

Health Potential of Chia (*Salvia hispanica* L.) Seeds-Derived α -linoleic Acid and α -linolenic Acids: A Review

Josiah Oyalo and Monica Mburu

ABSTRACT

The desirability of functional foods proceeds alongside non-communicable epidemic; diabetes, cardiovascular diseases, obesity and interrelated risk factors. Consequently, research on chia seeds (*Salvia hispanica* L.) has increased not only as seeds but also as oil due to their rich functional and nutritional proprieties. Chia seed is rich in essential fatty acids such as α -linolenic (ALA) and α -linoleic acids (LA) with ALA being the biological precursor to eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA). ALA is a plant-based essential omega-3 polyunsaturated fatty acids that must be obtained through the diet since humans do not possess the enzymes to synthesize the compound. The objective of this review was to identify the beneficial effects of chia seeds derived ALA and LA on human health. From the articles reviewed; it was observed that ALA and LA from chia seed could offer benefits for example; anti-obesity, improvement in glucose homeostasis, athletic performance, and anti-cholesterolemic effects and maintenance of healthy serum lipid level. Furthermore, some articles reported anti-inflammatory, anti-proliferative and apoptotic effects and anti-oxidant activity, which could strengthen the prevention of chronic diseases. Although these benefits are appealing to humans, mechanistic cell culture and animal models are required to enhance our knowledge on their mode of action.

Keywords: Health potential; chia; α -linoleic; α -linolenic acids; polyunsaturated fatty acids.

Submitted : March 30, 2021

Published : July 08, 2021

ISSN: 2684-1827

DOI: 10.24018/ejfood.2021.3.4.271

Josiah Oyalo*

Institute of Food Bioresources Technology, Dedan Kimathi University of Technology, Kenya.
(e-mail: Josiah.oyalo@dkut.ac.ke)

Monica Mburu

Institute of Food Bioresources Technology, Dedan Kimathi University of Technology, Kenya.
(e-mail: monica.mburu@dkut.ac.ke)

*Corresponding Author

I. INTRODUCTION

Chia (*Salvia hispanica* L.) is an oil seed belonging to a summer herbaceous plant of the Lamiaceae (mint) family [1–3]. It originated from northern Guatemala and southern Mexico where its seeds have traditionally been used as food or as functional food ingredient [1], [4]–[6]. For example, chia seeds is popularly consumed in many forms, for example chia fresca (a beverage mixed with chia seeds), baked items, cereal bars, fruit smoothies and salads [7], [8].

Chia seed composition is variable and is dependent on the region where it is grown [9]. Although chia plant grows well in the tropics and sub-tropical regions, it can also be cultivated in mild climates [8], [9]. Nevertheless, nutritionally, chia seed is a great source of protein (15–25%, predominantly prolamins, glutelins, globulins, albumins), carbohydrates (26–41%), dietary fiber (18–30% predominantly high dietary fibre), fats (30–33%), ash content (4–5%), vitamins (mainly from the B complex [thiamine, riboflavin, niacin and folic acid] and also ascorbic acid and α -tocopherols), minerals (calcium, phosphorus, potassium, magnesium, iron, zinc and selenium) and dry matter (90–93%) as well as high amounts of antioxidants regardless of the region of cultivation [2], [9], [10].

Regarding the fat content, chia seed is a great source of polyunsaturated fatty acids (PUFAs) such as α -linolenic acid (ALA, C18:3n-3, more than 60% [11]–[14] and linoleic acid (LA, C18:2n-6 approximately 20%) acids, presenting a very low ω -6/ ω -3 ratio (around 0.30) [5], [15], [16]. However, the oil content and the amount of oleic, α -linoleic and α -linolenic acids depends on the region of cultivation [9], [17].

Despite popular health and therapeutic potential claims associated with chia seed oil, such as reduced risks of cognitive decline, cancer, and cardiovascular heart disease, the mechanism of action of chia seed oils is unclear [4], [12], [18]. Therefore, humans rely on ALA from dietary sources due to lack of enzymes for *de novo* synthesis to synthesize the compound [19].

In this review article, we make a case of human health benefits derived from LA and ALA (Fig. 1) in chia seeds as well as clinically relevant data. This information can be beneficial to current consumers who are health-conscious with regards to high prevalence of epidemic disease for example, cardiovascular diseases, hypertension and diabetes etc.

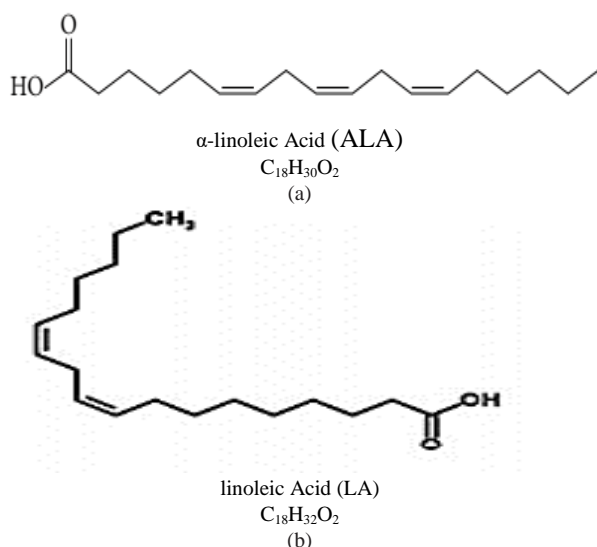


Fig. 1. Structure of (a) α -linolenic acid and (b) linoleic acids [19], [20].

II. MECHANISMS UNDERLYING THE BENEFITS OF ALPHA-LINOLEIC AND ALPHA LINOLENIC ACIDS FROM CHIA SEEDS

Plant based foods products that are high in dietary fibre and other components with potential health value often contain plentiful and readily available plant PUFAs [21]. Precursors for the synthesis of long chain PUFAs of the ω -6 and ω -3 series in mammals are LA and ALA respectively [22]–[24]. ALA an essential fatty acid is the main fatty acid derived from the chia seeds lipid fraction.

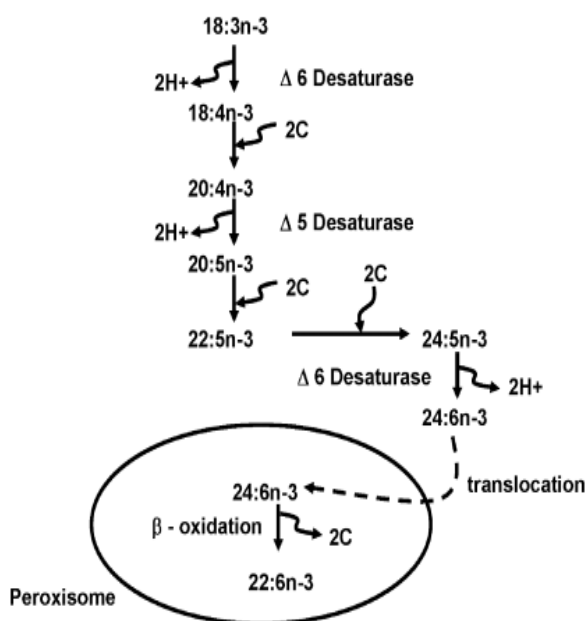


Fig. 2. Schematic diagram of Essential fatty acid desaturation / elongation pathway [22].

In the human system, ALA is converted to eicosapentaenoic acid (EPA; $C_{20:5n-3}$) and docosahexaenoic acid (DHA; $C_{22:6n-3}$) following a sequence of activities of Δ^6 and Δ^5 desaturases and elongation of carbon chain with docosapentaenoic acid (DPA) as an intermediate [13], [25], [26] in the liver as the primary conversion site followed by enterocytes (Fig. 2) [23], [25]. However, excessive amounts of linoleic acid slow down the formation of EPA and DHA.

After conversion of ALA, very low-density lipoproteins transports the newly synthesized EPA/DPA/DHA away from the liver to other parts of the body [26]. During the conversions of ALA, PUFAs derived from linolenic and linoleic fatty acids compete for metabolic enzymes; remarkably this competition exists during the esterification into triacylglycerols and plasma phospholipids [22], [25]. Enzymatic conversion of ALA to EPA and DHA is relatively inefficient in humans [19], with <1% converted to docosahexaenoic acid, while for eicosapentaenoic acid, the conversion in men is approximately 0.3% - 8% and up to 21% amongst women [3].

III. HEALTH OUTCOMES ATTRIBUTED TO CHIA SEEDS LINOLEIC AND ALPHA-LINOLENIC ACIDS

A. Antioxidant Potential

Ullah et al. [16] observed that fractionation of chia oil for enrichment of ω -3 with greater than 72% ALA, olein fraction of chia oil may be regarded as the richest source of α -linolenic acid. Ullah et al. [27] study on oxidative stability of ice cream supplemented with olein fraction of chia seeds revealed that when the experimental group control (100% milk fat) is replaced with olein fractions at percentages of 5%, 10%, 15%, and 20%, the 2,2-diphenyl-1-picrylhydrazyl free radical scavenging activity of control improves at percentages of 5.61%, 17.43%, 36.84%, 51.17%, and 74.91%, respectively (control to test article groups 1 to 4). Similarly, Marineli et al. (2014) observed that chia seed oil displayed a higher antioxidant activity than that found in wheat flour, barley and sorghum whole grain cereals (8.3, 14.9 and 51.7 trolox equivalent antioxidant coefficient (TEAC), mmol/g) and were similar to that of sorghum bran with high tannin content (512.0 TEAC, mmol/g).

Rincón-Cervera et al. [29] observed an increase in activity of carnitine palmitoyl-transferase I and an increase in deoxyribonucleic acid transcription factor peroxisome proliferator-activated receptor- α expression on a study involving rats. Chia-fed rats also showed an increased superoxide dismutase activity, carnitine acyl-carnitine transferase, glutathione peroxidase and increased glutathione monosulfide /glutathione disulfide (GSH/GSSG) ratio signifying an increase in the antioxidant status [2], [22], [29]. The lipogenic enzymes fatty acid synthase and acetyl-CoA carboxylase activity were also shown to be inhibited [2], [29]. However, dietary ALA in chia seed did not modify plasma parameters of oxidative stress as well as the modification of antioxidative enzymes. The action of these antioxidative enzymes was not changed in the control (*safflower group*) compared to chia seed oil [29], [30].

Creus et al. [31] also investigated the mechanism involved in the improvement of lipotoxicity and impaired lipid metabolism by dietary ALA rich chia seed in the heart of dyslipidemic insulin-resistant rats by normalizing potential of a sucrose-rich diet versus chia seeds with regards to parameters such as body weight, visceral adiposity and systolic blood pressure, however, the results showed no significant differences in glucose infusion rates, plasma metabolites and insulin levels. However, this combination of sucrose-rich diet with chia seed oil resulted in down

regulation of intramyocardial lipid accumulation in these animals as well [2], [6]. Use of chia seed oil was able to increase the proportion of active pyruvate dehydrogenase to 45.1% from the control levels in comparison to the sucrose group at 26.6%, thus an indicator of more responsive metabolism, without affecting the weight of the heart of the rats. These antioxidant actions can protect the organism from pathologies, like neurological diseases, inflammation, immunodeficiency, ischemic heart disease, strokes, Alzheimer's and Parkinson's diseases, and cancer [6], [31], [32]. For example, a few epidemiological studies have suggested a cardio-protective effect of high, long-term and an additive effect of ALA with ω -3 long-chain PUFAs from fish oil. However, there was no association of ALA and ischemic heart disease [33].

To prove its effect in low grade inflammation, 76 randomly selected obese adults consumed chia seeds or placebo for 12 weeks [21], [34]. Results indicated insignificant differences between groups, except for ALA levels which was increased in the treatment group that consumed chia seeds compared with placebo (24.4% vs 2.8%, $p = 0.012$). Therefore, chia consumption among obese and overweight individuals may regulate inflammation and reduce body weight.

B. Activities on Serum Lipids Profile and Anti-obesity Activities

Diets rich in ALA and LA have been shown in some animal studies to influence the concentration of lipoprotein cholesterol in plasma i.e., reduction of low-density lipoprotein cholesterol. This ability to decrease low density lipoprotein cholesterol may be vital since increased levels of low-density lipoprotein cholesterol in plasma are strongly correlated with increased risk of developing congenital heart defects and atherosclerosis [19], [35]. However, in humans, plasmatic low density lipoprotein cholesterol decrease reduction has not been found, despite ALA-enriched dietary sources affecting low density lipoproteins content when consumed in large amounts [19], [35], [36].

According to the study by Valenzuela et al. [30], consumption of vegetables oils rich in ALA (concentrations of 48% and 64%) resulted in a dramatic accretion of ω -3 long-chain PUFAs in Wistar rat liver, adipose tissue and plasma, while docosahexaenoic acid, total saturated and monounsaturated fatty acid content was unaffected. This, therefore, allows for its accretion into different tissues and its conversion to ω -3 long chain polyunsaturated fatty acids (EPA and DHA), which are also accreted in the plasma, liver and adipose tissue of the animals. However, a combination of chia seed oil and sachi oil (*Plukenetia volubilis* L.) resulted into a decreased ω -6/ ω -3 ratio with subsequent cardioprotective effect while DHA and EPA increased [2], [29], [37]. From the parameters tested in serum lipid profiles, ingestion of chia seed oil seemingly inhibited formation of liver triacylglycerols that generates very low density lipoprotein cholesterol, Fas ligands, coenzyme-A, glucose-6-phosphate dehydrogenase, and increased bioactivity involving β -oxidation of fatty acid and carnitine palmitoyl transferase by either averting or limiting dyslipidaemia [29], [30].

Jin et al. [1] explored whether supplementation of milled chia seeds increases plasma ALA and EPA in post-

menopausal women. Results showed that post-menopausal women who consumed milled chia seeds (25 g/day) for seven weeks experienced significant increases in plasma ALA and EPA, but not DPA and DHA. Plasma ALA levels increased within the 1st week to 138% above the baseline by 7th week. However, for EPA, the increase was smaller proportionally (30%) but was correlated across time with ALA [2], [37]. These results indicated that ALA is more easily incorporated into human blood plasma from milled oil seeds of chia than from whole seeds [1], [2], [38]. Poudyal et al. [12] also assessed whether chia seeds as a source of ALA induce lipid redistribution associated with cardio-protection and hepatoprotection in diet induced rats. Results suggests that with chia seed oil supplements, there is an improvement in visceral adiposity, insulin and glucose tolerance, cardiac and hepatic fibrosis, hepatic steatosis, and inflammation improved with chia seed oil supplementation. The stearoyl-CoA desaturase-1 products were depleted in the heart, liver, and the adipose tissue of chia seeds. Therefore, chia seed inhibits stearoyl-CoA desaturase activity, which is vital in the conversion of elaidic acid to conjugated linolenic acid [12]. The study suggested that LA is oxidized and transported into the mitochondria, which downregulates ω -6/ ω -3 levels. The inhibition of stearoyl-CoA desaturase provides protection from murine obesity, cellular lipid accumulation, and insulin resistance [12], [23].

Based on the work done by Poudyal et al. [12] and Whelan and Rust [38], Ayerza and Coates [13] reported that the serum lipid profile in rats improved as rats displayed higher ω -3 PUFAs (18: 3n-3, 20: 5n-3, and 22: 6n-3) plasma contents, and lower ω -6 PUFA (18: 2n-6 and 20: 4n-6) contents, which was probably due to a high chia's ω -3/ ω -6 ratio. In these rats, high-density lipoprotein cholesterol increased while triglycerides content decreased; however, the ratio between high density lipoproteins to low density lipoprotein content was not lowered. However, in these studies, no significant change in body weight was realized as well as haemoglobin, hematocrit feed intake, feed conversion and relative liver weight [12], [13].

According to Chicco et al. [39] study on whether dietary chia seed rich in ALA improves adiposity and normalizes hypertriacylglycerolaemia and insulin resistance in dyslipidemic rats. Results showed that dietary chia seed prevented the onset of dyslipidaemia and insulin resistance in the rats fed while glycaemia did not change. Dyslipidaemia and insulin resistance in the long-term were normalized without changes in insulinaemia when chia seed provided the dietary fat during the last two months of the feeding period. However, there was no significant difference in the liver fat percentage. These findings bear weight by supporting the notion that chia seed oil supplementation improves glucose homeostasis and cardiovascular health from an experimental model [1], [38].

C. Role in Athletic Performance

During exercise and training, α -linolenic acid may function as a fuel substrate during moderate to endurance exercise, especially in the cross over stage where fats becomes the leading substrate for adenosine triphosphate (ATP) after depletion of carbohydrate stores [3]. ALA is about 0.7% of total fatty acids in adipose tissue, and is strongly mobilized

during exercise, with plasma levels increasing nearly 6-fold following prolonged, intensive exercise [2], [3], [22]. Based on these reasons, ALA may function as a fuel source after depletion of carbohydrates stores especially in long endurance exercise. ALA is almost completely absorbed and followed by oxidation to carbon dioxide and water, thereafter it is incorporated into tissue lipids; or utilized in eicosanoid synthesis. Furthermore, greater than half of ingested ALA is broken down to carbon dioxide for energy, and the fractional recovery of ingested [¹³C]-labelled ALA as ¹³CO₂ is almost double that of palmitate, stearic, and oleic acids in human subjects [3], [22], [25].

Nieman et al. [3] studied the effects of ingesting chia seed oil on human running performance whereby the treatment group ingested a ¹³C-labelled ALA while placebo group consumed water alone. Results showed an increased levels of plasma ALA with chia seed oil (7 kcal/kg) use amongst the treatment group compared to water alone. The athletes also showed major increases in total leukocyte counts, plasma cytokines and plasma cortisol with no trial difference. Probably this was as a result run time to exhaustion which alters respiratory exchange ratio or counter elevations in cortisol and inflammatory outcome measures, which were not improved, although immediate post-run ALA levels did increase dramatically [2], [3], [40]. Results also showed a near doubled plasma ALA levels for example; 82% increase with seed, 91% increase with oil within two and half hours and this remained elevated for several hours [2]. However, the levels of ALA then fell to pre-ingestion levels without conversion to EPA or DHA within 24 hours compared to snack clusters not containing chia seed oil, resulting in an inconclusive picture of chia's effect on running performances. Additionally, the greater affinity of ALA to carnitine palmitoyl transferase-1, the rate limiting enzyme in mitochondria, compared to other unsaturated fatty acids could be a probable explanation for preferential use of ALA for β -oxidation [22].

D. Antiproliferative and Apoptotic Effects

Plant seed oils rich in ω -3 and ω -6 PUFAs may inhibit the growth of breast tumour cells in animals. Espada et al. [41] using Wistar rats studied the effects of chia seed and *Carthamus tinctorius* (safflower) vegetable oil sources of ω -3 and ω -6 PUFAs and related eicosanoids on the growth and metastasis formation of a murine mammary gland adenocarcinoma. Results showed that chia diet containing chia seed or powder mixed with 0.25 litres of water taken twice a day decreased the tumour weight and metastasis number with respect to safflower and control diet despite the membranes from the safflower oil diet containing a greater percentage of ALA with respect to control and chia oil. Apoptosis and T-lymphocyte infiltration were also higher, and mitosis decreased with respect to the other diets ($p < 0.05$). These changes were linked to a reduction in availability of arachidonic acid (AA) in the membrane which favours the biosynthesis of eicosapentaenoic acid derived 3-series prostanoids and 5-series leukotrienes and reducing desaturation and elongation of linoleic acid to arachidonic acid due to the higher affinity of ω -3 fatty acids to elongases and desaturases [41], [42]. EPA might have a direct apoptotic

effect by encouraging caspase activity, increasing the rate of programmed cell death [2], [41].

IV. CONCLUSIONS

In general, the review shows that chia seeds derived α -linoleic and α -linolenic acids have auspicious health benefits mainly anti-obesity, improvement in glucose homeostasis, athletic performance, and anticholesterolemic properties. However, most of these studies have been carried out with animals, and there are still limitations that exist in demonstrating specifically the pharmacokinetic mechanisms behind the derived benefits. Nevertheless, there is still a need for further clinical studies involving bigger sample sizes and external validation into different populations to make any substantive conclusions

ACKNOWLEDGMENT

This review was carried out at the Technical Facility of the Institute of Food Bioresources Technology, Dedan Kimathi University of Technology, Kenya.

DISCLOSURE STATEMENT

The authors declare that there is no conflict of interests regarding the publication of this paper.

FUNDING

This work was supported by the National Research Fund, Kenya.

COMPLIANCE WITH ETHICS REQUIREMENTS

This article does not contain any studies with human or animal subjects.

AUTHORS' CONTRIBUTIONS

Both authors were responsible for overall concept, data collection, editing the manuscript, critical analysis. Josiah Oyalo performed manuscript writing.

REFERENCES

- [1] Abdulrashed, R., Gazem, A., & Chandrashekariah, S. A. (2016). Pharmacological Properties of *Salvia Hispanica* (Chia) Seeds: a Review. *Journal of Critical Reviews*, 3(3), 63–67.
- [2] Ayerza, R., & Coates, W. (2007). 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*, 51(1), 27–34. <https://doi.org/10.1159/000100818>.
- [3] Bartosz, K., Joanna, K.-C., Maciej, T., Dominik, K., & Anna, G.-M. (2019). The chemical composition and nutritional value of chia seeds – current state of knowledge. *Nutrients*, 115(9), 1–16.
- [4] Blondeau, N., Lipsky, R. H., Bourourou, M., Duncan, M. W., Gorelick, P. B., & Marini, A. M. (2015). Alpha-linolenic acid: An omega-3 fatty acid with neuroprotective properties - Ready for use in the stroke clinic? *BioMed Research International*, 2015. <https://doi.org/10.1155/2015/519830>.

- [5] Burdge, G. C. (2006). Metabolism of α -linolenic acid in humans. *Prostaglandins Leukotrienes and Essential Fatty Acids*, 75(3), 161–168. <https://doi.org/10.1016/j.plefa.2006.05.013>.
- [6] Burdge, G. C., Finnegan, Y. E., Minihane, A. M., Williams, C. M., & Wootton, S. A. (2003). Effect of altered dietary n-3 fatty acid intake upon plasma lipid fatty acid composition, conversion of [13C] α -linolenic acid to longer-chain fatty acids and partitioning towards β -oxidation in older men. *British Journal of Nutrition*, 90(2), 311–321. <https://doi.org/10.1079/bjn2003901>.
- [7] Chicco, A. G., D'Alessandro, M. E., Hein, G. J., Oliva, M. E., & Lombardo, Y. B. (2009). Dietary chia seed (*Salvia hispanica* L.) rich in α -linolenic acid improves adiposity and normalises hypertriglycerolaemia and insulin resistance in dyslipaemic rats. *British Journal of Nutrition*, 101(1), 41–50. <https://doi.org/10.1017/S000711450899053X>.
- [8] Coates, W., & Ayerza, R. (1998). Commercial production of chia in Northwestern Argentina. *JAOCS, Journal of the American Oil Chemists' Society*, 75(10), 1417–1420. <https://doi.org/10.1007/s11746-998-0192-7>.
- [9] Creus, A., Ferreira, M., Oliva, M., & Lombardo, Y. (2016). Mechanisms Involved in the Improvement of Lipotoxicity and Impaired Lipid Metabolism by Dietary α -Linolenic Acid Rich *Salvia hispanica* L (Salba) Seed in the Heart of Dyslipemic Insulin-Resistant Rats. *Journal of Clinical Medicine*, 5(2), 18. <https://doi.org/10.3390/jcm5020018>.
- [10] Dąbrowski, G., Konopka, I., & Czaplicki, S. (2018). Supercritical CO₂ extraction in chia oils production: impact of process duration and co-solvent addition. *Food Science and Biotechnology*, 27(3), 677–686. <https://doi.org/10.1007/s10068-018-0316-2>.
- [11] de Souza Ferreira, C., de Sousa Fomes, L. de F., da Silva, G. E. S., & Rosa, G. (2015). Effect of chia seed (*Salvia hispanica* L.) consumption on cardiovascular risk factors in humans: A systematic review. *Nutricion Hospitalaria*, 32(5), 1909–1918. <https://doi.org/10.3305/nh.2015.32.5.9394>.
- [12] Enes, B. N., Moreira, L. P. D., Silva, B. P., Grancieri, M., Lúcio, H. G., Venâncio, V. P., Mertens-Talcott, S. U., Rosa, C. O. B., & Martino, H. S. D. (2020). Chia seed (*Salvia hispanica* L.) effects and their molecular mechanisms on unbalanced diet experimental studies: A systematic review. *Journal of Food Science*, 85(2), 226–239. <https://doi.org/10.1111/1750-3841.15003>.
- [13] Espada, C. E., Berra, M. A., Martinez, M. J., Eynard, A. R., & Pasqualini, M. E. (2007). Effect of Chia oil (*Salvia Hispanica*) rich in ω -3 fatty acids on the eicosanoid release, apoptosis and T-lymphocyte tumor infiltration in a murine mammary gland adenocarcinoma. *Prostaglandins Leukotrienes and Essential Fatty Acids*, 77(1), 21–28. <https://doi.org/10.1016/j.plefa.2007.05.005>.
- [14] Felemban, L. F., Attar, M. A. A., & Zeid, I. M. A. (2021). Medicinal and Nutraceutical Benefits of Chia Seed (*Salvia hispanica*). *Journal of Pharmaceutical Research International*, 32(41), 15–26. <https://doi.org/10.9734/jpri/2020/v32i4131040>.
- [15] Flachs, P., Rossmel, M., Bryhn, M., & Kopecky, J. (2009). Cellular and molecular effects of n-3 polyunsaturated fatty acids on adipose tissue biology and metabolism. In *Clinical Science* (Vol. 116, Issue 1, pp. 1–16). <https://doi.org/10.1042/CS20070456>.
- [16] Grancieri, M., Martino, H. S. D., & Gonzalez de Mejia, E. (2019). Chia Seed (*Salvia hispanica* L.) as a Source of Proteins and Bioactive Peptides with Health Benefits: A Review. *Comprehensive Reviews in Food Science and Food Safety*, 18(2), 480–499. <https://doi.org/10.1111/1541-4337.12423>.
- [17] Harper, C. R., Edwards, M. C., & Jacobson, T. A. (2006). Flaxseed oil supplementation does not affect plasma lipoprotein concentration or particle size in human subjects. *Journal of Nutrition*, 136(11), 2844–2848. <https://doi.org/10.1093/jn/136.11.2844>.
- [18] Harper, C. R., Edwards, M. J., DeFilipis, A. P., & Jacobson, T. A. (2006). Flaxseed oil increases the plasma concentrations of cardioprotective (n-3) fatty acids in humans. *Journal of Nutrition*, 136(1), 83–87. <https://doi.org/10.1093/jn/136.1.83>.
- [19] Hernández-Pérez, T., Valverde, M. E., & Paredes-López, O. (2021). Seeds from ancient food crops with the potential for antiobesity promotion. *Critical Reviews in Food Science and Nutrition*, 0(0), 1–8. <https://doi.org/10.1080/10408398.2021.1877107>.
- [20] Ikumi, P., Mburu, M., & Njoroge, D. (2019). Chia (*Salvia hispanica* L.) – A Potential Crop for Food and Nutrition Security in Africa. *Journal of Food Research*, 8(6), 104–118. <https://doi.org/10.5539/jfr.v8n6p104>.
- [21] Jin, F., Nieman, D. C., Sha, W., Xie, G., Qiu, Y., & Jia, W. (2012). Supplementation of Milled Chia Seeds Increases Plasma ALA and EPA in Postmenopausal Women. *Plant Foods for Human Nutrition*, 67(2), 105–110. <https://doi.org/10.1007/s11130-012-0286-0>.
- [22] Luvián-Morales, J., Varela-Castillo, F. O., Flores-Cisneros, L., Cetina-Pérez, L., & Castro-Eguiluz, D. (2021). Functional foods modulating inflammation and metabolism in chronic diseases: a systematic review. *Critical Reviews in Food Science and Nutrition*, 0(0), 1–22. <https://doi.org/10.1080/10408398.2021.1875189>.
- [23] Marineli, R. da S., Moraes, É. A., Lenquiste, S. A., Godoy, A. T., Eberlin, M. N., & Maróstica, M. R. (2014). Chemical characterization and antioxidant potential of Chilean chia seeds and oil (*Salvia hispanica* L.). *LWT - Food Science and Technology*, 59(2P2), 1304–1310. <https://doi.org/10.1016/j.lwt.2014.04.014>.
- [24] Melo, D., & Oliveira, B. (2018). Health Benefits of Chia Seeds' Dietary Consumption. *EC Nutrition*, 13, 738–741.
- [25] Mohd, A. N., Yeap, S. K., Ho, W. Y., Beh, B. K., Tan, S. W., & Tan, S. G. (2012). The promising future of chia, *Salvia hispanica* L. *Journal of Biomedicine and Biotechnology*, 2012. <https://doi.org/10.1155/2012/171956>.
- [26] Nieman, D. C., Caya, E. J., Austin, M. D., Henson, D. A., McAnulty, S. R., & Jin, F. (2009). Chia seed does not promote weight loss or alter disease risk factors in overweight adults. *Nutrition Research*, 29(6), 414–418. <https://doi.org/10.1016/j.nutres.2009.05.011>.
- [27] Nieman, D. C., Gillitt, N. D., Meaney, M. P., & Dew, D. A. (2015). No positive influence of ingesting chia seed oil on human running performance. *Nutrients*, 7(5), 3666–3676. <https://doi.org/10.3390/nu7053666>.
- [28] Nieman, D. C., Scherr, J., Luo, B., Meaney, M. P., Dréau, D., Sha, W., Dew, D. A., Henson, D. A., & Pappan, K. L. (2014). Influence of pistachios on performance and exercise-induced inflammation, oxidative stress, immune dysfunction, and metabolite shifts in cyclists: A randomized, crossover trial. *PLoS ONE*, 9(11), 1–12. <https://doi.org/10.1371/journal.pone.0113725>.
- [29] Onneken, P. (2018). *Salvia Hispanica* L (Chia Seeds) as Brain Superfood – How Seeds Increase Intelligence. *Global Journal of Health Science*, 10(7), 69. <https://doi.org/10.5539/gjhs.v10n7p69>.
- [30] Parker, J., Schellenberger, A. N., Roe, A. L., Oketch-Rabah, H., & Calderón, A. I. (2018). Therapeutic Perspectives on Chia Seed and Its Oil: A Review. *Planta Medica*, 84(9–10), 606–612. <https://doi.org/10.1055/a-0586-4711>.
- [31] Poudyal, H., Panchal, S. K., Waanders, J., Ward, L., & Brown, L. (2012). 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*, 23(2), 153–162. <https://doi.org/10.1016/j.jnutbio.2010.11.011>.
- [32] Rincón-Cervera, M. A., Valenzuela, R., Hernandez-Rodas, M. C., Barrera, C., Espinosa, A., Marambio, M., & Valenzuela, A. (2016). Vegetable oils rich in alpha linolenic acid increment hepatic n-3 LCPUFA, modulating the fatty acid metabolism and antioxidant response in rats. *Prostaglandins Leukotrienes and Essential Fatty Acids*, 111, 25–35. <https://doi.org/10.1016/j.plefa.2016.02.002>.
- [33] Schley, P. D., Jijon, H. B., Robinson, L. E., & Field, C. J. (2005). Mechanisms of omega-3 fatty acid-induced growth inhibition in MDA-MB-231 human breast cancer cells. *Breast Cancer Research and Treatment*, 92(2), 187–195. <https://doi.org/10.1007/s10549-005-2415-z>.
- [34] Sokoła-Wysockańska, E., Wysockańska, T., Wagner, J., Czyż, K., Bodkowski, R., Lochyński, S., & Patkowska-Sokoła, B. (2018). Polyunsaturated fatty acids and their potential therapeutic role in cardiovascular system disorders—a review. *Nutrients*, 10(10), 1–21. <https://doi.org/10.3390/nu10101561>.
- [35] Teoh, S. L., Lai, N. M., Vanichkulpitak, P., Vuksan, V., Ho, H., & Chaiyakunapruk, N. (2018). Clinical evidence on dietary supplementation with chia seed (*Salvia hispanica* L.): A systematic review and meta-analysis. *Nutrition Reviews*, 76(4), 219–242. <https://doi.org/10.1093/NUTRIT/NUX071>.
- [36] Ullah, R., Nadeem, M., & Imran, M. (2017). Omega-3 fatty acids and oxidative stability of ice cream supplemented with olein fraction of chia (*Salvia hispanica* L.) oil. *Lipids in Health and Disease*, 16(1), 1–8. <https://doi.org/10.1186/s12944-017-0420-y>.
- [37] Ullah, R., Nadeem, M., Khalique, A., Imran, M., Mehmood, S., Javid, A., & Hussain, J. (2016). Nutritional and therapeutic perspectives of Chia (*Salvia hispanica* L.): a review. *Journal of Food Science and Technology*, 53(4), 1750–1758. <https://doi.org/10.1007/s13197-015-1967-0>.
- [38] Valdivia-López, M. Á., & Tecante, A. (2015). Chia (*Salvia hispanica*): A Review of Native Mexican Seed and its Nutritional and Functional Properties. In *Advances in Food and Nutrition Research* (1st ed., Vol. 75). Elsevier Inc. <https://doi.org/10.1016/bs.afnr.2015.06.002>.
- [39] Valenzuela, R., Barrera, C., Ayala, J. M., Sanhueza, J., & Valenzuela, A. (2014). Vegetable oils rich in alpha linolenic acid allow a higher accretion of n-3 LCPUFA in the plasma, liver and adipose tissue of the rat. *Grasas y Aceites*, 65(2). <https://doi.org/10.3989/gya.110113>.

- [40] Vedtofte, M. S., Jakobsen, M. U., Lauritzen, L., & Heitmann, B. L. (2011). Dietary α -linolenic acid, linoleic acid, and n-3 long-chain PUFA and risk of ischemic heart disease. *American Journal of Clinical Nutrition*, *94*, 1097–1103. <https://doi.org/10.3945/ajcn.111.018762>.Am.
- [41] Whelan, J., & Rust, C. (2006). Innovative dietary sources of n-3 fatty acids. *Annual Review of Nutrition*, *26*, 75–103. <https://doi.org/10.1146/annurev.nutr.25.050304.092605>.
- [42] Wootton, S. A., & Burdge, G. C. (2002). Conversion of α -linolenic acid to eicosapentaenoic, docosapentaenoic and docosahexaenoic acids in young women. *British Journal of Nutrition*, *88*(4), 411–420. <https://doi.org/10.1079/bjn2002689>.