R. Ayerza and W. Coates, "Effect of dietary α -linolenic fatty acid derived from chia when fed as ground seed, whole seed and oil on lipid content and fatty acid composition of rat plasma," *Annals of Nutrition and Metabolism*, vol. 51, no. 1, pp. 27–34, 2007.

- [29] I. Fernandez, S. M. Vidueiros, R. Ayerza, W. Coates, and A. Pallaro, "Impact of chia (*Salvia hispanica* L.) on the immune system: preliminary study," *Proceedings of the Nutrition Society*, vol. 67, article E12, 2008.
- [30] W. Coates and R. Ayerza, "Chia (*Salvia hispanica* L.) seed as an n-3 fatty acid source for finishing pigs: effects on fatty acid composition and fat stability of the meat and internal fat, growth performance, and meat sensory characteristics," *Journal of Animal Science*, vol. 87, no. 11, pp. 3798–3804, 2009.
- [31] G. Masoero, G. Sala, G. Meineri, P. Cornale, S. Tassone, and P. G. Peiretti, "Nir spectroscopy and electronic nose evaluation on live rabbits and on the meat of rabbits fed increasing levels of Chia (*Salvia hispanica* L.) seeds," *Journal of Animal and Veterinary Advances*, vol. 7, no. 11, pp. 1394–1399, 2008.
- [32] A. Dalle Zotte and Z. Szendro, "The role of rabbit meat as functional food," *Meat Science*, vol. 88, no. 3, pp. 319–331, 2011.
- [33] R. Ayerza, "Chia as a new source of ω -3 fatty acids: advantage over other raw materials to produce ω -3 enriched eggs," in *Proceedings of the Symposium on Omega-3 Fatty Acids, Evolution and Human Health*, Washington, DC, USA, September 2002.
- [34] R. Ayerza, W. Coates, and M. Lauria, "Chia seed (*Salvia hispanica* L.) as an ω -3 fatty acid source for broilers: influence on fatty acid composition, cholesterol and fat content of white and dark meats, growth performance, and sensory characteristics," *Poultry Science*, vol. 81, no. 6, pp. 826–837, 2002.
- [35] M. S. Vedtofte, M. U. Jakobsen, L. Lauritzen et al., "Dietary alpha linoleic acid, linoleic acid and n-3 long-chain PUFA and risk of ischemic heart disease," *The American Journal of Clinical Nutrition*, vol. 94, pp. 1097–1103, 2011.
- [36] V. Y. Ixtaina, S. M. Nolasco, and M. C. Tomás, "Oxidative Stability of Chia (*Salvia hispanica* L.) Seed Oil: effect of Antioxidants and Storage Conditions," *Journal of the American Oil Chemists' Society*, vol. 89, pp. 1077–1090, 2012.
- [37] M. I. Capitani, V. Spotorno, S. M. Nolasco, and M. C. Tomás, "Physicochemical and functional characterization of by-products from chia (*Salvia hispanica* L.) seeds of Argentina," *LWT—Food Science and Technology*, vol. 45, no. 1, pp. 94–102, 2012.
- [38] V. Y. Ixtaina, F. Mattea, D. A. Cardarelli, M. A. Mattea, S. M. Nolasco, and M. C. Tomás, "Supercritical carbon dioxide extraction and characterization of Argentinean chia seed oil," *Journal of the American Oil Chemists' Society*, vol. 88, no. 2, pp. 289–298, 2011.
- [39] J. A. R. Uribe, J. I. N. Perez, H. C. Kaul, G. R. Rubio, and C. G. Alcocer, "Extraction of oil from chia seeds with supercritical CO₂," *Journal of Supercritical Fluids*, vol. 56, no. 2, pp. 174–178, 2011.
- [40] V. Y. Ixtaina, A. Vega, S. M. Nolasco et al., "Supercritical carbon dioxide extraction of oil from Mexican chia seed (*Salvia hispanica* L.): characterization and process optimization," *Journal of Supercritical Fluids*, vol. 55, no. 1, pp. 192–199, 2010.
- [41] R. Rendón-Villalobos, A. Ortiz-Sanchez, J. Solorza-Feria, and C. A. Trujillo-Hernandez, "Formulation, physicochemical, nutritional and sensorial evaluation of corn tortillas supplemented with chia seed (*Salvia hispanica* L.)," *Czech Journal of Food Sciences*, vol. 30, no. 2, pp. 118–125, 2012.
- [42] W. F. Baughman and G. S. Jamieson, "Chia seed oil," *Oil & Fat Industries*, vol. 6, no. 9, pp. 15–17, 1929.
- [43] The Chia Company, "Request for scientific evaluation of substantial equivalence application for the approval of Chia seeds (*Salvia hispanica*L.) from the Chia Company for use in bread," Food Law Consultants, 2010, <http://www.food.gov.uk/multimedia/pdfs/thechiacompany.pdf>.
- [44] R. Borneo, A. Aguirre, and A. E. León, "Chia (*Salvia hispanica* L.) gel can be used as egg or oil replacer in cake formulations," *Journal of the American Dietetic Association*, vol. 110, no. 6, pp. 946–949, 2010.
- [45] R. Ayerza and W. Coates, "An ω -3 fatty acid enriched chia diet: influence on egg fatty acid composition, cholesterol and oil content," *Canadian Journal of Animal Science*, vol. 79, no. 1, pp. 53–58, 1999.
- [46] R. Ayerza and W. Coates, "Dietary levels of chia: influence on yolk cholesterol, lipid content and fatty acid composition for two strains of hens," *Poultry Science*, vol. 79, no. 5, pp. 724–739, 2000.
- [47] R. Ayerza and W. Coates, "Dietary levels of chia: influence on hen weight, egg production and sensory quality, for two strains of hens," *British Poultry Science*, vol. 43, no. 2, pp. 283–290, 2002.
- [48] G. Meineri and P. G. Peiretti, "Apparent digestibility of mixed feed with increasing levels of chia (*Salvia hispanica* L.) seeds in rabbit diets," *Italian Journal of Animal Science*, vol. 6, no. 1, pp. 778–780, 2007.
- [49] G. Meineri, P. Cornale, S. Tassone, and P. G. Peiretti, "Effects of chia (*Salvia hispanica* L.) seed supplementation on rabbit meat quality, oxidative stability and sensory traits," *Italian Journal of Animal Science*, vol. 9, no. 10, pp. 45–49, 2009.
- [50] B. L. Olivos-Lugo, M. Á. Valdivia-López, and A. Tecante, "Thermal and physicochemical properties and nutritional value of the protein fraction of mexican chia seed (*Salvia hispanica* L.)," *Food Science and Technology International*, vol. 16, no. 1, pp. 89–96, 2010.
- [51] T. G. Illian, J. C. Casey, and P. A. Bishop, "Omega 3 chia seed loading as a means of carbohydrate loading," *Journal of Strength and Conditioning Research*, vol. 25, no. 1, pp. 61–65, 2011.
- [52] D. Lema, "Growth and productivity in Argentine agriculture," in *Conference on Causes and Consequences of Global Agricultural Productivity Growth*, Washington, DC, USA, May 2010, <http://www.farmfoundation.org/news/articlefiles/1725-Lema.pdf>.
- [53] R. Ayerza and W. Coates, "Seed yield, oil content and fatty acid composition of three botanical sources of ω -3 fatty acid planted in the Yungas ecosystem of tropical Argentina," *Tropical Science*, vol. 47, no. 4, pp. 183–187, 2007.
- [54] W. Coates and R. Ayerza, "Production potential of chia in northwestern Argentina," *Industrial Crops and Products*, vol. 5, no. 3, pp. 229–233, 1996.