

Review

Nutritional, health benefits and usage of chia seeds (*Salvia hispanica*): A review

Ashura Katunzi-Kilewela^{1,2}, Lillian D. Kaale¹, Oscar Kibazohi¹ and Leonard M. P. Rweyemamu^{1*}

¹Department of Food Science and Technology, University of Dar es Salaam, P. O. Box 35134 Dar es Salaam, Tanzania.
²Tanzania Bureau of Standards, P. O. Box 9524 Dar es Salaam, Tanzania.

Received 7 September, 2020; Accepted 18 January, 2021

As we enter the 3rd millennium, with improved life expectancy, and high media coverage of health care issues, people are becoming more aware of and interested in the potential benefits of nutritional support for disease control or prevention. The review aimed to gather published information regarding nutrition and health benefits associated with the use of chia seeds for human health. Researchers have reported chia seeds to have high nutritional content in the form of protein (15-25%), dietary fibre (18-35%), fat (15-35%) and ash content (4-6%). Apart from their rich nutritional content, chia seeds can improve the nutritional content of various food products when they are blended or mixed. This article reviews the nutritional content, bioactive compounds, and nutraceutical functionality of chia seeds and their use in the development of functional foods. Also highlights functional properties of chia seeds, usage in the food industry and fortification of food with chia seeds. The results showed the potential use of chia seeds with blending with other food to produce more nutrient dense food products that can be regarded as a functional food.

Key words: Chia seeds, functional foods, bioactive compounds, nutraceuticals, fortification.

INTRODUCTION

Suitable nutrition is a critical element in the prevention of numerous diseases related to civilization condition. The leading killer diseases due to unhealthy food today are cancer, depression, diabetes, and coronary heart disease (CHD) (Wang et al., 2016). However, the main challenge today, and even in the future, will be providing people with enough, safe, and healthy food. Foods from animals and fish, which contain essential ingredients such as

protein, unsaturated fat, and minerals, will be incredibly scarce (Kaale and Eikevik, 2014). With increased health awareness globally as a result of an increase in the number of non-communicable diseases, the demand for a healthier lifestyle through the consumption of foods that prevent and control these non-communicable diseases has increased (Berner et al., 2014; Chadare et al., 2019). The chia seed is an oilseed that is native to Central and

*Corresponding author. E-mail: leonard.rweyemamu@udsm.ac.tz. Tel: +255 0784478752.

South America (Nieman et al., 2009). It is considered as a pseudo-cereal, which is cultivated for different usage and commonly grown in several countries. The main chia producing countries are Bolivia, Ecuador, Guatemala, Mexico, and Peru (Ixtaina et al., 2008). It has been a significant food crop in the Aztec, Mayan, and Incan civilizations of the past. It was used as food and medicine, as well as in making paint. In recent years, chia seeds have attracted much interest in the following countries; Mexico, Argentina, Chile, Japan, the USA, Canada, Europe and Australia. In these countries, it is part of different food products (Porrás-Loaiza et al., 2014). Chia seeds were introduced into East Africa recently, and it is cultivated in Kenya, Rwanda, Uganda, and Tanzania. In Tanzania, chia seeds were firstly introduced in Kagera Region on the western shores of Lake Victoria in 2013 to improve rural farmers' income. Chia seeds in Tanzania used in raw form and added to drinking water, fruit juices, blending with other cereals for the formulation of composite flour and occasionally taken as nutritional supplements. The crop is increasingly earning popularity in East Africa because of its economic and human-health benefits (Kibui et al., 2018). It is referred to as "the seed of the 21st century", "new gold, super nutrient and superfood" (Dinçoğlu and Yeşildemir, 2019; Suri et al., 2016). The shape of the chia seed is flat and oval. It is 2.0-2.5 mm long, 1 to 2 mm wide, and 0.8-1.0 mm thick (Ixtaina et al., 2008; Suri et al., 2016). The colour of the coat of the seed varies from grey, black- and white-spotted, which are slightly different from each other. However, black seeds are more common, and white seeds are slightly larger than black seeds (Ixtaina et al., 2008; Segura-Campos et al., 2014; Ayerza, 2013). Increased consumption of chia seeds and a greater variety of plant foods provides most of the lost minerals and vitamins, in addition to phytochemicals.

The capacity and value of these safe, healthy, and high-quality foods, as well as other alternative sources of rich foods such as plants, are required. Various research studies have been conducted to identify inexpensive and sustainable solutions for supplementing the needed nutrients from different plant sources such as soybeans (SB), *Moringa oleifera* (Rweyemamu et al., 2015), and chia seeds (Otondi et al., 2020). Such sources of nutrients have shown positive results, especially in fighting micronutrient deficiency in developing countries (Rweyemamu et al., 2015). Chia seeds have great nutritional potential because of their composition. Their composition depends on genetic factors and on the effect of the ecosystems where the plants are grown (Marcinek and Krejpcio, 2017).

Current trends in healthier nutrient-dense foods show chia seeds are becoming more popular to researchers because of their nutritional composition, and benefits to the human-health. Chia seeds reported to contain protein (15-25%), fat (15-35%), ash (4-6%) dietary fibre (18-35%)

and carbohydrates (18-31%) (Coelho and Salas-Mellado, 2014; Ixtaina et al., 2008; Muñoz-González et al., 2019; Nieman et al., 2009; Porrás-Loaiza et al., 2014). Furthermore, in several developing countries, both micronutrient malnutrition (MNM) and protein-energy malnutrition (PEM) have increased, particularly among children. These are related to food insecurity and hence non-communicable diseases. Chia seeds might be used to combat these pandemics in many societies. Sub-Saharan African countries including Tanzania, child malnutrition and availability of healthy food is still a common problem in rural areas, and urban regions as the high number of population are of earners that have low-income. This review aimed to gather information about chia seeds nutritional benefits and potential usage with other food products to enhance nutritional composition.

THE CHEMICAL COMPOSITION OF CHIA SEEDS

Various studies have shown that chia seeds consist of vital macronutrient and micronutrient components (Coelho and Salas-Mellado, 2014; Ixtaina et al., 2008; Muñoz-González et al., 2019; Nieman et al., 2009; Porrás-Loaiza et al., 2014; Segura-Campos et al., 2014). The most common macronutrients are proteins, fats with a good quality profile of fatty acids, ash, carbohydrates, and dietary fibre (Table 1).

Suri et al. (2016) reported that different ecosystems influence the nutritional composition of protein, fatty acids, and fibre in chia seeds. Ixtaina et al. (2008), mentioned chia seeds comprise 90 to 93% of dry-matter. Coelho and Salas-Mellado (2014) stated that the dietary-fibre content was higher than 30% of the total weight of the seed, and approximately 19% of the seed contains proteins of high biological-value. Ullah et al. (2016) reported the chia seeds are good sources of vitamins, antioxidants and other important minerals. Suri et al. (2016) reported chia seeds contained protein content (15 to 23%), total dietary fibre (36 to 40%) and lipids average of 30.74%. The human health benefits of chia seeds have drawn much attention from researchers and consumers because of the essential fatty acids and a high level of proteins and other components like phytochemicals such as phenolic compounds, flavonoids, tocopherols, steroids, and carotenoids (Valdivia-López and Tecante, 2015; Prakash and Sharma, 2014). These include increased blood levels, improved blood sugar, lower blood pressure, and improvement of the health of guts (Marcinek and Krejpcio, 2017; Suri et al., 2016).

Fat composition of chia seeds

There are different classifications of fats and oils, depending on the structure of the seeds. Chia seeds oil

Table 1. Proximate composition of chia seeds.

Country of origin	Protein	Fat	Ash	Carbohydrate	Dietary fibre	Source
Salta, Argentina	15 - 25	30 - 33	4 - 5	26 - 41	18 – 30	Ixtaina et al. (2008)
Ecuador, Brazil	20 - 24	16 - 33	3.5 - 4.6	-	27 - 36	Carrillo et al. (2018); Coelho and Salas-Mellado (2014)
India	15 - 23	25 - 34	-	37 - 45	23 - 35	Many and Sarasvathi (2016); Suri et al. (2016)

Table 2. Composition of omega 3 and omega 6 for different types of vegetable oil.

Type of oil	Country of origin	Omega 3	Omega 6	Source
Chia	Mexico, Ecuador, Brazil and Argentina	54 - 67	17 -20	Álvarez-Chávez et al. (2008), Carrillo et al. (2018), Coelho and Salas-Mellado (2014), Ixtaina et al. (2011).
Sunflower	Czech Republic and Poland	0.16 – 0.50	55 - 65	Orsavova et al. (2015); Marcinek and Krejpcio (2017)
Pumpkin	Cameroon, Czech Republic and Poland	0.12 – 0.50	47 - 69	Fokou et al. (2009); Orsavova et al. (2015); Marcinek and Krejpcio (2017)
Wheat germ	Czech Republic and Poland	1.2 – 2.90	45 - 65	Orsavova et al. (2015); Marcinek and Krejpcio (2017)
Rapeseed	Czech Republic and Poland	1.2 – 9.80	18 - 20	Orsavova et al. (2015); Marcinek and Krejpcio (2017)

has been reported to contain an excessive amount of fatty acids, especially polyunsaturated fatty acids (PUFA), which consist of more than 60% α -linoleic acid and more than 20% linoleic acid (Di Marco et al., 2020; Segura-Campos et al., 2014).

Increasing environmental concerns on water sources in terms of pollutants, overfishing, and the use of un-approved fishing gear have prompted the use of plant origin sources, which give polyunsaturated-fatty-acids (PUFAs). Among the common PUFAs of great interest to researchers are omega -3 fatty acids, which have certain nutritional benefits. Rajaram (2014) reported that α -linolenic acid, which is derived from plant origin, has the potential to reduce cardiovascular disease, fracture, and Type 2 diabetes. Table 2 shows the composition of omega 3 and omega 6 fatty acids from different seeds, including chia seeds.

Chia seeds have a substantial lipids amount

that is around 40% of the entire weight of chia seeds (Table 2). Carrillo et al. (2018) used a soxhlet method to extract oil from chia seeds and used a gas chromatography-mass selective detector (GC-MSD) to profile fatty acid. Carrillo et al. (2018) reported the composition of omega 3 as 54.08%, the content of omega 6 as 18.69%, and omega 9 as 10.24%. All are from the total fats that are present in chia seeds. Coelho and Salas-Mellado (2014) used acid hydrolysis to extract oil from chia seeds and used gas chromatography (GC) to profile fatty acids.

The high content of PUFAs, primarily linolenic acid and linoleic acid, in chia seeds, has attracted the attention of many researchers. Chia seeds contain a prodigious amount of PUFAs, primarily linolenic acid and linoleic acid (Enes et al., 2020a; Ghafoor et al., 2020) which are beneficial to the human-health. The fatty acids found in chia seeds also contain several phenolic compounds,

antioxidants that play a significant role in human health (Oliveira-Alves et al., 2017). In recent healthy diet trends, the consumption of unsaturated oils has increased because of an increase in the number of non-communicable diseases like cardiovascular diseases and hypertension, and because of people's consciousness about health. Subsequently, physicochemical characteristics and the nutritional composition of chia seeds influenced the use of the seeds to enhance human health (Coates 2011; Ixtaina et al., 2011).

Ullah et al. (2016) reported a high intake of α -linolenic acid by humans reduces the risk of heart failure. This may be due to the anti-inflammatory, anti-thrombotic and anti-arrhythmic role that chia seeds, as a natural source of omega 3 and 6 fatty acids, play (Oliveira-Alves et al., 2017; Arredondo-Mendoza et al., 2020). A study conducted by Koh et al. (2015) showed that increased intake of

Table 3. Essential amino acid composition of chia seeds (g per 100 g).

Country of origin	Amino acid	Quantity	Health/nutritional benefit	Source
Poland and Slovakia	Leucine	1.37- 1.42	Regulates blood sugar, promotes growth, and repairs muscles and bones. It is also responsible for wound healing.	Nitrayová et al. (2014); Kulczyński et al. (2019)
Poland and Slovakia	Phenylalanine	1.02– 1.6	It plays a vital role in specific brain functions and the structure and function of other proteins and enzymes.	Nitrayová et al. (2014); Kulczyński et al. (2019)
Poland and Slovakia	Lysine	0.93- 0.97	Immunity functions of the body, energy production, collagen, and elastin, which support body tissues.	Nitrayová et al. (2014); Kulczyński et al. (2019)
Poland and Slovakia	Valine	0.79- 0.95	Responsible for muscle growth, regeneration, and energy productions	Nitrayová et al. (2014); Kulczyński et al. (2019)
Poland and Slovakia	Isoleucine	0.74- 0.80	Production of haemoglobin and energy regulations	Nitrayová et al. (2014); Kulczyński et al. (2019)
Poland and Slovakia	Threonine	0.54- 0.71	Responsible for healthy skin and teeth, fat metabolism and immune functions	Nitrayová et al. (2014); Kulczyński et al. (2019)
Poland and Slovakia	Methionine	0.59- 0.67	Health flexibility of skin and hair. It is responsible for tissue growth and facilitates the absorption of vital minerals.	Nitrayová et al. (2014); Kulczyński et al. (2019)
Poland and Slovakia	Histidine	0.53- 0.61	Acts as a protective barrier which surrounds nerve cells and facilitates growths	Nitrayová et al. (2014); Kulczyński et al. (2019)

omega 3 fatty acids from marine or plant sources by humans reduces the risk of cardiovascular diseases, which are among the most chronic non-communicable diseases in the world is facing at present. There are other sources of PUFA like flaxseed and marine products. These other sources have disadvantages or shortcomings which are associated with their usage like digestive problems and a fishy flavour (Tur et al., 2012).

Proteins composition of chia seeds

Knowledge of protein in any food compound is essential as proteins contribute to the physical and functional properties, which can also improve the sensory properties of food and, therefore, consumer acceptability (Otondi et al., 2020). Most food products, like cereals and grains, are

consumed after being subjected to any form of heat treatment. During this process, protein denaturation is likely to occur and contributes to the functional properties of a particular food item (Boye et al., 2017). Being the main building block in the human body for blood, bones, cartilage, muscles, and skin, protein must be sufficient in the human body for all these processes to take place. With a 20% protein content, chia seeds have the potential to correct and prevent protein-energy malnutrition. Ullah et al. (2016) noted that chia seeds do not have gluten in which gluten intolerance people can utilize the seeds so that they do not suffer from coeliac diseases. Chia seeds contain 18 out of 22 amino acids, of which 9 are essential which contribute significantly to human health (Ullah et al., 2016). Table 3 shows that chia seeds contain the following essential amino acids: phenylalanine, valine, threonine, tryptophan, methionine, leucine, isoleucine, lysine,

and histidine.

The consumption of foods that are rich in protein contributes to weight loss because of the reduction of fat in the body (Ullah et al., 2016). The protein content of chia seeds was reported to be in the range of 15-26% (Table 1), oats (15.3%), wheat (14%), corn (14%), barley (9.2%) and rice (8.5%) (Coates, 2011). These variations are justified by different seed sources due to geographical, agronomic, and environmental conditions. However, the level of protein in chia seeds is still significantly higher than that of other kinds of grain (Ullah et al., 2016).

Carbohydrates and dietary fibre

Among the nutritional contents of chia seeds are carbohydrates and fibre. The nutritional benefits of dietary fibre include the regulation of bowel health.

Table 4. The micronutrient composition of chia seeds (g per 100 g).

Country of origin	Micronutrient	Quantity	Nutritional benefit	Sources
Poland and the USA	Niacin – B ₃ (mg)	8.83	Healthy skin, blood cells, brain and nervous system	Jin et al. (2012); Kulczyński et al. (2019)
Poland and the USA	Ascorbic acid – C (mg)	1.6	Improve immune system, building connective tissues, antioxidant	Jin et al. (2012); Kulczyński et al. (2019)
Poland and the USA	Thiamine - B ₁ (mg)	0.62	Healthy hair, brain and skin as well as important for nerve function.	Jin et al. (2012); Kulczyński et al. (2019)
Poland and the USA	Phosphorus (mg)	860 - 919	Protect bones and teeth. It helps shuttle nutrients into and out of cells	Jin et al. (2012); Kulczyński et al. (2019)
Poland and the USA	Calcium (mg)	456 - 631	Builds and protects bones and teeth. Assist nerve impulse transmission, muscle relaxation and contraction, as well as blood clotting. Enzyme activation and hormone secretion. Helps maintain healthy blood pressure	Jin et al. (2012); Kulczyński et al. (2019)
Poland and the USA	Potassium (mg)	407 - 726	Balances blood fluids	Jin et al. (2012); Kulczyński et al. (2019)
Poland and the USA	Magnesium (mg)	335 - 449	Chemical reactions in the bodywork with calcium.	Jin et al. (2012); Kulczyński et al. (2019)
Poland and the USA	Iron (mg)	7.72 – 9.18	Blood production and the making of amino acids, collagen, neurotransmitters, and hormones	Jin et al. (2012); Kulczyński et al. (2019)
Poland and the USA	Zinc (mg)	4.58 – 6.47	Enhance the immune system, sense of taste and smell, and wound healing	Jin et al. (2012); Kulczyński et al. (2019)

There are two types of carbohydrates in chia seeds, namely dietary fibre and starch. Dietary fibre (DF) can be classified into soluble DF (such as, gums, pectins, mucilages, and algal polysaccharides), insoluble DF (such as, cellulose and hemi-celluloses),/mixed (such as bran), fermentable and non-fermentable DF (Coelho and Salas-Mellado 2014; Fernandes and de las Mercedes Salas-Mellado 2017; Suri et al., 2016). Soluble dietary fibre absorbs water, turning it into gel-like, highly hydrated masses that are almost entirely fermented in the colon by microorganisms. The main purpose of the dietary-fibre in the human body is to retain healthy digestive system in the human body (Capitani et al., 2012).

It has been reported that the high content of gum and mucilage in chia seeds is a potential means of application in the food industry (Fernandes and de las Mercedes Salas-Mellado

2017; Suri et al., 2016; Coelho and Salas-Mellado 2014) reported that chia seeds contain 5-6% mucilage which can be used as dietary fibre. Muñoz et al. (2012) noted that chia seeds can form a gelatinous mass when soaked in water. This is due to the occurrence of a large amount of mucilages and gums, which make the seeds strongly hydrophilic and thus capable of absorbing several times their weight in liquids such as water that can absorb up to 12 times its weight (Attalla and El-Hussieny, 2017). The mucilage can be extracted from chia seeds and hydrated to archive water retention of 27 times its weight in water. This property makes chia seeds a functional ingredient that can be used in the food industry as, for example, a thickener and stabilizer. Because of this property, chia also improves the function of the digestive system and helps to improve the health of the guts through a

prolonged time of gastro-intestinal (Anderson et al., 2009; Suri et al., 2016).

MICRONUTRIENT COMPOSITION OF CHIA SEEDS

There are different vitamins needed by the human body in different quantities for various metabolic purposes. The human body as vitamin D, can synthesize other vitamins obtained from an additional food source like vitamin C. Researchers have shown that chia seeds consist of some vitamins and minerals (Suri et al., 2016; Ullah et al., 2016). The minerals found in chia seeds are calcium, phosphorus, potassium, iron, zinc, and magnesium. The vitamins found in chia seeds are thiamine, riboflavin, niacin, folic acid, ascorbic acid, and vitamin A (Suri et al., 2016). Table 4

shows the micronutrient composition of chia seeds, as well as their quantities and nutritional benefits.

Muñoz et al. (2012) noted that chia seeds are richer in niacin than in other cereals like corn, soybean, and rice. Vitamin B1 and vitamin B3 are similar to corn and rice, but chia seeds have six times more calcium, eleven times more phosphorus, and four times more potassium than milk, which is only 100 g (Muñoz et al., 2012; Suri et al., 2016).

CHIA SEEDS AS A NATURAL FUNCTIONAL FOOD

In its unchanged or changed form, chia seed is a functional food (Marcinek and Krejpcio, 2017). An unchanged natural food is a food that has not undergone human interference to improve its nutritional/health benefits. Functional foods are foods that offer additional nutrition and health benefits and can perform three functions. Their primary function is a particular food's nutritional value. Furthermore, their secondary functions are the food's sensory appeal, sensory satisfaction, or organoleptic properties. The tertiary function refers to the food's physiological aspects, such as neutralizing harmful substrates, regulation of body functions and physical conditions, prevention of diseases related to nutrition, and elevation of the mental and physical health of people (Yao et al., 2012).

There is no specific meaning of the functional food concept, which has been proposed. However, the /Functional Food Institute in Dallas or/ Functional Food Centre describes functional foods as "*processed or natural foods that comprise of unknown or known compounds which are biologically-active; which, is defined in non-toxic and effective amounts, that can deliver a documented and clinically proven health-benefit for the treatment, management and prevention of diseases that are chronic*" (Martirosyan and Singh, 2015). The Institute of Food Technology (IFT) considers the term "functional food" as evolving, and it uses it to refer to foods and food components that provide health benefits besides basic nutrition. Functional foods offer important nutrients, usually beyond quantities needed for usual maintenance, development and growth of other biologically active components and/or the target population desirable to provide required physiological effects or health-benefits (Rajaram, 2014). Functional foods can also be beneficial in increasing the number of nutrients by providing particular dietary food components that intensify their palatability and availability (Ullah et al., 2016).

More research should be directed on the provision of functional foods through either enriched or fortified food with the use of natural sources like chia seeds so as to come up with a new formulation of known concentration and reported therapeutic benefits expected. The expected processing conditions and the possible chemical and

biological changes during food preparation, as well as food bioavailability and its bio-accessibility after its consumption was established.

Phytochemicals in chia seeds

The phytochemical compounds that have been detected in chia seeds include carotenoids, sterols tocopherols, and phenolic compounds, including quercetin, myricetin, caffeic acid kaempferol and chlorogenic (Capitani et al., 2012; Oliveira-Alves et al., 2017). The phytochemicals, either alone or in combination with others, have the therapeutic potential to cure various ailments (Marcinek and Krejpcio, 2017). Epidemiological and animal studies suggest that dietary intake of phytochemicals may have certain health benefits and protect people against human chronic degenerative disorders such as neuro-degenerative diseases, cancer, cardiovascular diseases, kidney diseases, and as well as diabetes (Tokuşoğlu and Hall III, 2011). Majority of foods, such as whole grains, legumes, fruits, vegetables, and herbs, contain phytochemicals (Tokuşoğlu and Hall III, 2011). Tables 5 and 6 shows nutritional bioactive compounds and antioxidant compounds in chia seeds, as reported by various researchers.

Functional properties of chia seeds

Besides considering the nutritional quality of new food products, consumers have expressed a need to have more knowledge of the functional properties and nutritional quality of the food-products (Limsangouan et al., 2010). The functional properties of any food item shows how their starch, protein, and lipids in it behave during the processing of that particular food item and their effects on the final food product in relation to properties of an organoleptic (smell, appearance, texture and taste). The behaviour of these nutrients is essential in relation to technological and dietary formulation in developing novel functional foods (Brennan et al., 2016).

Food items in flour form, common functional properties that describe how ingredients behave during preparation and cooking are emulsion stability, bulk density and least-gelation concentration, swelling capacity, foam stability, gelatinization temperature, oil absorption capacity, foam capacity, emulsion activity and water absorption capacity. Olivos-Lugo et al. (2010) reported the protein functional properties such as foaming and gelling, oil holding capacity and water holding capacity, are from chia seeds. It was observed that the protein from chia seeds has good water holding capacity and excellent oil retention capacity, which makes chia a useful ingredient in products from the bakery.

Segura-Campos et al. (2014) reported a study

Table 5. Nutritional bioactive compounds in chia seeds.

Phytochemical	Nutraceutical value (Health benefit)	Source
Linolenic acid	Cancer preventive, reduce the risk of coronary heart Disease, Coronary Heart Disease, Bone Health, Immune Response Disorders, Weight Gain, Stroke Prevention, Mental Health, Cancer and Visual Acuity	Koh et al. (2015) McClements et al. (2009)
Linoleic acid	It helps the body to build muscle rather than store fat and has anti-inflammatory properties. It also prohibits cancer.	Martínez-Cruz and Paredes-López, (2014)
Tocopherols	Contributes to the antioxidant's composition of chia seeds, which helps to reduce inflammation, promoting anti-cancer cells, anti-ageing, and other antioxidant activities in the stabilization of cell membranes.	Marcinek and Krejpcio, (2017)
Sterols	Plant sterols are effective in inhibiting cholesterol incorporation into mixed micelles, which is an essential step at the intestinal-epithelium for the absorption of cholesterol.	Tokuşoğlu and Hall III, (2011)
Carotenoids	Cancer, Coronary Heart Disease, Macular Degeneration, and Cataracts	Maruyama et al. (2014)
Glutamic acid	Proper brain functioning	Olivos-Lugo et al. (2010)
Dietary-fibre	Treating and preventing diseases of the circulatory and digestive systems, kidney stones, diabetes, haemorrhoids colorectal cancer and disorder in the metabolic system	Valdivia-López and Tecante (2015)
Phenolic compounds	Protective role against cardiovascular illness, cancer, and diabetes; Antioxidant protectants for human beings and play a beneficial role in reducing the risk of hypertension, diabetes, coronary heart disease, and some types of cancer.	Oliveira-Alves et al. (2017) Prakash and Sharma (2014)
Caffeic acid	Hypoglycemic activity, memory protective effect Anti-carcinogenic, antihypertensive, neuron protective effects and antioxidant activity	Oliveira-Alves et al. (2017) Enes et al. (2020b)
Rosmarinic Quercetin	The immuno-regulatory function that includes antimicrobial, antioxidant and anti-inflammatory activities and antidiabetic effect. A potent antioxidant, anti-inflammatory, antibacterial, antiviral, anti-hepatotoxic, reduces LDL oxidation, vasodilator and blood thinner	Oliveira-Alves et al. (2017) Prakash and Sharma (2014)
Myricetin	Exhibits antibacterial activity and has anti-gonadotropic activity	Prakash and Sharma (2014)
Kaempferol	Antimicrobial Antioxidant, anti-cancer, cardioprotective, anti-inflammatory, antidiabetic, anti-osteoporotic, anxiolytic, neuroprotective, anti-estrogenic/estrogenic, analgesic, and anti-allergic activities Reduction in hot flushes and menopausal symptoms	Prakash and Sharma (2014)
Protocatechuic acid	Antioxidant properties, anti-inflammatory, anti-hyperglycaemic, and antimicrobial effects against gram-positive and harmful bacteria and fungi.	Semaming et al. (2015)
Gallic acid	Cytotoxic and anti-oxidative activities, antileukemic, antioxidant, anti-cancer, antineoplastic, anti-inflammatory, antidiabetic	Prakash and Sharma (2014)
Chlorogenic acid	Anti-carcinogenic, antihypertensive, neuron protective effects; Antioxidant activity that can reduce the production of free radicals in the body, inhibit peroxidation of fats.	Oliveira-Alves et al. (2017) Alagawany et al. (2020)

Table 6. Composition of antioxidant compounds in chia seeds (mg/g).

Country of origin	Polyphenol	Chlorogenic acid	Caffeic acid	Quercetin	Kaempferol	Source
Mexico	0.51-0.88	0.046-0.102	0.003-0.007	0.15-0.27	0.36-0.51	Reyes-Caudillo et al. (2008)
Bolivia, Ecuador and Paraguay	0.91-0.98	0.214-0.235	0.141-0.156	0.006	0.024-0.025	Ayerza (2019)
Brazil, Mexico	0.64	0.005	0.02 - 0.03	0.1- 0.2	0.0002	Coelho and Salas-Mellado (2014); Martínez-Cruz and Paredes-López (2014)

concerning the functional properties such as water absorption, oil holding capacity and water holding capacity of the chia-seed gum, which they confirmed that good functional and physicochemical properties of chia-seed gum could be useful in food industries. Most of the studies on the functional properties of chia seeds have been conducted on specific items like the amount of protein in the seeds, the gum and mucilage (Iglesias-Puig and Haros 2013; Olivos-Lugo et al., 2010; Pizarro et al., 2013; Segura-Campos et al., 2014; Zettel et al., 2015).

Uses of chia seeds in the food industry

Chia seeds because of the various nutritional properties, multiple studies have been conducted for different purposes, including their composition, characterization of the compounds, application in the food industry as well as usage in cosmetic industries (Iglesias-Puig and Haros 2013; Many and Sarasvathi 2016; Olivos-Lugo et al., 2010; Pizarro et al., 2013; Segura-Campos et al., 2014; Zettel et al., 2015).

The high content of gum and mucilage in chia seeds makes the seeds potentially useful in the food industry (Fernandes and de las Mercedes Salas-Mellado 2017; Suri et al., 2016). The seeds are mostly used in the baking industry. This is because of the higher amount of carbohydrates in

the baked products compared to other nutrients which are essential (Romankiewicz et al., 2017). Among the products in which chia seeds have been included are bread, pasta, biscuits, and cakes. Chia seeds can also be used in beverages, snacks, and other products (Coelho and Salas-Mellado, 2014; Steffolani et al., 2014).

Also, among the products which have been fortified with chia seeds is wheat bread (Romankiewicz et al., 2017). The presence of bioactive compounds in chia seeds has contributed significantly to the formulation of various functional foods (Bresson et al., 2009). However, the addition of chia seeds to original products made the products have characteristics different from their original characteristics. (Zettel et al., 2015) analyzed the effects of chia on the production of wheat bread and noted a reduction in bread firmness. Coelho and Salas-Mellado (2014) noted that breadcrumbs incorporated with whole chia seeds were softer than chia flour. Romankiewicz et al. (2017) added 4 to 6% of chia seeds to wheat flour during the baking of bread and noted a reduction in the amount of the bread obtained. In addition, 6 to 8% chia seeds to wheat flour reduced baking loss because the high content of dietary fibre in chia combines with water and prevents evaporation during bread baking. This indicates that when chia seeds are incorporated into flour products, they might influence the swelling capacity and water-holding

capacity of the products. Iglesias-Puig and Haros (2013) noted dark colour in the bread baked into which chia seeds had been incorporated because of phenolic compounds.

Fortification of foods with chia seeds

Subsequently chia seeds are rich of omega-3 fatty acids, protein, fibre, vitamins, minerals, and phytochemicals, they can be used as nutritional additives in food, a nutritional supplement, and a base for beverages. According to Dary and Hurrell (2006), food fortification is the addition of one or more essential nutrients to food so as to reduce or prevent the deficiency of nutrient(s) in a given population (Dary and Hurrell, 2006). Food fortification is precisely stated as the addition of one/more components of another food item that is not naturally occurred to increase its nutritional/health benefits of the newly designed/formulated food product (Świeca et al., 2014). Food fortification is among the techniques commonly used in the development or formulation of functional foods.

There are two principal reasons for fortifying foodstuffs. The first reason is when legislation demands it through public health policy. Examples of this include fortification of baby foods, weight reduction products, and even national programs requiring the staple foods fortification for example

wheat flour, maize flour, and cooking oil, which is common in developing countries (Dary and Hurrell, 2006). The second reason for fortifying foods is market differentiation. The non-compulsory fortification of dairy products, breakfast cereals, and drinks has been effectively used to boost sales through enhanced nutritional claims (Dary and Hurrell, 2006). Certainly, fortified beverages and food products can decrease dietary deficiencies of which is resulting from a progressively reliance on processed food products and busy lifestyle that, without fortification, may be viewed as “empty calorie” products (Dary and Hurrell, 2006; Iwatani and Yamamoto, 2019; McClements et al., 2009; Tokuşoğlu and Hall III, 2011).

Boosting the bioavailability of chia seed phytochemicals using a food matrix design

Contrary to conventional practices, the composition and structure of foods are typically optimized to improve their quality characteristics such as mouth-feel, appearance, taste and texture. Foods have of late been intended to improve their nutritional profiles by plummeting the levels of the macronutrients. These are believed to have adverse health effects. Such effects are saturated fats, digestible carbohydrates, and salt. On the other way, such foods can be improved with other food components that are supposed to have health effects which are beneficial, for instance minerals, nutraceuticals vitamins or dietary fibre (McClements et al., 2009). Nevertheless, the potential advantages of a significant number of these nutraceuticals are not ideally comprehended, as a result of their comparatively low as well as adjustable oral bioavailability (McClements et al., 2015). Both the composition and structure of a food matrix can influence the bioavailability of co-ingested nutraceuticals (McClements et al., 2009; McClements et al., 2015).

Chia seeds have nutritional and nutraceutical benefits. They are a good source of material for the fortification of consumed cereals, roots, and tubers. Foods fortified with chia seeds improve people’s health, especially pregnant women, and children. Some of these deficiencies may result in irreversible effects like stunting for children, and congenital disabilities and death (Coelho and Salas-Mellado, 2014). However, more studies have to be conducted on different food products that are developed to produce functional foods and to confirm its quality characteristics of fortified foods (McClements et al., 2015; Yao et al., 2012).

Chia seeds as a vehicle for bioactive components in food products

Chia is a crucial ingredient for the development of

functional food products (Dinçoğlu and Yeşildemir, 2019). The bioactive components found in chia seeds may be used to fortify food, besides being used as a vehicle for increasing the number or amount of vital nutrient intake (Coelho and Salas-Mellado, 2014). The formulation of new functional foods with the incorporation of chia seeds is a promising and innovative way of protecting and delivering omega-3 fatty acids into a range of food products (Garg et al., 2006; Geelen et al., 2004; Koh et al., 2015).

Considerations to ensure the number of bioactive compounds present in commercial food products are satisfactory

Ideally, it is desirable to design chia-based functional food products that are stable in many different applications. Food ingredient manufacturers usually have functional food formulations designed for different food categories. Examples of common available functional foods already in the market include infant formula, bakery products, dairy, and liquid beverage, of which all have different requirements. There are various challenges relating to the final food formulation with regard to food standard regulations, shelf-life, and quantity of bioactive components present (McClements et al., 2015; Ottaway, 2008). Some of the critical issues that must be considered so that there are enough chia bioactive components in commercial food products include the following:

(i) *Compliance with regulatory standards* – availability of product standards from regulatory bodies to ensure that the ingredients chosen as nutraceutical-rich (health-promoting) foods are approved for usage in each country where a given product will be marketed or sold. This step will minimize the time for seeking regulatory approval when the final product is ready to go into the market (Dary and Hurrell, 2006; Ottaway, 2008).

(ii) *Definition of a final product application to ensure a uniform product – dry blending with other food powders* – it is necessary for the nutraceutical-rich (health-promoting) food ingredient like powder before usage in combination with other food items, to be matched in terms of physical and functional properties like water activity, bulk density, and particle size to achieve the homogeneous end product. Also, to avoid possible physical separation during the transportation, storage, or use of a newly formulated food product. For liquid products, the rehydration and re-dispersion behaviour of the powder is vital if a powder format is chosen (Dary and Hurrell, 2006; Ottaway, 2008).

(iii) *Understanding of the protection and release*

requirements during processing – Knowledge and understanding of the processing steps and the unit operations involved in manufacturing the final food product is important to be able to design functional food properties in such a way that the core is protected during the process and released at the desired time (Dary and Hurrell, 2006; Ottaway, 2008).

(iv) *Understanding how and where to add chia* – familiarity with the setup and layout of a food manufacturing plant is also required in order to identify the stage at which it is appropriate to add chia seeds to a food product (such as how and where chia seeds should be added), without any other process modification (McClements et al., 2015).

(v) *Understanding possible interactions with other ingredients* – when the new nutraceutical-rich food ingredient is added to a food product, the final food product properties, including sensory and physical properties, as well as the shelf life of the food may be affected by possible ingredient interactions. Sometimes these interactions may be minimized by making minor modifications to the process or formulation. However, sometimes even small changes cannot be made because of some limitations in the plant's layout/setup or further modifications could add significant capital investment (Majeed et al., 2013; McClements et al., 2015).

(vi) *“Working in partnership”* – all stakeholders or corresponding partners in the value chain should be aware of what is going on and, therefore, work together to ensure that the final product is of good or high quality (Dary and Hurrell 2006; Ottaway, 2008).

CONCLUSION

Chia seeds richness is due to its high composition of protein (15-25%), fats (15-35%), fat (15-35%), ash (4-6%) and presence of minerals, vitamins, phytochemicals and antioxidants. The nutritional composition of chia seeds varies because of their geographical origins and climatic and environmental conditions. Characterization of chia seeds grown in different locations is crucial before the development of any new food product, and for food fortification or enrichment purposes using other local food products and chia seeds. This review recommends usage of chia seeds on its natural form or in combination with other less dense food products. During the development of new functional foods with the incorporation of chia seeds, consideration of the physical and functional properties of the new food product to be developed is essential. Emphasis on product's attributes like shelf life, usability and consumer acceptability not affected as compared to those of the original product (unfortified product). A systematic approach is important during

product formulation for different food products so that the nutrients needed (recommended dietary intake – RDI) do not negatively affect the acceptability of products. The functional foods to be developed should have supported scientific evidence for the availability of nutritional and health benefits to ensure that they are not lost in the food chain before the food is consumed.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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