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Nutritional and Medicinal Benefits of *Salvia hispanica L. (Chia):* A Comprehensive Review

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Abstract: Salvia hispanica L., commonly known as chia, is an ancient pseudocereal that originated in Mesoamerica and has been utilized by indigenous civilizations for thousands of years. In recent decades, chia has gained significant international attention due to its exceptional nutritional profile and diverse pharmacological properties. This comprehensive review synthesizes current scientific evidence regarding the botanical characteristics, phytochemical composition, nutritional value, and therapeutic applications of chia seeds. The plant is characterized by high concentrations of omega-3 polyunsaturated fatty acids (55-65% of total oil content), complete protein containing all essential amino acids, dietary fiber (27-30%), and numerous polyphenolic antioxidants including rosmarinic acid, caffeic acid, and flavonoids. Pharmacological investigations have demonstrated significant cardioprotective, anti-inflammatory, antioxidant, antidiabetic, antimicrobial, and immunomodulatory properties. This review provides an in-depth analysis of the traditional uses documented in historical codices, modern scientific validations of claimed benefits, and emerging therapeutic potentials for chronic disease management. Current evidence suggests that chia seeds and their derivatives represent a valuable functional food with considerable nutraceutical potential for preventing and managing cardiovascular disease, diabetes, obesity, and other metabolic disorders. However, further clinical trials are warranted to establish optimal dosing regimens and safety profiles in specific patient populations. This review consolidates information from recent peer-reviewed literature to provide practitioners and researchers with evidence-based knowledge regarding chia's therapeutic significance in contemporary healthcare and nutrition sciences.
Keywords: Salvia hispanica L.; Chia seeds; Nutritional composition; Medicinal properties; Functional food

I. INTRODUCTION

The prevalence of chronic non-communicable diseases has increased substantially over the past two decades, creating an urgent need for preventive and therapeutic interventions. Within this context, there has been a resurgence of interest in traditional plants with documented medicinal properties. Salvia hispanica L., collectively known as "chia," represents one of the most promising functional foods with both historical significance and contemporary scientific validation. The word "chia" derives from the Nahuatl language, meaning "oily," reflecting the plant's remarkable lipid content. Archaeological and historical evidence, including the Codex Mendoza and Codex Florentino, documents the cultivation and utilization of chia by pre-Columbian Aztec and Mayan civilizations dating back approximately 3,500 years.[1,2,3,4]

In pre-Hispanic times, chia seeds were valued alongside corn, beans, and amaranth as staple crops and were integral to Aztec religious ceremonies, cosmetics, and medicinal practices. Warriors consumed chia during arduous journeys due to its sustaining nutritional properties, while traditional healers employed chia preparations to address wounds, injuries, digestive disturbances, and respiratory complaints. Following the Spanish conquest, chia cultivation declined precipitously, and the plant remained largely obscure outside Latin America until the late 20th century. The dramatic resurgence of chia consumption globally over the past 15 years stems from scientific investigations confirming its nutritional superiority and pharmacological efficacy for addressing contemporary health challenges. The primary objectives of this comprehensive review are to: (1) present detailed botanical and taxonomic information regarding Salvia hispanica; (2) characterize the macroscopic morphology and physical properties of chia seeds; (3) elucidate the phytochemical profile including bioactive compounds; (4) synthesize evidence regarding pharmacological mechanisms of action; (5) document traditional ethnobotanical uses; and (6) evaluate contemporary clinical applications and safety considerations. This synthesis of information aims to provide healthcare professionals, researchers, nutritionists, and interested individuals with authoritative, evidence-based knowledge regarding chia's therapeutic potential and appropriate utilization within comprehensive health management strategies.

II. MORPHOLOGY AND TAXONOMY OF SALVIA HISPANICA L

A. Systematic Classification

Salvia hispanica L. belongs to one of the largest and most diverse genera within the flowering plant kingdom. The systematic taxonomic position of chia within the plant kingdom is as follows:

- Kingdom: Plantae (Plants)
- Subkingdom: Tracheobionta (Vascular plants)
- Superdivision: Spermatophyta (Seed plants)
- Division: Magnoliophyta (Flowering plants/Angiosperms)
- Class: Magnoliopsida (Dicotyledons)
- Subclass: Asteridae
- Order: Lamiales
- Family: Lamiaceae (Mint family, also known as Labiatae)
- Genus: Salvia L. (Sage)
- Species: Salvia hispanica L. (Chia)

The Lamiaceae family comprises approximately 6,000 species distributed across 240 genera worldwide, making it one of the most economically important plant families. Within this family, Salvia represents the most diverse genus, encompassing approximately 900 recognized species. The genus Salvia demonstrates remarkable distribution across temperate and subtropical regions globally, with highest species diversity concentrated in Mexico and Central America, representing the primary center of origin for numerous Salvia species including S. hispanica.

B. Plant Habit and General Characteristics

Salvia hispanica is an annual herbaceous plant that exhibits characteristic features typical of the mint family. The plant typically attains heights ranging from 1 to 1.75 meters (approximately 3 to 5.7 feet), with an upright growth habit displaying branching that originates from the basal region. The plant demonstrates moderate vigor during the growing season and exhibits rapid development from germination to reproductive maturity, typically completing its life cycle within 120-150 days under favorable environmental conditions. The plant’s structure includes a well-developed root system, woody or semi-woody stems, and profuse branching creating a densely foliated canopy. The plant exhibits annual growth behavior, completing a single reproductive cycle and senescing following seed maturation. Under cultivation, chia demonstrates moderate drought tolerance relative to many herbaceous plants, though maximum productivity is achieved under adequate moisture conditions. The plant is sensitive to photoperiod changes and typically flowers in response to shortening day length characteristic of late summer and autumn seasons. Chia plants display natural pest resistance relative to many cultivated crops, attributed to the presence of bioactive secondary metabolites that deter herbivorous insects and pathogenic microorganisms.

C. Leaf Characteristics

The leaves of Salvia hispanica exhibit distinctive morphological features characteristic of the Lamiaceae family. Leaves are arranged in an opposite, decussate (alternating at right angles) pattern along the stems, a typical arrangement within the mint family. Individual leaves are generally oblong to lanceolate in shape, with pronounced serrated or toothed margins. The leaf surface demonstrates a rough texture resulting from the presence of trichomes (hair-like epidermal outgrowths) that are characteristic of many Salvia species. These trichomes may contain essential oils and other secondary metabolites.

Leaf dimensions typically range from 4 to 8 centimeters in length and 3 to 5 centimeters in width, though some variation occurs depending on environmental conditions and leaf position along the stem. Younger leaves at stem apices tend to be somewhat smaller than mature leaves in the mid-stem region. Leaf color ranges from mild to dark green, with mature leaves typically displaying darker pigmentation than developing leaves. The venation pattern is pinnate (feather-like), with a prominent midvein and secondary lateral veins creating a reticulated pattern visible on the abaxial (lower) leaf surface. The leaf petioles (stems) are relatively short, ranging from 0.5 to 1.5 centimeters in length.

D. Flower Morphology and Reproductive Structures

The flowers of Salvia hispanica are small, delicate structures arranged in distinctive inflorescence patterns characteristic of the Lamiaceae family. Individual flowers are tiny, tubular, and bilipped (zygomorphic), displaying the typical mint family flower architecture with a two-lipped corolla (fused petals).

Flowers are hermaphroditic (containing both staminate and pistillate reproductive organs) and pedicellate (attached by small stalks). The flowers are arranged in whorled clusters termed verticillasters, which are spaced at intervals along the main inflorescence axis, creating a characteristic spike inflorescence at the terminal (apical) portions of stems.

Flower color exhibits considerable variation depending on cultivar and possibly environmental factors, ranging from lavender, light purple, deep purple, to occasionally white or pale blue hues. Individual flower dimensions are minute, typically measuring 3 to 4 millimeters in length. The calyx (sepals) comprises five fused sepals forming a persistent structure, while the corolla comprises five fused petals arranged in a characteristic two-lipped configuration. The stamens typically number four in bilaterally symmetrical arrangement, consistent with many Lamiaceae genera. The pistil comprises a superior ovary developing into a four-lobed structure that produces four distinct seeds upon maturation.

Flowers produce copious amounts of nectar and are attractive to various pollinating insects, particularly bees, making chia an important nectar source in agricultural settings. The flowering period extends over several weeks, producing sequential flowers that continue the reproductive season and enhance overall seed set. Cross-pollination predominates, though some self-pollination occurs. The extended flowering period ensures continuous seed production and germination opportunities across environmental conditions.[5,6,7]

E. Seed Morphology and Physical Properties

The seeds of Salvia hispanica are the economically and nutritionally most important plant parts. Chia seeds are characterized as small, oval-shaped structures exhibiting pronounced heterogeneity in appearance. Seed dimensions average approximately 2 to 2.5 millimeters in length and 1 to 1.5 millimeters in width, with thickness measuring approximately 0.8 to 0.85 millimeters. Precise measurements reveal that dark seeds average 2.11 mm length, 1.32 mm width, and 0.81 mm thickness, while white/light-colored seeds measure slightly larger at 2.15 mm length, 1.40 mm width, and 0.83 mm thickness, respectively.

Seeds exhibit a mottled appearance with a variable color pattern including combinations of brown, black, gray, and white coloration. This heterogeneous pigmentation results from anthocyanin and other phenolic pigment accumulation within the testa (seed coat). The seed surface displays characteristic patterning with a smooth, hard exterior seed coat. The thousand-seed weight ranges from 80 to 100 grams, depending on cultivar and environmental growing conditions. White seeds, produced only by plants carrying specific recessive genetic traits, are somewhat larger than dark seeds and may contain marginally higher omega-3 fatty acid concentrations.

A distinctive and commercially significant property of chia seeds is their remarkable hydrophilic (water-loving) nature. The seeds absorb water progressively, expanding to approximately 9 to 12 times their original weight when immersed in liquid over 10-15 minutes. This water absorption results in the development of a characteristic gelatinous, mucilaginous coating surrounding the seed, creating a unique physical texture that has become a defining characteristic of chia-based beverages and food preparations. The mucilage comprises approximately 10% of the seed mass and consists primarily of water-soluble polysaccharides.

III. SYNONYMS AND RELATED SPECIES

Salvia hispanica L. is sometimes referred to by alternative common names including Salba, Salba-chia, or simply chia. The scientific nomenclature has remained relatively stable since the species was formally described by Carl Linnaeus in 1753. However, botanical confusion occasionally arises because numerous plant species are colloquially designated as “chia,” though only a few represent the true Salvia hispanica species.

Botanical literature documents that many plants cultivated commercially as Salvia hispanica are actually Salvia officinalis subsp. lavandulifolia (synonymously designated as S. lavandulifolia), a distinct species with different biochemical profiles and somewhat different nutritional characteristics. This taxonomic confusion reflects historical patterns where native Salvia species from Mexico and Central America were sometimes substituted with Mediterranean Salvia species following the plant’s extinction or rarity in its indigenous ranges post-conquest. Close examination of morphological characteristics, essential oil composition, and fatty acid profiles permits differentiation between S. hispanica and related Salvia species.

Other Salvia species with ethnobotanical significance in Mexico include Salvia tiliaefolia, which is traditionally harvested wild by the Tarahumara indigenous peoples of northern Mexico and employed in traditional medicine practices, though with somewhat different medicinal applications than S. hispanica. Salvia divinorum, known as the diviner’s sage, represents another historically significant Salvia species with profound psychoactive properties that was employed in Mazatec shamanic rituals, though this species has different pharmacological properties and applications than culinary/nutritional chia varieties.

IV. MACROSCOPIC CHARACTERISTICS

A. Physical and Structural Properties

The macroscopic examination of Salvia hispanica plants and seeds reveals several distinctive characteristics facilitating botanical identification and understanding of plant biology. The stems are herbaceous to semi-woody, displaying quadrangular (four-angled) cross-sectional morphology characteristic of the Lamiaceae family. The epidermis of stems displays fine trichomes that give the plant surfaces a characteristic velvety texture. The stems demonstrate good structural integrity with relatively high tensile strength, permitting the plant to support the mass of the profusely developed canopy and reproductive structures without significant lodging (toppling). The plant displays characteristic branching patterns with lateral branches arising from the main stem at relatively regular intervals throughout the growing season. This branching architecture creates a pyramidal or conical plant silhouette, which is efficient for light capture and reproduction. The basal region demonstrates the strongest structural development, with stem diameter progressively decreasing toward the apical regions. Vascular tissue distribution within stems reflects the plant's herbaceous nature, with well-developed phloem and xylem systems supporting nutrient and water transport throughout the plant body.

B. Density, Porosity, and Mechanical Properties of Seeds

Detailed investigations of chia seed physical properties reveal measurements of critical importance for processing, storage, and commercial applications. The bulk density of chia seeds ranges from 0.667 to 0.722 grams per cubic centimeter, indicating relatively efficient packing despite the seeds' irregular geometry. The true density (accounting for the actual volume of seed material excluding air spaces) ranges from 1.075 to 1.2 grams per cubic centimeter. Overall porosity of chia seed masses ranges from 22.9% to 35%, indicating substantial air space within seed aggregates. Individual seed volume averages approximately 1.19 cubic millimeters, while geometric diameter (calculated from three-dimensional measurements) ranges from 1.31 to 1.34 millimeters. Sphericity measurements, reflecting the degree to which seeds approach a perfect sphere, range from 62.2% to 66.8%, demonstrating that chia seeds exhibit moderate deviation from spherical geometry. These measurements indicate chia seeds possess favorable flow characteristics and can be processed through conventional grain handling equipment with minimal difficulty. The static coefficient of friction against various surfaces influences the angle of repose (the maximum slope angle at which seed piles remain stable) and impacts equipment design for seed handling and storage.

C. Microstructural Features and Surface Topology

Microscopic examination reveals that chia seed surfaces display minute morphological features affecting water absorption and mucilage development. The testa (seed coat) comprises multiple cellular layers including the outer epidermis, which displays papillate projections and microscopic pores facilitating rapid water penetration. Upon hydration, the outer cell layers swell dramatically and gelatinize, releasing soluble polysaccharides that constitute the characteristic mucilage.

The seed interior reveals a large endosperm tissue that comprises the bulk of seed mass and contains nutrient reserves supporting embryonic development. The endosperm demonstrates heterogeneous composition with distinct regions enriched in lipids (particularly in the superficial regions) and carbohydrates (predominantly in the central regions). The embryo occupies a relatively small portion of the seed, typically comprising less than 5% of total seed mass.

V. PHYTOCHEMICAL COMPOSITION OF SALVIA HISPANICA

A. Fatty Acid Profile and Lipid Composition

Salvia hispanica seeds represent one of the richest plant sources of omega-3 polyunsaturated fatty acids (ω-3 PUFA), the nutritional characteristic most prominently associated with chia's commercial and therapeutic significance. Total lipid content in chia seeds ranges from 28 to 32 percent of dry seed mass, representing an exceptionally high concentration for plant-based foods. This lipid content rivals that of tree nuts and far exceeds that of most cereal grains and legumes. The composition of chia seed oil demonstrates predominant enrichment with polyunsaturated fatty acids, which comprise approximately 88% of total lipid content.

The most abundant fatty acid in chia seed oil is alpha-linolenic acid (ALA; 18:3ω-3), a plant-derived omega-3 fatty acid that comprises 55 to 65 percent of total oil content. This concentration of ALA is substantially higher than that documented in most other commonly consumed plant foods, exceeding that of flaxseeds, walnuts, and other plant sources often promoted as omega-3 sources. The second most abundant fatty acid is linoleic acid (LA; 18:2ω-6), an omega-6 polyunsaturated fatty acid comprising approximately 18 to 24 percent of total oil. The ratio of omega-3 to omega-6 fatty acids in chia seed oil averages approximately 2.65:1, which represents a more favorable ratio than the typical Western diet ratio of approximately 1:10-1:20.

Additional fatty acids detected in chia seed oil include oleic acid (18:1ω-9, a monounsaturated fatty acid) at approximately 6 to 8 percent, stearic acid (18:0, saturated) at approximately 2 to 3 percent, and various other fatty acids in smaller quantities. Saturated fatty acids comprise only 8 to 12 percent of total chia seed oil, a favorable profile for cardiovascular health. The chia seed oil contains appreciable concentrations of tocopherols (vitamin E forms), with total tocopherol content ranging from 200 to 300 milligrams per kilogram of seed. The presence of natural antioxidant compounds including tocopherols, phenolic acids, and flavonoids endows chia seed oil with remarkable oxidative stability and extended shelf life compared to many other plant oils.[8,9,10]

B. Protein Content and Amino Acid Composition

Protein comprises 18 to 24 percent of chia seed dry mass, representing a substantially higher concentration than most cereal grains and many legumes. This protein content rivals that of soybeans and exceeds that of wheat, corn, and rice. A distinctive advantage of chia protein is that it comprises a complete amino acid profile containing all nine essential amino acids required for human nutrition, making chia seeds a complete protein source from a plant origin.

Amino acid analysis reveals particularly high concentrations of several amino acids significant for human health. Arginine comprises approximately 8.9 percent of total amino acids, reflecting concentrations essential for vascular health and immune function. Glutamic acid comprises approximately 12.4 percent, aspartic acid comprises 7.64 percent, and alanine comprises 4.31 percent of total amino acids. Essential amino acids including leucine (5.89%), isoleucine (3.21%), valine (5.1%), phenylalanine (4.73%), lysine (4.44%), and others are present in appropriate proportions for supporting human protein synthesis requirements. Histidine comprises 2.57 percent, methionine comprises 0.36 percent, and tryptophan comprises 1.29 percent of total amino acids.

The biological value of chia seed protein, reflecting the efficiency of protein utilization following absorption, approaches 70-80%, which is respectable for plant proteins though somewhat lower than animal proteins. However, the complete amino acid profile and relatively high protein concentration make chia seeds valuable dietary components for vegetarian and vegan populations, as well as for general population protein supplementation. Chia protein hydrolysates obtained through enzymatic digestion demonstrate additional bioactive properties including antimicrobial, anticancer, immunomodulatory, and antihypertensive activities discussed in subsequent sections.

C. Carbohydrate and Dietary Fiber Content

Carbohydrates comprise approximately 37 to 41 percent of chia seed dry mass, with a distinctive characteristic being the very high dietary fiber fraction. Total dietary fiber content ranges from 27 to 30 percent of seed mass, representing one of the highest dietary fiber concentrations documented in plant foods. This dietary fiber comprises both soluble fiber (primarily the mucilage fraction) and insoluble fiber (primarily cellulosic and hemicellulosic components from the seed coat and endosperm cell walls).

The soluble fiber fraction contributes substantially to chia's gel-forming properties and cholesterol-lowering potential, as discussed in subsequent sections. The mucilage comprises approximately 10 percent of total seed mass and consists primarily of complex polysaccharides including glucose, mannose, and uronic acids linked through glycosidic bonds. Upon hydration, these mucilaginous polysaccharides swell dramatically, producing a gelatinous matrix that surrounds the seed. This mucilage composition endows chia with distinctive functional properties affecting digestive behavior, nutrient bioavailability, and satiety signaling.

Net digestible carbohydrates (total carbohydrates minus fiber) constitute only approximately 8-10 percent of seed mass, resulting in a relatively low glycemic index and minimal impact on blood glucose levels. This characteristic renders chia seeds particularly valuable for individuals with diabetes or those employing low-carbohydrate dietary approaches. The glycemic index of chia seeds has been documented at approximately 15-17, classifying chia among the lowest glycemic index plant foods. This favorable carbohydrate profile contributes substantially to chia's therapeutic potential for glycemic management and metabolic health.

D. Polyphenolic and Antioxidant Compounds

Chia seeds demonstrate exceptionally high concentrations of phenolic compounds and antioxidant substances, representing a major component of chia's pharmacological activity. Total phenolic content in chia seeds has been quantified at 0.88 to 1.8 milligrams of gallic acid equivalents per gram of seed, indicating concentrations that rival many fruits and vegetables. The major phenolic compounds detected in chia seeds include various phenolic acids and flavonoid derivatives that contribute substantially to antioxidant activity. Rosmarinic acid represents the predominant phenolic acid detected in chia seeds, comprising approximately 926.7 micrograms per gram of seed or approximately 0.93 milligrams per gram. This concentration of rosmarinic acid exceeds that documented in most Salvia species and many other plant sources.

Rosmarinic acid demonstrates multiple pharmacological properties including potent antioxidant activity, anti-inflammatory effects, and antimicrobial capabilities. Protocatechuic acid ethyl ester comprises the second major phenolic component at approximately 0.74 milligrams per gram of seed.

Caffeic acid represents an important phenolic acid component at 0.027 to 0.086 milligrams per gram of seed, with documented antioxidant, anti-cancerogenic, and anti-hypertensive properties. Chlorogenic acid comprises 0.013 to 0.074 milligrams per gram of seed, demonstrating similar bioactive properties. Additional phenolic acids detected in lower concentrations include gallic acid (0.0115 milligrams per gram), ferulic acid, and various other cinnamic acid derivatives.

Flavonoid compounds represent an important secondary category of polyphenolic compounds in chia seeds, contributing significantly to antioxidant capacity. Quercetin comprises 0.0181 to 0.209 milligrams per gram of seed, with documented antioxidant, anti-inflammatory, and anticancer properties. Kaempferol comprises 0.0057 to 0.0435 milligrams per gram of seed. Myricetin has been documented in chia seeds in measurable quantities. These flavonoid compounds work synergistically with phenolic acids to provide comprehensive antioxidant protection through multiple mechanisms.

Isoflavone compounds have been identified in chia seeds, including daidzin (0.0066 milligrams per gram), glycitin (0.0014 milligrams per gram), genistin (0.0034 milligrams per gram), and genistein (0.0051 milligrams per gram). These isoflavones display estrogenic activity and demonstrate potential benefits for hormonal health and postmenopausal symptom management. The cumulative antioxidant capacity of chia seeds, as assessed through free radical scavenging assays such as the 2,2-diphenyl-1-picrylhydrazyl (DPPH) radical assay, demonstrates inhibition rates of 65 to 68.83 percent, surpassing values documented for most other plant foods.

E. Vitamins and Minerals

Chia seeds represent excellent sources of various essential vitamins and minerals important for human health and nutrition. Vitamin content analysis reveals the presence of thiamine (vitamin B1) at approximately 0.89 milligrams per 100 grams of seed, riboflavin (vitamin B2) at 0.2 milligrams per 100 grams, niacin (vitamin B3) at 11.2 milligrams per 100 grams, and pyridoxine (vitamin B6) in measurable quantities. Tocopherols (vitamin E compounds) comprise approximately 29 milligrams per 100 grams of seed, providing substantial antioxidant protection. Vitamin A (as carotenoid precursors) has been documented at 44 IU per 100 grams of seed.

Mineral content in chia seeds demonstrates exceptional concentrations of several essential minerals. Calcium comprises approximately 500 to 630 milligrams per 100 grams of seed, representing a concentration rivaling dairy products. However, the bioavailability of calcium from chia requires careful consideration due to the presence of phytic acid and other compounds potentially affecting absorption. Phosphorus comprises approximately 535 to 550 milligrams per 100 grams. Magnesium comprises approximately 290 to 350 milligrams per 100 grams, a mineral essential for neuromuscular function and energy metabolism.

Potassium comprises approximately 600 milligrams per 100 grams, contributing to cardiovascular health and blood pressure regulation. Iron comprises 6.5 to 8.2 milligrams per 100 grams, with bioavailability enhanced by the vitamin C content and the presence of organic acids in chia. Zinc comprises approximately 4.67 to 5 milligrams per 100 grams, important for immune function and wound healing. Copper comprises approximately 1.5 milligrams per 100 grams, and manganese has been documented in measurable quantities. Boron, selenium, and other trace minerals have been identified in chia seeds in smaller concentrations.

F. Essential Oils and Volatile Compounds

Chia seeds produce light-colored essential oil in relatively high concentration compared to many plant sources. The essential oil fraction comprises approximately 1 to 2 percent of seed mass by volume, with specific chemical composition varying based on cultivar, geographic origin, and environmental growing conditions. The essential oil has traditionally been employed in cosmetic formulations and as a flavoring agent in culinary preparations.

Volatile compounds identified in chia essential oil include various terpenoids and aromatic compounds that contribute to the plant's characteristic odor and flavor profile. Beta-caryophyllene, a sesquiterpene compound, has been identified in chia essential oil and demonstrates biological activities including modulation of mood and anxiety responses. Additional volatile compounds contributing to chia's sensory properties include various esters, aldehydes, and other organic compounds in lower concentrations. The essential oil also contains some of the phenolic compounds previously mentioned, though in lower concentrations than in the seed's extractable polyphenolic fractions.[11,12,13,14,15,16,17]

VI. PHARMACOLOGICAL ACTIONS AND MECHANISMS OF SALVIA HISPANICA

A. Antioxidant and Free Radical Scavenging Properties

One of the most fundamental and well-documented pharmacological properties of Salvia hispanica is potent antioxidant activity resulting from its rich polyphenolic composition. The mechanisms underlying chia's antioxidant effects involve multiple pathways through which the bioactive compounds protect cells from oxidative damage. The polyphenolic compounds in chia seeds demonstrate capacity to donate hydrogen atoms to free radicals, thereby neutralizing these highly reactive molecular species. This hydrogen donation mechanism directly reduces free radical concentration and prevents chain-propagating oxidative reactions.

Additionally, chia polyphenols possess the capacity to chelate (bind and sequester) metal ions such as iron and copper, which would otherwise catalyze the generation of free radicals through Fenton-type reactions. The polyphenolic compounds also demonstrate capacity for direct scavenging of reactive oxygen species (ROS) including superoxide anion, hydroxyl radicals, hydrogen peroxide, and singlet oxygen. The synergistic interactions among multiple phenolic compounds (rosmarinic acid, caffeic acid, flavonoids, isoflavones) provide comprehensive antioxidant protection across multiple cellular compartments and biochemical pathways.

The antioxidant activity of chia has been validated through multiple in vitro assays demonstrating 65 to 68.83 percent inhibition of DPPH radicals, exceeding values documented for many fruits, vegetables, and other plant foods. The ferric reducing ability of chia polyphenols has also been documented, confirming capacity to reduce ferric ions and protect against iron-catalyzed oxidative processes. Animal models demonstrate that chia supplementation elevates expression of endogenous antioxidant enzymes including superoxide dismutase (SOD), catalase (CAT), and glutathione peroxidase (GPX), thereby enhancing the body's intrinsic antioxidant defense systems. This upregulation of antioxidant enzymes represents a particularly valuable mechanism, as endogenous enzyme systems provide sustainable, amplified protection against oxidative stress.

B. Cardiovascular Effects and Vascular Function

Extensive pharmacological research demonstrates that Salvia hispanica exerts multiple beneficial effects on the cardiovascular system through distinct mechanistic pathways. The cardioprotective properties of chia derive primarily from its exceptional omega-3 polyunsaturated fatty acid content, combined with polyphenolic compounds and bioactive peptides. Omega-3 fatty acids, particularly alpha-linolenic acid, serve as precursors for multiple critical biochemical compounds including prostaglandins, leukotrienes, and thromboxanes, which regulate numerous physiological processes affecting cardiovascular function.

The omega-3 polyunsaturated fatty acids in chia demonstrate capacity for blocking calcium and sodium channel dysfunctions that otherwise precipitate hypertension and arrhythmias. Multiple clinical and animal studies document that chia supplementation reduces systolic and diastolic blood pressure in both normotensive and hypertensive individuals. One clinical trial demonstrated that supplementation with 40 grams daily of chia seeds for 12 weeks significantly reduced systolic blood pressure in individuals with type 2 diabetes and hypertension. The mechanisms underlying blood pressure reduction involve improved endothelial function and increased nitric oxide (NO) bioavailability.

Chia seed extracts demonstrate direct vasorelaxant effects on isolated vascular tissue through mechanisms involving the nitric oxide-cyclic guanosine monophosphate (NO-cGMP) pathway. Nitric oxide produced by endothelial nitric oxide synthase (eNOS) in the vascular endothelium diffuses into adjacent smooth muscle cells, where it activates guanylate cyclase, increasing cGMP concentrations and inducing smooth muscle relaxation and vasodilation. The presence of mannitol and other compounds in chia seed extracts facilitates this NO-mediated vasodilation mechanism. This direct vasodilatory activity complements the systemic cardiovascular effects of chia consumption.

Chia supplementation also demonstrates substantial effects on lipid metabolism, reducing circulating concentrations of low-density lipoprotein (LDL) cholesterol, very-low-density lipoprotein (VLDL), and triglycerides while increasing high-density lipoprotein (HDL) cholesterol. These lipid-altering effects derive from multiple mechanisms including enhanced fecal cholesterol excretion secondary to the high dietary fiber content, direct inhibition of hepatic cholesterol synthesis by bioactive compounds, and modulation of lipid absorption in the small intestine. Studies in animal models with hyperlipidemia demonstrate that chia supplementation (at 10% of daily calories in the form of chia oil) significantly reduces serum lipid profiles and prevents atherosclerotic lesion development. Chia's anti-inflammatory properties also contribute substantially to cardiovascular protection. The inflammatory markers TNF-α and IL-6 are significantly reduced in individuals consuming chia, and C-reactive protein (CRP), an important cardiovascular risk marker, demonstrates dose-dependent reductions with chia supplementation. The capacity of chia to reduce platelet aggregation, thereby decreasing thrombotic risk, represents an additional cardioprotective mechanism. These multiple cardiovascular benefits position chia as a valuable dietary intervention for reducing risk of myocardial infarction, stroke, and other atherosclerotic cardiovascular events.

C. Anti-inflammatory and Immunomodulatory Properties

Accumulating evidence demonstrates that Salvia hispanica possesses significant anti-inflammatory properties operating through multiple discrete cellular and molecular mechanisms. The anti-inflammatory effects derive primarily from the omega-3 polyunsaturated fatty acids and polyphenolic compounds that modulate inflammatory signaling pathways. Chia seed protein hydrolysates (CPH), obtained through enzymatic digestion of chia protein, demonstrate remarkable capacity for suppressing pro-inflammatory responses in activated immune cells.

In vitro studies with primary human monocytes demonstrate that chia protein hydrolysates reduce lipopolysaccharide (LPS)-induced production of reactive oxygen species (ROS) and nitric oxide (NO), which are important pro-inflammatory mediators. This reduction in ROS and NO production occurs through suppression of inducible nitric oxide synthase (iNOS) expression and NADPH oxidase activation. Simultaneously, chia protein hydrolysates significantly reduce the production of pro-inflammatory cytokines including interleukin-1 beta (IL-1β), interleukin-6 (IL-6), and tumor necrosis factor-alpha (TNF-α). These effects derive from suppression of nuclear factor-kappa B (NF-κB) signaling, a master transcription factor controlling expression of numerous pro-inflammatory genes.

Notably, chia protein hydrolysates simultaneously enhance production of anti-inflammatory mediators including interleukin-10 (IL-10), while promoting macrophage polarization from the pro-inflammatory M1 phenotype toward the anti-inflammatory, tissue-repairing M2 phenotype. This reversal of macrophage polarization represents a particularly valuable pharmacological action, as chronic inflammation characterized by excessive M1 macrophage accumulation contributes to numerous disease processes. The M1-to-M2 polarization induced by chia derivatives involves upregulation of the mannose receptor-1 (MRC1) and increased IL-10 production, while simultaneously reducing expression of pro-inflammatory markers including CCR7 and TNF-α.

At the molecular level, chia-derived compounds activate peroxisome proliferator-activated receptors (PPAR), which represent master regulators of anti-inflammatory and metabolic homeostasis. Activation of PPAR-α and PPAR-γ by omega-3 fatty acids and polyphenolic compounds enhances expression of anti-inflammatory genes while suppressing pro-inflammatory gene expression through interference with NF-κB signaling. The dietary fiber in chia also contributes to anti-inflammatory effects through modification of gut microbiota composition, enhanced production of short-chain fatty acids (particularly butyrate) by commensal bacteria, and improved intestinal barrier function.

Animal models of inflammatory disease provide compelling evidence for chia's therapeutic anti-inflammatory potential. In models of complete Freund's adjuvant (CFA)-induced rheumatoid arthritis, chia seed extract administration significantly reduced articular inflammation, improved joint histopathology, and reduced systemic inflammatory markers including TNF-α while enhancing IL-10 production. In experimental autoimmune encephalomyelitis (EAE), a model for multiple sclerosis, chia oil administration ameliorated motor impairment and reduced mechanical sensitivity through anti-inflammatory and immunomodulatory mechanisms. These findings suggest potential therapeutic applications of chia for managing chronic inflammatory and autoimmune diseases.

D. Antidiabetic Effects and Glycemic Control

Extensive research demonstrates that Salvia hispanica exerts significant antidiabetic effects through multiple distinct pharmacological mechanisms, establishing chia as a potentially valuable dietary intervention for diabetes prevention and management. The primary mechanisms underlying chia's antidiabetic activity involve modulation of glucose absorption, enhancement of insulin sensitivity, and reduction of oxidative and inflammatory stress associated with hyperglycemia.

The high dietary fiber content in chia seeds contributes substantially to antidiabetic effects through multiple mechanisms. Soluble dietary fiber increases intestinal viscosity and extends gastrointestinal transit time, thereby reducing glucose absorption rate and post-prandial (after-meal) glycemic excursions. This flattening of the postprandial glucose curve reduces insulin secretion demands and prevents the rapid blood glucose oscillations that damage vascular and neurological tissue. Research demonstrates that addition of 25 grams of chia seeds to meals significantly reduces postprandial glucose excursions in both diabetic and non-diabetic individuals, with effects comparable to some pharmaceutical glucose-lowering agents.

At the cellular level, chia constituents enhance insulin signaling through multiple pathways. Evidence indicates that chia polyphenols enhance tyrosine phosphorylation of insulin receptor substrate-1 (IRS-1) and subsequent phosphorylation of protein kinase-B (PKB/Akt), which are critical early steps in the insulin signaling cascade. These signaling events promote translocation of glucose transporter-4 (GLUT-4) to the plasma membrane in skeletal muscle cells, thereby enhancing glucose uptake. Additionally, chia bioactive compounds upregulate expression of AMP-activated protein kinase (AMPK) in hepatic tissue, which promotes glucose uptake and oxidation while reducing hepatic gluconeogenesis and fatty acid synthesis.

The polyphenolic compounds in chia, particularly those with antioxidant activity, reduce hyperglycemia-induced oxidative stress that is a primary mechanism of diabetic complications. Elevated glucose concentrations generate excessive ROS through multiple pathways including the polyol pathway, advanced glycation end products (AGE) formation, and mitochondrial superoxide production. The abundant antioxidants in chia attenuate these glucose-driven ROS-generating pathways and enhance expression of endogenous antioxidant enzymes (SOD, CAT, GPX), thereby protecting tissues from oxidative damage. This is particularly important because oxidative stress drives diabetic complications including neuropathy, nephropathy, and retinopathy.

Clinical and preclinical studies have demonstrated beneficial effects of chia consumption on key diabetes biomarkers. Some studies report modest reductions in fasting blood glucose levels following chia supplementation, though effects on glycated hemoglobin (HbA1c) in some studies were less pronounced. However, consistent improvements have been documented in insulin sensitivity measures, with reduced fasting insulin concentrations and improved HOMA-IR (Homeostatic Model Assessment of Insulin Resistance) scores in overweight and obese individuals with or at risk for type 2 diabetes. Studies in animal models with streptozotocin-induced or diet-induced diabetes demonstrate that chia supplementation significantly reduces fasting blood glucose, improves glucose tolerance testing, and reduces diabetic complications including nephropathy and neuropathy.

E. Antimicrobial and Antifungal Properties

Recent investigations have revealed that Salvia hispanica possesses significant antimicrobial properties, primarily attributed to bioactive peptides and polyphenolic compounds, establishing potential applications for chia in combating microbial infections. A thermostable trypsin inhibitor isolated from chia seeds, designated ShTI (molecular weight 11.558 kDa), demonstrates remarkable thermal stability (remaining active after 100°C exposure for 2 hours) and pH stability (active across pH 2-10 range), with proven antibacterial activity against pathogenic bacteria including methicillin-resistant Staphylococcus aureus (MRSA).

The antimicrobial mechanism of action of ShTI involves reactive oxygen species (ROS) production and formation of membrane pores in bacterial cell membranes, disrupting membrane integrity and causing bacterial cell death. ShTI demonstrates synergistic interaction with the antibiotic oxacillin against MRSA strains, suggesting potential therapeutic applications in treating antibiotic-resistant infections. The remarkable stability of ShTI across temperature and pH ranges positions it as a promising candidate for developing novel antimicrobial agents for medical and food preservation applications.

Chia seed protein hydrolysates demonstrate antibacterial activity, with peptide fractions of less than 1 kiloDalton (F<1) demonstrating inhibition of gram-positive bacteria including Staphylococcus aureus, Bacillus subtilis, and Listeria monocytogenes, with greatest inhibitory effects against L. monocytogenes. The minimum inhibitory concentration (MIC) for L. monocytogenes inhibition was 635.4 ± 3.6 micrograms per milliliter. These peptide fractions demonstrate pH-dependent activity, with enhanced bactericidal effect at neutral pH, suggesting potential applications in food preservation in relatively neutral products such as milk and egg products, though reduced activity in acidic foods.

Beyond antibacterial properties, recent investigations reveal antifungal activity of chia seed bioactive compounds. ShTI demonstrates antifungal effects against various Candida species, including both azole-susceptible and azole-resistant strains, with potential for synergistic interaction with the antifungal agent fluconazole. This antifungal potential is particularly significant given the increasing prevalence of azole-resistant Candida infections worldwide and the need for novel antifungal therapies. The mechanisms of antifungal action appear to involve ROS generation and disruption of fungal cell membrane integrity, similar to the antibacterial mechanisms.

F. Anticancer and Antiproliferative Properties

Accumulating evidence from in vitro and animal model studies demonstrates that Salvia hispanica possesses significant anticancer properties through multiple distinct mechanisms. Chia seed protein fractions obtained through enzymatic hydrolysis and ultrafiltration demonstrate cytotoxic effects against multiple cancer cell lines including MCF-7 (breast cancer), Caco2 (colon cancer), PC-3 (prostate cancer), and HepG2 (hepatocellular carcinoma) cells, without demonstrating toxicity toward normal human fibroblasts, indicating selectivity for cancer cells.

The protein fraction <1 kDa, at a concentration of 1 milligram per milliliter, demonstrated the highest cytotoxic effect across all tested cancer cell lines. Mass spectrometry analysis of peptide sequences identified the peptide KLKKNL, with putative anticancer activity and potential for development as a novel anticancer agent. This selective targeting of cancer cells while sparing normal cells represents a valuable pharmacological property potentially enabling development of anticancer therapeutics with reduced toxicity to normal tissues.

Chia seed extracts demonstrate significant anti-lung cancer effects in chemically induced lung cancer models. Alcohol and ether extracts of chia reduce expression of cancer-associated genes including c-MYC (which drives cancer cell proliferation) by 80-96% and MMP9 (matrix metalloproteinase-9, which promotes cancer cell invasion and metastasis) by 60-69% compared to untreated lung cancer controls. These extracts significantly reduce Ki67 expression, a biomarker of cellular proliferation, indicating suppression of cancer cell division. Chia extracts reduce angiogenesis (new blood vessel formation supporting tumor growth) by reducing vascular endothelial growth factor (VEGF) expression and promote apoptosis (programmed cancer cell death) by reducing anti-apoptotic BCL2 expression.

The anticancer mechanisms of chia polyphenolic compounds involve multiple pathways including DNA damage prevention through antioxidant activity, suppression of cancer cell proliferation through cell cycle arrest, promotion of cancer cell apoptosis through mitochondrial depolarization and caspase activation, and inhibition of cancer cell invasion and metastasis through reduced proteolytic enzyme expression. The polyphenolic compounds in chia appear to exert these effects through epigenetic mechanisms affecting cancer-related gene expression, particularly through interference with signaling pathways including NF-κB, which is typically constitutively active in cancer cells.[18,19,20,21]

G. Weight Management and Anti-obesity Effects

Salvia hispanica demonstrates significant potential for weight management and obesity prevention through multiple distinct pharmacological mechanisms. The mechanism most commonly emphasized involves the exceptional dietary fiber content providing satiety signaling, thereby reducing overall energy intake. The soluble fiber fraction (mucilage) comprises approximately 10% of seed mass and upon hydration creates a gelatinous mass that extends gastrointestinal transit time, enhances gastric distension signaling, and promotes satiety hormone secretion including glucagon-like peptide-1 (GLP-1) and peptide YY (PYY).

The protein fraction of chia seeds also contributes substantially to satiety through thermogenic effects (increased post-meal metabolic rate) and through gastrointestinal hormone secretion. Studies demonstrate that incorporation of chia seeds into standard meals produces acute increases in satiety sensation and reduced post-meal hunger, with effects persisting for several hours following consumption. The combination of elevated satiety with reduced glycemic excursions (secondary to low net carbohydrate content) makes chia particularly valuable for weight management applications.

Beyond acute satiety signaling, longer-term chia supplementation reduces adiposity (body fat) in overweight and obese individuals and animal models. The alpha-linolenic acid (omega-3 PUFA) in chia suppresses adipogenesis (development of new fat cells) through modulation of PPAR-gamma activity and affects lipid partitioning, reducing adipose tissue accumulation while potentially enhancing lean muscle mass. Some studies document improvements in systolic blood pressure and reductions in inflammatory markers including C-reactive protein with chia supplementation, independent of weight loss, suggesting that anti-inflammatory effects contribute to metabolic improvements beyond those attributable to weight reduction.

However, it is important to note that evidence for weight loss effects varies across studies, with some investigations showing significant weight reduction while others document minimal weight loss despite improved metabolic parameters. The variation in outcomes likely reflects differences in study duration, chia dosage (ranging from 25-40 grams daily), baseline participant characteristics, and integration of chia into overall dietary patterns. The most beneficial effects appear to occur when chia is incorporated into comprehensive dietary and lifestyle modifications rather than as an isolated intervention.

H. Additional Pharmacological Properties

Beyond the major pharmacological actions detailed above, research suggests additional therapeutic potential for Salvia hispanica. Chia has demonstrated neuroprotective properties in some experimental models, with certain investigations suggesting potential benefits for cognitive function and neurodegeneration-related diseases. However, findings regarding Alzheimer's disease are inconsistent, with some studies suggesting potential exacerbation of disease progression in certain experimental conditions, indicating the need for cautious interpretation and further investigation.

Chia seed extracts demonstrate protective effects against oxidative stress-induced testicular damage, with research showing that chia administration prevents arsenic-induced testicular toxicity through antioxidant and anti-inflammatory mechanisms. The flavonoid content and comprehensive antioxidant activity of chia seeds appear responsible for these testicular protective effects. Studies in reproductive models demonstrate improved sperm parameters, increased serum sex hormone levels, and enhanced antioxidant enzyme activity (SOD, CAT, GPX) in chia-treated animals.

Chia's protective effects extend to bone health through multiple mechanisms. While calcium bioavailability from chia is lower than from some sources due to the presence of phytic acid and other bioavailability-reducing factors, chia consumption maintains bone health when incorporated into diets meeting adequate calcium recommendations. The bioactive compounds in chia exert anti-inflammatory and antioxidant effects that reduce inflammatory bone loss and protect bone structure, particularly important in models of postmenopausal osteoporosis.

Hepatoprotective effects of chia have been documented in animal models of metabolic dysfunction and chemical-induced liver injury. Chia supplementation improves liver function biomarkers including aspartate aminotransferase (AST), alanine aminotransferase (ALT), and non-alcoholic fatty liver disease (NAFLD) fibrosis scores (NFS) in models of high-fat diet-induced hepatic steatosis. The anti-inflammatory and antioxidant properties of chia appear to reduce lipid accumulation in hepatic tissue and prevent progression to fibrosis.

VII. TRADITIONAL AND ETHNOBOTANICAL USES OF SALVIA HISPANICA

A. Historical Uses in Aztec and Pre-Columbian Civilizations

The history of Salvia hispanica utilization extends far into antiquity, with archaeological and historical documentation indicating cultivation dating back approximately 3,500 years before the present era. Historical codices including the Codex Mendoza, Codex Florentino, and various chronicles written by Spanish conquistadors provide detailed accounts of chia's significance in pre-Columbian Aztec and Mayan civilizations. The Codex Mendoza specifically identifies chia as one of the primary tribute crops demanded by the Aztec Empire from conquered territories, alongside corn, beans, and amaranth, indicating its economic and strategic importance to Aztec civilization. In pre-Hispanic times, chia held profound religious and ceremonial significance within Aztec spiritual practices. The plant was believed to have been given to the Aztec people by Chicome Coatl, the goddess of creation and life, and chia seeds were offered at her pyramid shrine alongside corn, beans, and amaranth as sacred offerings to ensure abundant harvests and the survival of Aztec civilization. The seeds were incorporated into ceremonial preparations and religious rituals central to Aztec spiritual observances. Chia seed oil, extracted through pressing and grinding of the seeds, served as the base medium for ceremonial body paints applied during important religious observances and warrior rituals.

B. Nutritional and Culinary Applications in Indigenous Cultures

The primary historical application of chia seeds involved nutritional supplementation, with the seeds providing concentrated calories, protein, and omega-3 fatty acids supporting intense physical exertion and military campaigns. Aztec warriors consumed chia seeds during arduous military conquests and extended territorial travels, with historical accounts documenting that a single teaspoon of chia mixed with water and other ingredients could sustain warriors during an entire day of demanding physical activity. The traditional preparation, termed "chianatolli," consisted of roasted and ground chia seeds mixed with amaranth seed, corn flour, and maguey syrup, creating a nutrient-dense paste consumed regularly and ceremonially.

Among the Tarahumara indigenous peoples of northern Mexico, chia preparations continue to hold traditional significance, with "chia fresca" (a beverage of ground chia seeds mixed with water, sugar, and lime juice) consumed during the celebrated long-distance mountain runs for which the Tarahumara are renowned. These traditional practices reflected intuitive understanding of chia's physiological benefits, later validated through modern nutritional science.

C. Medicinal Applications Documented in Historical Sources

The Codex Florentino, written between 1548-1579, provides detailed documentation of medicinal applications of chia by Aztec healers, representing one of the most authoritative historical sources regarding pre-Hispanic medical practices. According to this historical document, ground chia root was employed to treat dry cough and hemoptysis (coughing of blood), conditions that would likely correspond to pulmonary tuberculosis or other chronic respiratory diseases in modern medical classification. Chia oil, expressed from the seeds, was employed in ophthalmological applications to remove foreign bodies lodged in the eye, an application reflecting understanding of the viscous, gelatinous properties that modern science has identified as the mucilage fraction. Chia seed gruels prepared as infusion bases for herbal medicines were employed in treating various digestive and gastrointestinal complaints, likely including diarrhea, dysentery, and inflammatory bowel conditions. Chia preparations were utilized for treating wounds and injuries, with the anti-inflammatory and antimicrobial properties identified through modern research likely contributing to the observed healing benefits. Aztec women consumed chia preparations for women's health conditions, including menstrual regulation and support during pregnancy and lactation, applications potentially reflecting the plant's hormonally active compounds and nutritional density.

D. Contemporary Traditional Medicine Applications

In contemporary Mexico and Central American indigenous communities, chia preparations continue to be employed within traditional medicine frameworks for supporting digestive health, enhancing athletic performance, and providing general nutritional supplementation. Traditional preparations continue to emphasize chia's capacity for sustained energy provision and its role in women's health. In some communities, chia is combined with complementary herbs and traditional medicinal plants within comprehensive healing preparations.

The Tarahumara peoples continue traditional chia utilization, with the plant remaining an important dietary staple supporting the demanding physical lifestyle characteristic of this indigenous community. Contemporary traditional knowledge remains largely concordant with modern scientific findings, suggesting that indigenous practices reflected sophisticated empirical understanding of the plant's physiological effects despite lack of modern biochemical knowledge.

VIII. CONCLUSION

Salvia hispanica L., commonly known as chia, represents a nutrient-dense plant-based food with extraordinary potential for supporting human health and preventing chronic disease. Centuries of indigenous utilization, followed by modern scientific investigation spanning several decades, have established chia as a genuine functional food capable of exerting multiple beneficial pharmacological effects through diverse biochemical mechanisms.

The exceptional nutritional profile of chia seeds—comprising complete protein, omega-3 polyunsaturated fatty acids at concentrations rivaling marine sources, high-quality dietary fiber, comprehensive mineral content, and abundant antioxidant polyphenolic compounds—provides a biochemical foundation supporting the numerous documented pharmacological properties. The mechanisms of action underlying chia's beneficial effects operate at multiple biological levels, from direct antioxidant and free radical scavenging activities at the molecular level, to complex immunomodulatory and metabolic effects operating at the cellular and systems physiology levels. The evidence supporting cardioprotective effects is particularly robust, with documented mechanisms including blood pressure reduction, favorable effects on lipid metabolism, endothelial function improvement, platelet aggregation reduction, and comprehensive anti-inflammatory activity. The antidiabetic properties of chia have been extensively investigated, demonstrating effects on multiple facets of glucose homeostasis including postprandial glucose control, insulin sensitivity enhancement, and protection against hyperglycemia-induced oxidative damage. The anti-inflammatory and immunomodulatory properties position chia as potentially valuable for managing inflammatory and autoimmune diseases, with animal models demonstrating therapeutic potential in rheumatoid arthritis and multiple sclerosis-like models. The emerging evidence regarding anticancer properties, antimicrobial and antifungal activity, and neuroprotective potential suggests additional therapeutic applications requiring further clinical investigation. The capacity of chia to support weight management through satiety enhancement and metabolic optimization positions the plant as valuable for addressing obesity and related metabolic dysfunction. Traditional applications in supporting women's health and athletic performance have begun receiving scientific validation, though additional research is warranted. However, several important caveats and areas requiring additional investigation merit emphasis. While the evidence base is generally supportive, the quality of clinical evidence varies, with many studies conducted in animal models rather than human subjects. Published clinical trials, while increasingly numerous, often involve relatively small sample sizes and relatively short intervention durations. The optimal dosing regimens for different health outcomes remain incompletely defined, with studies employing varying doses from 12 to 50 grams daily. Individual variation in response to chia supplementation requires recognition, with some individuals benefiting markedly while others demonstrate minimal response. The calcium bioavailability from chia, despite high calcium content, is lower than from some sources due to the presence of phytic acid and other bioavailability-reducing compounds, requiring consideration when chia is relied upon as a primary calcium source. The potential for adverse effects including digestive discomfort, allergic reactions in sensitive individuals, and possible interactions with certain medications warrants clinical consideration and appropriate patient screening. The possible exacerbation of cognitive decline in early-stage Alzheimer's disease, identified in one study, requires careful interpretation and further investigation before chia is recommended as a therapeutic intervention for neurodegenerative diseases. Future research directions should include: (1) adequately powered, long-duration randomized controlled clinical trials evaluating chia's effects on hard endpoints including cardiovascular events, cancer incidence, and mortality; (2) investigation of optimal dosing regimens and identification of patient populations most likely to benefit from chia supplementation; (3) mechanistic studies elucidating the precise molecular pathways through which chia bioactive compounds exert their effects; (4) investigation of bioavailability and metabolism of chia's bioactive compounds following oral consumption; (5) evaluation of potential drug-herb interactions affecting therapeutic efficacy of conventional medications; and (6) investigation of potential adverse effects and establishment of safety profiles in diverse patient populations.

In conclusion, Salvia hispanica L. represents an exceptional plant-based food with remarkable nutritional density, comprehensive antioxidant and anti-inflammatory properties, and well-documented therapeutic potential for preventing and managing multiple chronic diseases. The convergence of historical usage spanning millennia, traditional knowledge documented in indigenous cultures, modern scientific investigation validating claimed benefits, and demonstrated pharmacological properties through multiple mechanistic pathways establishes chia as a legitimate and valuable component of comprehensive preventive and therapeutic healthcare strategies. When integrated thoughtfully into balanced dietary and lifestyle approaches, chia seeds offer potential for enhancing health outcomes and supporting longevity. However, recognition of individual variation in response, understanding of chia's proper role as a complementary dietary component rather than a replacement for conventional medicine, and ongoing scientific investigation of emerging applications remain essential for optimizing therapeutic benefits while ensuring safety.[21,22,23,24,25]

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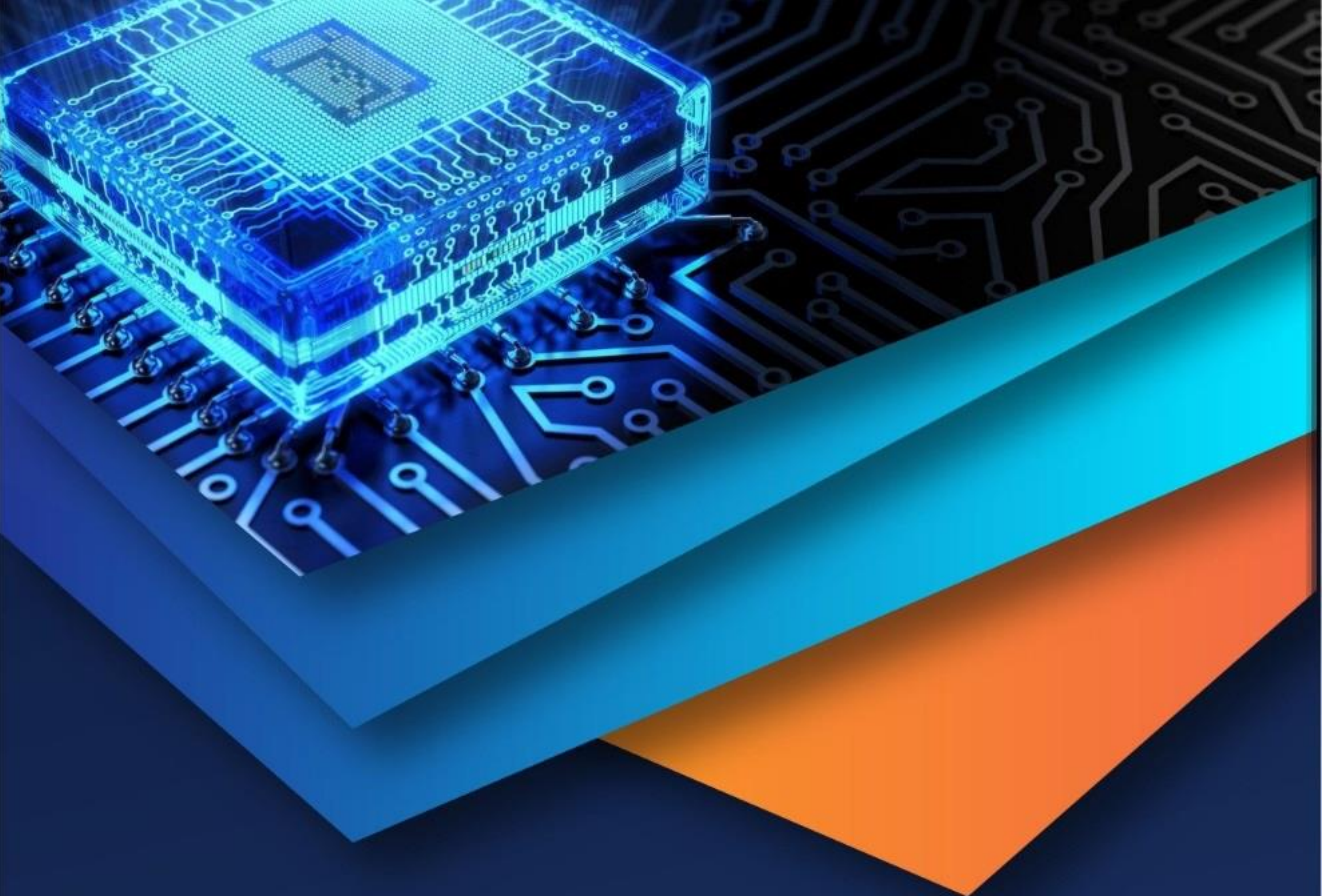

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