Chia seeds products: an overview

Article *in* Phytochemistry Reviews · May 2017

DOI: 10.1007/s11101-017-9511-7

CITATIONS
9

READS
5,208

3 authors:

Bruna de Falco
University of Naples Federico II
16 PUBLICATIONS **74** CITATIONS
SEE PROFILE

Mariana Amato
Università degli Studi della Basilicata
75 PUBLICATIONS **1,182** CITATIONS
SEE PROFILE

Virginia Lanzotti
University of Naples Federico II
165 PUBLICATIONS **3,900** CITATIONS
SEE PROFILE

Phytochem Rev (2017) 16:745–760
DOI 10.1007/s11101-017-9511-7

Chia seeds products: an overview

Bruna de Falco · Mariana Amato · Virginia Lanzotti

Received: 27 March 2017 / Accepted: 3 May 2017 / Published online: 9 May 2017

Abstract Chia, *Salvia hispanica* L., is a medicinal and dietary plant species used since ancient times by Mayan and Aztec. Its product is a dry indehiscent fruit which is commonly called seed. In recent times, there was an increasing attention and diffusion of the seeds of the plant for their health benefits and uses in cooking. In fact, seeds are a rich source of nutrients first of all the polyunsaturated omega-3 fatty acids that protect from inflammation, enhance cognitive performance and reduce the level of cholesterol. Seeds are also rich in polyphenols derived from caffeic acid that are antioxidant compounds protecting the body from free radicals, aging and cancer. In addition, carbohydrate based fibers, present at high concentration levels, are associated with reducing inflammation, lowering cholesterol and regulating bowel function. This review summarizes the current knowledge on the phytochemistry and pharmacological properties of the seeds of this plant, with special emphasis on the nutritional, and phytochemical analysis of the plant, including the recently developed metabolomic studies.

Keywords *Salvia hispanica* · Seeds · Phytochemical analysis · Nutritional value · Antioxidant activity · Industrial uses · Oil · Fiber · Mucilage

B. de Falco · V. Lanzotti (✉)
Dipartimento di Agraria, Università di Napoli "Federico II", Via Università 100, Portici, 80055 Naples, Italy
e-mail: lanzotti@unina.it

M. Amato
Scuola di Scienze Agrarie, Forestali, Alimentari ed Ambientali, Università della Basilicata, Viale dell'Ateneo Lucano 10, 85100 Potenza, Italy

Introduction

Salvia hispanica L. (Lamiaceae), also known as Chia, is an annual herbaceous plant, native of southern Mexico and northern Guatemala. The genus *Salvia* consists of ca 900 species (Ayerza and Coates 2005) and its name comes from the latin word "salvere", referring to the curative properties of the well known culinary and medicinal herb *Salvia officinalis* (Dweck 2005). Nowadays, some species are still used all over the world for their nutritional properties and their beneficial effect on human health. The species *S. hispanica* produces numerous dry indehiscent fruits which are commonly called seeds. These small white and dark seeds in pre-Columbian times, along with corn, beans and amaranth, were one of the basic foods in the diet of several Central American civilizations including Mayan and Aztec populations. The seeds had also been used like a tribute to the capital of Aztec Empire (Codex Mendoza 1542) and offered to Aztec gods (de Sahagun 1579). Due to its religious implications chia was banned under the rule of the European

conquerors and was re-discovered in the 1990s. Since then it has spread in Argentina, Australia, Bolivia, Colombia, Guatemala, Mexico and Peru and outside America, in Australia, Africa and Europe (Bochicchio et al. 2015). Chia is a macrothermal short-day flowering plant. This means that Chia needs to be sown in late spring and will not flower until late summer or fall at high latitudes; therefore, its chances of producing seed are low since grain filling is hampered by frost (Ayerza and Coates 2005). As there was no source of natural long day Chia available, Jamboonsri et al. (2012) developed early flowering Chia germplasm by genetic mutations. The metabolomic profile of four Chia seeds early flowering genotype, G3, G8, G17, W13.1, was studied by de Falco et al. (2017) and compared to the profile of commercial black and white seeds by ^{1}H NMR spectroscopy coupled with multivariate data analysis. Results showed that W13.1 has the highest content of many bioactive compounds, such as sucrose, raffinose, flavonoids genistein and quercetin, as well as the caffeoyl derivatives caffeic, chlorogenic and rosmarinic acids. The relative content of the identified amino acids was significantly lowest in the G3 and highest in G17 which also showed the highest content of saturated and unsaturated fatty acids. Chia seeds commercialized today have a coat colour ranges from black and black spotted to white. Ayerza (2013a) showed that there is no difference in the chemical composition between two genotypes Tzotzol and Iztac, which produce black-spotted and white seeds, respectively. Chia seeds is also used to increase the ω-3 fatty acid content of animal products like eggs, poultry and rabbit (Peiretti and Meineri 2008). Several classes of secondary metabolites belong to the sage seeds such as flavonoids and their glycosides, polyphenols, which are mainly composed by caffeic acid building block, anthocyanins and proanthocyanidins. Fiber is one important component of Chia seeds studied for its insoluble and soluble fraction that can be used as foam stabiliser, suspending agent and emulsifier for food and pharmaceutical purpose due to its physical properties (Reyes-Caudillo et al. 2008) including water holding capacity and viscosity (Vázquez-Ovando et al. 2009). However, the chemical composition and the amount of each class of compounds in Chia seeds vary depending on several factors including genetic modifications, environmental conditions and agricultural practices.

Chemical composition

Chia seeds have a very important role as functional food and nutritional supplement (Coelho et al. 2014). The composition and the concentration of their bioactive compounds depend on several factors: climatic conditions, geographical origin and by the extraction methods (Ayerza and Coates 2004, 2009a, b, 2011; Capitani et al. 2012; Ixtaina et al. 2011). Seeds are composed by total dietary fiber from 47.1 to 59.8% (Weber et al. 1991) and contain up to 40% of oil with high content of unsaturated fatty acids, of which α-linolenic acid represents up to 68% (Ayerza 1995; Taga et al. 1984). Moreover, they are a good source of proteins (19.0–26.5%), dietary fiber, vitamins, minerals and antioxidants (Bushway et al. 1981). These data capture the attention of researchers because in the last few years there was an increasing interest in all of these compounds (Capitani et al. 2012; Ayerza and Coates 2004, 2011). Furthermore, Chia seeds do not contains toxic compounds and gluten, thus making seeds a safe ingredient also for gluten free diets (Menga et al. 2017).

Caffeic acid derivatives

Caffeic acid plays an important role from both chemical and biological point of view in Chia seeds extract. This phenolic acid, composed by a dihydroxyphenyl group linked with acrylic acid, represents the molecular skeleton of several metabolites in the Lamiaceae family. Caffeic acid, also classified as hydroxycinnamic acid, can be bound to quinic acid in different positions to give rise to a class of metabolites named caffeoylquinic acids, of which chlorogenic acid is the most abundant in the polar extract of Chia seeds (Martínez-Cruz and Paredes-López et al. 2014). Moreover, in the metabolome of Chia seeds, are presents monomers of caffeic acid building block but also condensation products such as polymers (Table 1). Monomeric derivatives including caffeic acid itself and ferulic acid have been isolated from Chia seeds (Ixtlahuacán, Colima, Mexico) by ultra-high performance liquid chromatography (UHPLC) (Martínez-Cruz and Paredes-López et al. 2014). The authors found a concentration of caffeic acid (0.0274 mg/g) higher than that reported for mango (0.0077 mg/g), papaya (0.0159 mg/g) and blueberry (0.0216 mg/g), but lower than that reported for peach

Table 1 Caffeic acids derivatives and flavonoids from *Salvia hispanica* seeds

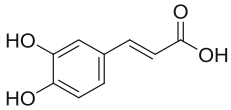
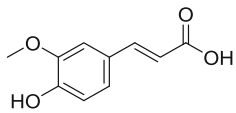
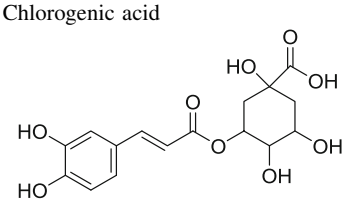
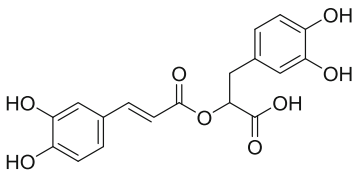
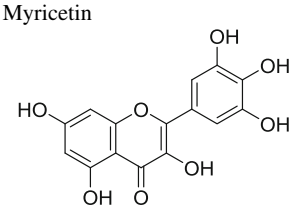
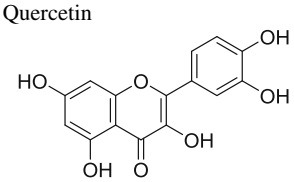
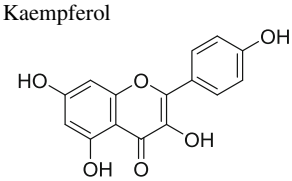
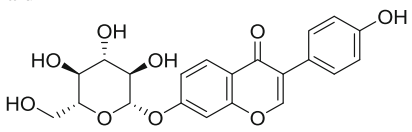
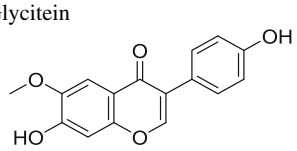
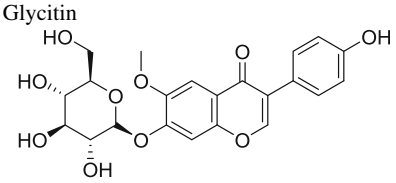
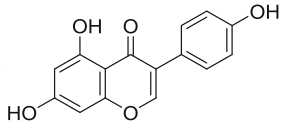
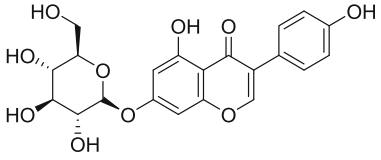
Chemical constituent	Quantification	Origin	Analytical technique	References
Caffeic acids derivatives				
Caffeic acid 	0.0274 mg/g	Chionacalyx (Mexico)	UHPLC	Martínez-Cruz and Paredes-López et al. (2014)
	0.139–0.149 mg/g	Tzotzol and Iztac (Ecuador)	HPLC	Ayerza (2013b)
	0.003–0.006 mg/g	Jalisco and Sinaloa (Mexico)	HPLC	Reyes-Caudillo et al. (2008)
	0.030 mg/g	l.m. (São Paulo, Brazil)	UPLC	Coelho et al. (2014)
	6.6×10^{-3} mol/kg	l.m. (West Lafayette, US)	TLC, GLC and UV	Taga et al. (1984)
Ferulic acid 	T	Chionacalyx (Mexico)	UHPLC	Martínez-Cruz and Paredes-López et al. (2014)
Chlorogenic acid 	0.226–0.218 mg/g	Tzotzol and Iztac (Ecuador)	HPLC	Ayerza (2013b)
	0.102–0.045 mg/g	Jalisco and Sinaloa (Mexico)	HPLC	Reyes-Caudillo et al. (2008)
	0.004 mg/g	l.m. (São Paulo, Brazil)	UPLC	Coelho et al. (2014)
Rosmarinic acid 	0.9267 mg/g	Chionacalyx (Mexico)	UHPLC	Martínez-Cruz and Paredes-López et al. (2014)
Flavonoids				
Myricetin 	3.1×10^{-3} mol/kg	l.m. (West Lafayette, US)	TLC, GLC and UV	Taga et al. (1984)
	0.115–0.121 mg/g	Tzotzol and Iztac (Ecuador)	HPLC	Ayerza (2013b)
Quercetin 	0.2×10^{-3} mol/kg	l.m. (West Lafayette, US)	TLC, GLC and UV	Taga et al. (1984)
	0.150–0.268 mg/g	Jalisco and Sinaloa (Mexico)	HPLC	Reyes-Caudillo et al. (2008)
	0.007–0.006 mg/g	Tzotzol and Iztac (Ecuador)	HPLC	Ayerza (2013b)
	0.17 μg/g	l.m. (São Paulo, Brazil)	UPLC	Coelho et al. (2014)

Table 1 continued

Chemical constituent	Quantification	Origin	Analytical technique	References
Kaempferol 	1.1×10^{-3} mol/kg	l.m. (West Lafayette, US)	TLC, GLC and UV	Taga et al. (1984)
	0.360–0.509 mg/g	Jalisco and Sinaloa (Mexico)	HPLC	Reyes-Caudillo et al. (2008)
	0.025–0.024 mg/g	Tzotzol and Iztac (Ecuador)	HPLC	Ayerza (2013b)
Daidzin 	0.006 mg/g	Chionacalyx (Mexico)	UHPLC	Martínez-Cruz and Paredes-López et al. (2014)
Glycitein 	0.0005 mg/g	Chionacalyx (Mexico)	UHPLC	Martínez-Cruz and Paredes-López et al. (2014)
Glycitin 	0.0014 mg/g	Chionacalyx (Mexico)	UHPLC	Martínez-Cruz and Paredes-López et al. (2014)
Genistein 	0.0051 mg/g	Chionacalyx (Mexico)	UHPLC	Martínez-Cruz and Paredes-López et al. (2014)
Genistin 	0.0034 mg/g	Chionacalyx (Mexico)	UHPLC	Martínez-Cruz and Paredes-López et al. (2014)

T traces, *l.m.* purchased from local market

(0.0371 mg/g) (Balasundram et al. 2006). Ayerza (2013a), after HPLC analysis, also reported the chlorogenic acid as the most abundant phenol (0.222 mg/g) followed by caffeic acid (0.144 mg/g). These results are in agreement with those reported by Reyes-Caudillo et al. (2008), who also analyzed Chia seeds from Mexico using by HPLC. Particularly, he found chlorogenic acid as the most abundant phenols followed by caffeic acid, but the concentrations are slightly lower (0.102 and 0.003 mg/g respectively) if compared to Ayerza results. On the contrary, Coelho et al. (2014) showed a high content of caffeic acid among phenols. Caffeic acid dimers are also frequent in Chia samples and among them rosmarinic acid is the most abundant one. Martínez-Cruz and Paredes-López et al. (2014) also reported the rosmarinic acid as the major phenolic compound of Chia seeds (0.9267 mg/g). Several biological activities have been described for rosmarinic acid such as antioxidant, astringent, anti-inflammatory, antithrombotic, antimutagen, antibacterial and antiviral (Huang and Zhang, 1991; Parnham and Kesselring 1985; Zou et al. 1992). Looking at the details, trimers and tetramers of caffeic acid building block, including salvianolic acid A–K

Table 2 Chemical constituents from Oil of chia seeds

Chemical constituent	Quantification (%)	Origin	Analytical technique	References
Polyunsaturated fatty acids				
Arachidonic acid (C20:4)	0.13	l.m. (Yucatan, Mexico)	GC–MS	Segura-Campos et al. (2014a)
Eicosatrienoic acid (C20:3)	0.01	l.m. (Yucatan, Mexico)	GC–MS	Segura-Campos et al. (2014a)
	0.03	l.m. (São Paulo, Brazil)	GC	Coelho et al. (2014)
α-linolenic acid (C18:3)	62.02	l.m. (São Paulo, Brazil)	GC	Coelho et al. (2014)
	64.5 and 63.3	Tzotzol and Iztac (Ecuador)	HPLC	Ayerza (2013b)
	57.71 and 58.39	Peru and Australia	HPLC–MS	Amato et al. (2015)
	68.52	l.m. (Yucatan, Mexico)	GC–MS	Segura-Campos et al. (2014a)
	69.0	l.m. (West Lafayette, US)	GLC	Taga et al. (1984)
	62.80	l.m. (Santiago, Chile)	GC-EASI(+)-MS	da Silva Marineli et al. (2014)
	63.4	Catamarca (Argentina)	GLC	Ayerza (1995)
	62.7			
	62.4			
	52.0			
	60.7			
	63.20	Northwestern Argentina	GLC	Ayerza and Coates (2004)
	57.50			
	58.55			
	54.20			
	62.00			
	62.20			
	61.65			
	64.20			
	64.5 and 66.7	Argentina and Guatemala	Pressing and solvent extract, GC	Ixtaina et al. (2011)
	65.6 and 69.3			
Linoleic acid (C18:2)	17.5 and 18.4	Tzotzol and Iztac	HPLC	Ayerza (2013b)
	18.82 and 20.74	Peru and Australia	HPLC–MS	Amato et al. (2015)
	17.36	l.m. (São Paulo, Brazil)	GC	Coelho et al. (2014)
	15.3	l.m. (West Lafayette, US)	GLC	Taga et al. (1984)
	20.40	l.m. (Yucatan, Mexico)	GC–MS	Segura-Campos et al. (2014a)
	18.23	l.m. (Santiago, Chile)	GC-EASI(+)-MS	da Silva Marineli et al. (2014)
	19.8	Catamarca (Argentina)	GLC	Ayerza (1995)
	20.2			
	20.8			
	20.3			
	20.3			
	18.00	Northwestern Argentina	GLC	Ayerza and Coates (2004)

Table 2 continued

Chemical constituent	Quantification (%)	Origin	Analytical technique	References
	19.25			
	19.10			
	20.50			
	20.30			
	20.10			
	21.05			
	18.35			
	20.3 and 17.5	Argentina and Guatemala	Pressing and solvent extract, GC	Ixtaina et al. (2011)
	19.7 and 16.6			
Monounsaturated fatty acids				
Oleic acid (C18:1)	6.65 and 6.8	Tzotzol and Iztac (Ecuador)	HPLC	Ayerza (2013b)
	10.55	l.m. (São Paulo, Brazil)	GC	Coelho et al. (2014)
	7.30 and 7.04	Peru and Australia	HPLC–MS	Amato et al. (2015)
	7.6	l.m. (West Lafayette, US)	GLC	Taga et al. (1984)
	2.43	l.m. (l.m. (Yucatan, Mexico)	GC–MS	Segura-Campos et al. (2014a)
	7.04	l.m. (Santiago, Chile)	GC-EASI(+)-MS	da Silva Marineli et al. (2014)
	7.3	Catamarca (Argentina)	GLC	Ayerza (1995)
	7.8			
	7.3			
	7.6			
	8.2			
	3.40	Northwestern Argentina	GLC	Ayerza and Coates (2004)
	3.50			
	10.30			
	13.25			
	7.15			
	6.75			
	6.85			
	6.90			
	5.4 and 5.5	Argentina and Guatemala	Pressing and solvent extract, GC	Ixtaina et al. (2011)
	5.3 and 5.8			
Palmitoleic acid (C16:1)	0.09	l.m. (São Paulo, Brazil)	GC	Coelho et al. (2014)
	T	l.m. (West Lafayette, US)	GLC	Taga et al. (1984)
	0.06	l.m. (l.m. (Yucatan, Mexico)	GC–MS	Segura-Campos et al. (2014a)
	0.08	l.m. (Santiago, Chile)	GC-EASI(+)-MS	da Silva Marineli et al. (2014)

Table 2 continued

Chemical constituent	Quantification (%)	Origin	Analytical technique	References
Saturated fatty acids				
Stearic acid (C18:0)	2.67	l.m. (São Paulo, Brazil)	GC	Coelho et al. (2014)
	3.65 and 4.1	Tzotzol and Iztac (Ecuador)	HPLC	Ayerza (2013b)
	2.99 and 3.19	Peru and Australia	HPLC–MS	Amato et al. (2015)
	2.9	l.m. (West Lafayette, US)	GLC	Taga et al. (1984)
	0.29	l.m. (l.m. (Yucatan, Mexico)	GC–MS	Segura-Campos et al. (2014a)
	3.36	l.m. (Santiago, Chile)	GC-EASI(+)-MS	da Silva Marineli et al. (2014)
	3.3	Catamarca (Argentina)	GLC	Ayerza (1995)
	3.1			
	3.1			
	3.1			
	3.7			
	3.40	Northwestern Argentina	GLC	Ayerza and Coates (2004)
	3.50			
	3.55			
	3.55			
	2.95			
	2.75			
	2.75			
	3.00			
	3.1 and 4.4	Argentina and Guatemala	Pressing and solvent extract, GC	Ixtaina et al. (2011)
	3.0 and 2.7			
Margaric acid (C17:0)	0.06	l.m. (São Paulo, Brazil)	GC	Coelho et al. (2014)
	0.07	l.m. (Santiago, Chile)	GC-EASI(+)-MS	da Silva Marineli et al. (2014)
Palmitic acid (C16:0)	12.32 and 10.17	Peru and Australia	HPLC–MS	Amato et al. (2015)
	5.2	l.m. (West Lafayette, US)	GLC	Taga et al. (1984)
	6.5 and 6.2	Tzotzol and Iztac (Ecuador)	GC	Ayerza (2013b)
	6.69	l.m. (São Paulo, Brazil)	GC	Coelho et al. (2014)
	7.47	l.m. (Yucatan, Mexico)	GC–MS	Segura-Campos et al. (2014a)
	7.07	l.m. (Santiago, Chile)	GC-EASI(+)-MS	da Silva Marineli et al. (2014)
	6.2	Catamarca (Argentina)	GLC	Ayerza (1995)
	6.3			
	6.4			
	7.1			
	6.9			
	7.25	Northwestern Argentina	GLC	Ayerza and Coates (2004)

Table 2 continued

Chemical constituent	Quantification (%)	Origin	Analytical technique	References
	7.65			
	7.60			
	7.65			
	6.55			
	7.40			
	6.95			
	7.15			
6.6 and 5.9 6.2 and 5.5	Argentina and Guatemala	Pressing and solvent extract, GC	Ixtaina et al. (2011)	
Pentadecanoic acid (C15:0)	0.05	l.m. (Santiago, Chile)	GC-EASI(+)-MS	da Silva Marineli et al. (2014)
	0.03	l.m. (São Paulo, Brazil)	GC	Coelho et al. (2014)
Myristic acid (C14:0)	0.07	l.m. (Santiago, Chile)	GC-EASI(+)-MS	da Silva Marineli et al. (2014)
	0.03	l.m. (São Paulo, Brazil)	GC	Coelho et al. (2014)
Tocopherols				
α-Tocopherol	7.53–7.46 mg/kg	Peru and Australia	HPLC	Amato et al. (2015)
δ-Tocopherol	12.99–13.45 mg/kg	Peru and Australia	HPLC	Amato et al. (2015)
γ-Tocopherol	457.38–489.52 mg/kg	Peru and Australia	HPLC	Amato et al. (2015)
	225 and 325 mg/kg 250 and 410 mg/kg	Argentina and Guatemala	Pressing and solvent extract, HPLC	Ixtaina et al. (2011)
Pigment				
Chlorophyll	1.80–2.40 mg/kg	Peru and Australia	spectrophotometry	Amato et al. (2015)

% of total fatty acids; mg/kg of oil chia seed

T trace, *l.m.* purchased from local market

and lithospermic acid, were reported from other *Salvia* species such as *S. miltiorrhiza*, *S. officinalis, S. cavaleriei*, *S. flava*, *S. chinensis* (Ai et al. 1994; Ai and Li 1992; Lu and Foo 1999, 2001; Zhang and Li 1994). However, from the best of our knowledge, there are no reports showing the presence of salvianolic and lithospermic acids in Chia seeds.

Flavonoids

Flavonoids, ubiquitous compounds present in plants, belong to a polyphenolic subclass having a fifteen-carbon skeleton which consist of two benzene rings (A and B) linked via a heterocyclic pyrane ring (C). They are the major responsible for color, taste and prevention of fat oxidation in food (Yao et al. 2004). Flavonoids have many biochemical activities such as antioxidant, hepatoprotective, antibacterial, anti-inflammatory, anticancer and antiviral (Critchfield et al. 1996; Cushnie and Lamb 2005; Li et al. 2000; Zandi et al. 2011; Zhu et al. 2012). They are widely distributed in Chia seeds and their synthesis increase as a result of microbial infection (Dixon et al. 1983). Taga et al. (1984) reported the presence of myrcetin, quercetin and kaempferol in methanolic hydrolyzed extracts of Chia seeds and evaluated their antioxidant activity (see below and Table 1). Reyes-Caudillo et al. (2008) also studied both hydrolyzed and crude extracts of Chia seeds obtained from two different regions of Mexico. They identified quercitin-phenolic glycosides and kaempferol–phenolic glycosides as the major components of the crude extract. After hydrolysis of the extract the authors quantified the free aglycon forms as quercitin 0.150 and 0.268 mg/g and kaempferol 0.360 mg/g e 0.509 mg/g in Jalisco and Sinaloa

seeds, respectively. On the contrary, Ayerza (2013a) reported myrcetin as the major flavonols in the Tzotzol and Iztac Chia seeds genotypes (0.115 and 0.121 mg/g respectively) followed by kaempferol and quercitin. Another research on Chia seeds var. Chionacalyx from Mexico was achieved by Martínez-Cruz and Paredes-López et al. (2014), who detected daidzin, glycitin, genistin, glycitein, and genistein as the major isoflavones in the phenolic extract. Daidzin was found at the concentration of 0.066 mg/g of sample. To note that recently Lowe et al. (2008) reported such compound at high concentration (4.685 mg/g) in Kudzu roots, *Pueraria lobate*, as naturally occurring anti-alcohol-addiction agent in complex with human mitochondrial aldehyde dehydrogenase.

Oil composition

Since ancient times oil extracted from Chia seeds has been used in the traditional medicine against eye infections and for the treatment of stomach disorders (Lu and Foo 2002; Reyes-Caudillo et al. 2008). Chia seeds oil ranges from 25 to 50% and contains high concentrations of polyunsaturated fatty acids (Bushway et al. 1981; Taga et al. 1984) (Table 2; Fig. 1). Research demonstrated that oil extracted from Chia seeds also contain several phenolic compounds such as tocopherols, phytosterols and carotenoids with their related antioxidant activity that play a very important role in the deterioration of the oil due to lipid oxidation (Matthaus 2002; Ixtaina et al. 2011). A consumption of 7.3 g of chia seed per day provides 100% of the recommended intake of omega-3 fatty acids, which help to prevent chronic diseases related to diet. It was widely demonstrated that in *S. hispanica* seeds ω-3 is the most abundant component among fatty acids, in particular, the content of α-linolenic acid (C18:3) is over than 50% of all fatty acids (Palma et al. 1947; Ayerza 1995, 2011; Segura-Campos et al. 2014a). Therefore, Chia seed can be considered as a natural source of ω-3 which play a very important role in human nutrition and in human health due to its anti-inflammatory, antiarrhythmic and antithrombotic activity (Garg et al. 2006; Geelen et al. 2004; Din et al. 2004; Wall et al. 2010). da Silva Marineli et al. (2014) characterized the Chia seed oil from Chile using the positive ion easy ambient sonic-spray ionization mass spectrometry (EASI MS) technique and reported ranks of fatty acids abundance in the following order: α-linolenic acid (62.8%), linoleic acid (18.23%), palmitic acid (7.07%), oleic acid (7.04%) and stearic acid (3.36%). These results are in agreement with those reported in other studies (Ayerza 1995; Ayerza and Coates 2004). Amato et al. (2015) reported the first data on the quality of Chia seeds produced in Europe, from an experiment conducted in Basilicata (South Italy), particularly the oil extracted from Italian Chia seeds was not significantly different from those grown in traditional area (Peru) and in a new area (Australia). However, the oil extracted in Italy was more rich in chlorophyll, carotenoids and α-linolenic acid but showed a higher

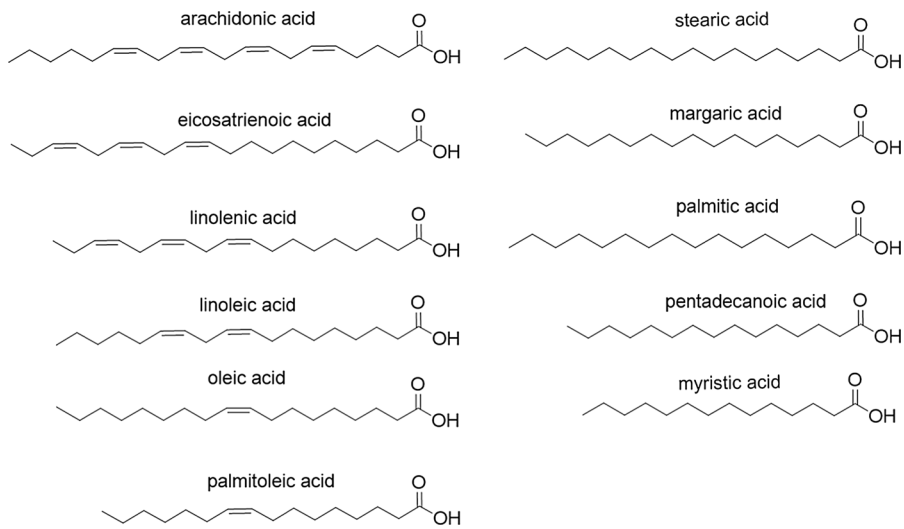


Fig. 1 Chemical structures of fatty acids from chia seeds

free acidity and peroxides. As mentioned previously, chemical composition and oil yield can be affected by several factors such as extraction technique and geographical area. For example, Ixtaina et al. (2011) used two extraction techniques to obtain oil from Chia seeds purchased from different source, Argentina and Guatemala. In both seeds, the oil yield was much lower in pressing than in solvent extraction (20.30 and 24.8% compared to 26.70 and 33.6%, respectively). This finding is in agreement with that reported by Dąbrowski et al. (2016), who also evaluated the influence of the extraction method on the composition of Chia seed oil. In fact, the recovery of oil was reported lower by pressing than by extraction methods.

Another important example is the study conducted on the effect of six different ecosystems of South America on the protein and oil contents, fatty acid composition and peroxide index of Chia seeds from Argentina (Ayerza and Coates 2004; Ayerza 2013b). The authors demonstrated that the chemical composition of the seeds is widely affected by the location and environmental factors such as temperature, light and soil type.

Storage proteins

Olivos-Lugo et al. (2010) determined the thermal, functional and nutritional properties of chia seeds proteins by differential scanning calorimetry, gelling, foaming, water-holding capacity and oil-holding capacity, amino-acid profile, chemical score and in vitro digestibility tests. They found the protein fraction composed by albumins (39 g/kg protein), globulins (70 g/kg protein), prolamins (538 g/kg protein) and glutelins (230 g/kg protein). Ayerza and Coates (2011) determined the total protein content of chia seeds grown at different altitudes as crude nitrogen composition by a standard micro-Kjeldahl method using a 5.71 conversion factor. They found a general decrease of protein content as the altitude of the seed grown location increased. On 2012 the seed storage proteins of chia seeds were studied by Sandoval-Oliveros and Paredes-López that reported the main protein fraction corresponding to globulins (52%). This fraction was showed to contain mostly 11S and 7S proteins whose molecular sizes ranged from 15 to 50 kDa and electrophoretic experiments, under native conditions, confirmed four bands of globulins in the range of 104–628 kDa. The denaturation temperatures of crude albumins, globulins, prolamins, and glutelins were 103, 105, 85.6, and 91 °C thus indicating a good thermal stability for albumins and globulins. Selected globulin peptides analyzed by mass spectrometry showed homology to sesame proteins. A good balance of essential amino acids was found in the seed flour and globulins, especially for methionine and cysteine (Sandoval-Oliveros and Paredes-López 2012).

Fibers

Chia seeds constitute a potential ingredient in food industry applications due to its dietary fiber content. Since the early 1950s, it was discovered the importance of the fibers for human health and nutrition. On 1953, Hipsley first coined the multiple term "dietary fiber". Later on, Trowell redefined the term as the remnants of plant components that are resistant to hydrolysis by human alimentary enzymes (Hipsley 1953; Trowell et al. 1976). Nowadays the definition is broader including not only the plant components but all the carbohydrate polymers with $\geq$10 monomeric units, which are not hydrolyzed by the endogenous enzymes in the small intestine of humans (Codex Alimentarius Commission 2009). Dietary fiber is a class of compounds including oligosaccharides and polysaccharides such as cellulose and hemicellulose that may be associated with other components (e.g., lignin, pectins, gums and mucilage). The total dietary fiber (TDF) has become an important component of the diet, especially for their physiological functionality based on the swelling property after water absorption, due to the presence of carbohydrates with free polar groups that interact with hydrophilic links within the matrix leading to formation of gel and consequent increase of peristalsis. Published reports indicate that many health benefits are associated to the intake of TDF. In fact, the fiber has prebiotic effect and it is active on coronary heart disease, stroke, hypertension, diabetes, obesity and gastrointestinal disorders (Lairon et al. 2005; Liu et al. 1999; Montonen et al. 2003; Petruzziello et al. 2006; Steffen et al. 2003; Whelton et al. 2005). Chia seed is a good source of TDF, which are composed by soluble dietary fiber (SDF) and insoluble dietary fiber (IDF). Particularly, the

SDF are partially expelled from the seed as mucilaginous gel when it comes in contact with water, and fermented in the colon (Anderson et al. 2009). On the contrary, IDF may only be fermented to a limited extent in the colon (Anderson et al. 2009). TDF in Chia seeds from Chile were analysed using enzymatic gravimetric AOAC method by da Silva Marineli et al. (2014) which reported higher amount of TDF (37.50 g/100 g) with predominant IDF (35.07 g/100 g), these findings agree with other reports (Capitani et al. 2012; Weber et al. 1991), but lower amount were reported by Ayerza (2013a) (TDF 24.56 g/100 g with IDF 14.35 g/100 g). The same analytical technique was used by Reyes-Caudillo et al. (2008), who characterized TDF in Jalisco and Sinaloa seeds (*S. hispanica* L.), particularly, the SDF and IDF content of Jalisco seeds were 6.84 and 34.9 g/100 g, respectively, while in Sinaloa seeds 6.16 and 32.87 g/100 g, respectively. The main component found in IDF was the Klason lignin, which plays an important role in the protection of unsaturated fats and it is responsible for the hypocholesterolemic activity associated with fiber intake (Tolba et al. 2011). The percentage of neutral sugars was also reported in both fractions, 13.79–14.97% and 4.69–5.12% for IDF and SDF, respectively. Highest amount of the insoluble fiber-rich fraction (FRF) was also detected in *S. hispanica* seeds from Mexico by Vázquez-Ovando et al. (2009). Particularly they evaluated the FRF obtained by dry processing of defatted flour of Chia seeds and reported 29.56 g/100 g of crude fiber content, 56.46 g/100 g of TDF content, of which 53.45 g/100 g was IDF and 3.01 g/100 g was SDF. Compared to other reports, these values clearly show that dry fractionation with 100 mesh effectively concentrated TDF content.

A part of the fiber in chia is located in the outer cells of the fruit and is partly extruded from the fruit surface upon hydration in the form of a clear mucilaginous capsule which adheres firmly to the fruit itself. Capitani et al. (2013) described this process using scanning electron microscopy (SEM) after 5, 10, 30 and 60 min after Chia seeds become wetted. Chia mucilage is part of the SDF (Ayerza and Coates 2001; Reyes-Caudillo et al. 2008) and in order to obtain high amount of mucilage, Muñoz et al. (2012a) performed the extraction with different seeds/distilled water ratio, pH and temperature condition. An optimum yield value (7%) was achieved at 80 °C with pH = 8 and seed/water ratio of 1:40. Chia seed gum (CSG) is mainly composed by sugars as xylose, glucose, arabinose, galactose, glucuronic and galacturonic acids, but little is known about the whole chemical structure of mucilage (Timilsena et al. 2016). From the best of our knowledge, the only tentative structural identification of mucilage was proposed by Lin et al. (1994), who obtained β-D-xylose, α-D-glucose and 4-*O*-methyl-α-D-glucuronic acids by acid hydrolysis and characterized a tetrasaccharide with 4-*O*- methyl -α-D-glucoronopyranosyl residues occurring as branches of β-D-xylopyranosyl on the main chain using by mass spectrometry and ^{13}C NMR spectroscopy.

Total polyphenolic content and their antioxidant activity

Chia seeds and oil contain a large number of natural antioxidant such as tocopherols, phytosterols, carotenoids (Álvarez-Chávez et al. 2008), polyphenolic compounds which are mainly constructed from the caffeic acid building block and flavonoids, including the flavones myricetin, quercetin and kaempferol. This class of compounds is the main responsible for the antioxidant activity of Chia seeds due to their ability to scavenge free-radicals, to chelate metal ions and to donate hydrogens. In particular, the B ring of flavones is the major responsible of ROS and RNS scavenging activity because the transfer of a hydrogen and an electron to hydroxyl, peroxyl, and peroxynitrite radicals, that stabilize them giving rise to a relatively stable flavonoid radical (Cao et al. 1997). Antioxidant compounds reduce the risk of chronic diseases including cancer and heart disease, they offer protection against some disorders such atherosclerosis, stroke, diabetes and neurodegenerative diseases such as Alzheimer and Parkinson (Vuksan et al. 2007; Wu et al. 1998; Yagi et al. 1989; Zhao et al. 1996). The highest amount of total polyphenol was found by Martínez-Cruz and Paredes-López et al. (2014) (1.6398 ± 0.2081 mg GAE/g of Chia seed, *S. hispanica* L. var. Chionacalyx) who developed an ultrahigh performance liquid chromatography (UHPLC) method for the analysis of phenolic compounds and isoflavones content. Although, the results of Amato et al. (2015) are lower (0.53–0.98 mg

GAE/g of Chia seed), they are in agreement with other studies (de Falco et al. 2017; da Silva Marineli et al. 2014; Porras-Loaiza et al. 2014; Reyes-Caudillo et al. 2008; Coelho et al. 2014). The antioxidant activity of hydrolysed and nonhydrolyzed extract of Chia seeds was also evaluated by using the oxidation reaction of β-carotene and linoleic acid (Miller 1971). Results showed flavanols glycosides as the major antioxidant in the nonhydrolyzed extract followed by chlorogenic acid and caffeic acid, while in the hydrolysed fraction caffeic acid is the major antioxidant source and myricetin has ca. 1.5 times the activity of quercetin followed by kaempferol (Taga et al. 1984). Other methods were used over the years to evaluate the antioxidant activity, for example $ABTS^{\cdot+}$, $DPPH^{\cdot}$, and FRAP were used by Sargi et al. (2013) to analyse Chia seeds obtained from Brazil and they reported 2.56 ± 0.03; 1.72 ± 0.09 and 2.86 ± 0.10 mmol TEAC/g, respectively. Antioxidant activity, quantified with the $ABTS^{\cdot+}$ decolorization assay, was also evaluated on Chia seeds obtained from Mexico and Argentina, but lower values were detected, 0.446 and 0.488 mmol TEAC/g, respectively (Capitani et al. 2012; Vázquez-Ovando et al. 2009). As mentioned before, the growth of Chia in different places can affect the chemical composition of seeds. da Silva et al. (2017) reported that Chia grown in Rio Grande do Sul showed higher concentration of lipids, minerals and antioxidant capacity (478.2 ± 0.02 µmol TEAC/g sample) than Chia grown in Mato Grosso (466.3 ± 0.06 µmol TEAC/g sample).

Industrial uses

Chia gum

Dietary fibers in foods have not only physiological functionality for their beneficial effect on human health but also technological functionality which greatly depends on hydration properties (Borderìas et al. 2005). These are water-holding and absorption capacity, solubility and swelling, viscosity and gelling.

Chia is a starting material in the food industry for its dietary fiber content. Gum can be extracted from dietary fiber fraction of Chia by treatment of seeds with water for use as an additive to control viscosity, stability, texture, and consistency in food systems (Capitani et al. 2015). The gum is also stable at high temperature (up to 244 °C), thus making gum extracted from chia seed as a promising agent in high value food formulations (Timilsena et al. 2016). Segura-Campos et al. (2014b) studied the chemical and functional properties of Chia seed gum and reported the ability to water holding (110.5 g/g) as an important physicochemical characteristic in the food industry. Chia gum was shown to contain the 26.2% of fat and when submitted to fat extraction produced two fractions: gum with fat (FCG) and gum partially defatted (PDCG) (Segura-Campos et al. 2014b). The PDCG has high content of protein, ash and carbohydrate than the FCG. The authors compared functional properties of fatted and defatted Chia gum reporting lower oil holding ability (11.67 g/g) and water absorption (36.26 g/g) in defatted gum, and greater retention oil holding (25.79 g/g) and water absorption (44.08 g/g) in fatted gum.

Fiber fraction

As mentioned before, the FRF is mainly composed of insoluble dietary fiber (94.6%) with only a very minor amount of soluble fiber (5.4%) (Vázquez-Ovando et al. 2009). The authors obtained FRF from defatted Chia flour to determine its possible applications in products requiring hydration. The FRF water-holding capacity was 15.41 g/g, higher than reported for soy bean, wheat and maize hulls (Mongeau and Brassard 1982; Yeh et al. 2005). This may be due to the particular structure of the mucilage and to hemicellulose and lignin ratio. In contrast, Chia FRF had a low oil-holding capacity of 2.02 g oil/g sample. They also evaluated other two important properties of Chia FRF, that were the emulsifying activity, which is the ability to facilitates the solubilization or dispersion of two immiscible liquids, and the emulsifying stability, the ability to maintain an emulsion (53.26 mL/100 mL and 94.84 mL/100 mL, respectively). Its emulsifying activity may be due to the high content of protein 28.14 g/100 g in FRF, which are strong emulsifying agents (Pearce and Kinsella 1978). It can be therefore a valid alternative in foods as foam stabilizer and emulsifier. Microstructural features of Chia seeds were also studied by light and scanning electron microscopy by Muñoz et al. (2012a), who explained the great capacity of Chia mucilage hydration reporting a water retention of 27 times of its own weight,

almost double that those reported by Vázquez-Ovando et al. (2009), in which only the FRF was hydrated. Later on, they produced a mixture of mucilage of *S. hispanica* and whey protein concentrates in proportions 1:3 and 1:4 as a new source of polymer blends to develop coatings and edible films which may be used as protective water vapor barrier (Muñoz et al. 2012b). It is also used as such or in whole-seeds as a component of biodegradable film (Capitani et al. 2016), thickening agent for bread and pasta, especially in gluten-free formulations (e.g., Menga et al. 2017), cosmetic use and medical uses (Vuksan et al. 2010). Recent studies demonstrated that Chia seeds have great potential on the development of healthy and good-quality meat and fish products. Scapin et al. (2015) reported that hydroethanol extract of chia seeds at concentration of 2% decreases lipid oxidation of the pork sausages and can be used as a natural antioxidant. A more recent report conducted by Ding et al. (2017) demonstrated that a combination of Chia (1%) and carrageenan (0.5%) increases production yield of restructured ham-like products and decreases lipid and protein oxidation. Chia oil also contributed to an enhancement in the nutritional quality of tilapia fillets (*Oreochromis niloticus*), both in terms of fatty acids content (especially omega-3) and total antioxidant capacity (Montanher et al. 2016). It has been reported that macerated chia seeds in methanol show an anti-corrosion effect on steel mainly attributed to the unsaturated fatty acids (Hermoso-Diaz et al. 2014).

Conclusion

Salvia hispanica L. is a plant known since ancient times whose seeds were used as a basic food in the diet of Mayan and Aztec populations. Chia seeds are a good source of nutraceuticals and a number of reports have shown their beneficial effects on human health due to their chemical composition. They are rich in dietary fiber and polyunsaturated fatty acids, especially α-linolenic acid. *S. hispanica* seeds also contain high amount of polyphenols, including caffeic and chlorogenic acids, myricetin, quercetin and kaempferol, which give rise to high antioxidant activity. Due to its mucilaginous gel, Chia seeds can be also used in cosmetic, pharmaceutical and food companies as protective agent against moisture, foam stabilizer and emulsifier agents for its particular composition rich in carbohydrates. However, further studies are needed to fully clarify the molecular structure of Chia mucilage.

References

Ai CB, Li L-N (1992) Salvianolic acids D and E: two new depsides from *Salvia miltiorrhiza*. Planta Med 58:197–199

Ai CB, Deng QH, Song WZ, Li LN (1994) Salvianolic acid J, a depside from *Salvia flava*. Phytochemistry 37:907–908

Álvarez-Chávez LM, Valdivia-López MDLA, Aburto-Juarez MDL, Tecante A (2008) Chemical characterization of the lipid fraction of Mexican chia seed (*Salvia hispanica* L.). Int J Food Prop 11:687–697

Amato M, Caruso MC, Guzzo F, Commisso M, Bochicchio R, Galgano F, Labella R, Favati F (2015) Nutritional quality of seeds and leaf metabolites of Chia (*Salvia hispanica* L.) from Southern Italy. Eur Food Res Technol 241:615–625

Anderson JW, Baird P, Davis RH, Ferreri S, Knudtson M, Koraym A, Williams CL (2009) Health benefits of dietary fiber. Nutr Rev 67:188–205

Ayerza R (1995) Oil content and fatty acid composition of chia (*Salvia hispanica* L.), from five northeastern locations in northwestern Argentina. J Am Oil Chem Soc 72:1079–1081

Ayerza R (2011) The seed's oil content and fatty acid composition of chia (*Salvia hispánica* L.) var. Iztac 1, grown under six tropical ecosystems conditions. Interciencia 36:620–624

Ayerza R (2013a) Seed composition of two chia (*Salvia hispanica* L.) genotypes which differ in seed color Emir. J Food Agric 25:495–500

Ayerza R (2013b) Composition of chia (*Salvia hispanica*) grown in six tropical and subtropical ecosystems of South America. J Food Agric 25:495–500

Ayerza R, Coates W (2001) Chia seeds: new source of omega-3 fatty acids, natural antioxidants and dietetic fiber Southwest center for natural products research and commercialization. Office of Arid Lands Studies, Tucson

Ayerza R, Coates W (2004) Composition of chia (*Salvia hispanica* L.) grown in six tropical and subtropical ecosystems of South America. Trop Sci 44:131–135

Ayerza R, Coates W (2005) Chia: rediscovering a forgotten crop of the Aztecs. The University of Arizona Press, Tucson

Ayerza R, Coates W (2009a) Some quality components of four chia (*Salvia hispanica* L.) genotypes grown under tropical coastal desert ecosystem conditions. Asian J Plant Sci 8:301–307

Ayerza R, Coates W (2009b) Influence of environment on growing period and yield, protein, oil and linolenic content of three chia (*Salvia hispanica* L.) selections. Ind Crop Prod 30:321–324

Ayerza R, Coates W (2011) Protein content, oil content and fatty acid profiles as potential criteria to determine the origin of commercially grown chia (*Salvia hispanica* L.). Ind Crop Prod 34:1366–1371

Balasundram N, Sundram K, Samman S (2006) Phenolic compounds in plants and agri-industrial by-products:

antioxidant activity, occurrence and potential uses. Food Chem 99:191–203
Bochicchio R, Philips TD, Lovelli S, Labella R, Galgano F, Di Marsico A, Perniola M, Amato M (2015) Innovative crop productions for healthy food: the case of chia (*Salvia hispanica* L.). In: Vastola A (ed) The sustainability of agro-food and natural resource systems in the mediterranean basin 2015. Springer, Berlin, pp 15–27
Borderìas AJ, Sanchez-Alonso I, Pérez-Mateos M (2005) New applications of fibres in food: addition to fishery products. Trends Food Sci Technol 16:458–465
Bushway AA, Belyea PR, Bushway RJ (1981) Chia seed as a source of oil, polysaccharide, and protein. J Food Sci 46:1349–1350
Cao G, Sofic E, Prior RL (1997) Antioxidant and prooxidant behavior of flavonoids: structure-activity relationships. Free Radic Biol Med 22:749–760
Capitani MI, Spotorno V, Nolasco SN, Tomas MC (2012) Physicochemical and functional characterization of by-products from chia (*Salvia hispanica* L.) seeds of Argentina. LWT—Food Sci Technol 45:94–102
Capitani MI, Ixtaina VY, Nolasco SM, Tomás MC (2013) Microstructure, chemical composition and mucilage exudation of chia (*Salvia hispanica* L.) nutlets from Argentina. J Sci Food Agric 93:3856–3862
Capitani MI, Corzo-Rios LJ, Chel-Guerrero LA, Betancur-Ancona DA, Nolasco SM, Tomás MC (2015) Rheological properties of aqueous dispersions of chia (*Salvia hispanica* L.) mucilage. J Food Eng 149:70–77
Capitani MI, Matus-Basto A, Ruiz-Ruiz JC, Santiago-García JL, Betancur-Ancona DA, Nolasco SM, Tomás MC, Segura-Campos MR (2016) Characterization of biodegradable films based on *Salvia hispanica* L. protein and mucilage. Food Bioprocess Technol 9:1276–1286
Codex Alimentarius Commission; Food and Agriculture Organization; World Health Organization (2009) Report of the 30th session of the Codex Committee on nutrition and foods for special dietary uses. ALINORM 09/32/26
Codex Mendoza (1542) Edition of Francisco del Paso and Troncoso (1925). Museo Nacional de Arqueologia, Historia y Etnografia, Mexico
Coelho SM, de las Mercedes Salas-Mellado M (2014) Chemical characterization of chia (*Salvia hispanica* L.) for use in food product. J Food Nutr Res 2:263–269
Critchfield JW, Butera ST, Folks TM (1996) Inhibition of HIV activation in latently infected cells by flavonoid compounds. AIDS Res Hum Retrovir 12(1):39–46
Cushnie TPT, Lamb AJ (2005) Antimicrobial activity of flavonoids. Int J Antimicrob Agents 26:343–356
da Silva Marineli R, Moraes ÉA, Lenquiste SA, Godoy AT, Eberlin MN, Maróstica MR (2014) Chemical characterization and antioxidant potential of Chilean chia seeds and oil (*Salvia hispanica* L.). Food Sci Technol 59:1304–1310
da Silva BP, Anunciação C, da Silva Matyelka JC, Della Lucia CM, Martino HSD, Pinheiro-Sant'Ana HM (2017) Chemical composition of Brazilian chia seeds grown in different places. Food Chem 221:1709–1716
Dąbrowski G, Konopka I, Czaplicki S, Tańska M (2016) Composition and oxidative stability of oil from *Salvia hispanica* L. seeds in relation to extraction method. Eur J Lipid Sci Technol. doi:10.1002/ejlt.201600209
de Falco B, Incerti G, Bochicchio R, Phillips TD, Amato M, Lanzotti V (2017) Metabolomic analysis of *Salvia hispanica* seeds using NMR spectroscopy and multivariate data analysis. Ind Crop Prod 99:86–96
de Sahagun B (1579) Historia general de las cosas de Nueva España. Reprinted 1982 by School of American Research, Santa Fe
Din JN, Newby DE, Flapan AD (2004) Omega 3 fatty acids and cardiovascular disease—fishing for a natural treatment. Br Med J 328:30–35
Ding Y, Lin HW, Lin YL, Yang DJ, Yu YS, Chen JW, Wang SY, Chen YC (2017) Nutritional composition in the chia seed and its processing properties on restructured ham-like products. J Food Drug Anal. doi:10.1016/j.jfda.2016.12.012
Dixon RA, Dey PM, Lamb CJ (1983) Phytoalexins: enzymology and molecular biology. Adv Enzymol Relat Areas Mol Biol 55:1–136
Dweck AC (2005) The folklore and cosmetic use of various *Salvia* species. In: Kintzios SE (ed) Sage: the Genus Salvia. Harwood Academic Publishers, Amsterdam, pp 1–25
Garg ML, Wood LG, Singh H, Moughan PJ (2006) Means of delivering recommended levels of long chain n − 3 polyunsaturated fatty acids in human diets. J Food Sci 71:66–71
Geelen A, Brouwer IA, Zock PL, Katan MB (2004) Antiarrhythmic effects of n − 3 fatty acids: evidence from human studies. Curr Opin Lipidol 15:25–30
Hermoso-Diaz IA, Velázquez-González MA, Lucio-Garcia MA, Gonzalez-Rodriguez JG (2014) A study of *Salvia hispanica* as green corrosion inhibitor for carbon steel in sulfuric acid. Chem Sci Rev Lett 3:685–697
Hipsley EH (1953) Dietary "fibre" and pregnancy toxaemia. Br Med J 2:420–422
Huang YS, Zhang JT (1991) Antioxidative effect of three water-soluble components isolated from *Salvia miltiorrhiza* in vitro. Yao Xue Xue Bao = Acta Pharm Sin 27:96–100
Ixtaina VY, Martinez ML, Spotorno V, Mateo CM, Maestri DM, Diehl BWK, Nolasco SM, Tòmas MC (2011) Characterization of chia seed oils obtained by pressing and solvent extraction. J Food Compos Anal 24:166–174
Jamboonsri W, Phillips TD, Geneve RL, Cahill JP, Hildebrand DF (2012) Extending the range of an ancient crop, *Salvia hispanica* L.—a new ω3 source. Gen Resour Crop Evolut 59:171–178
Lairon D, Arnault N, Bertrais S, Planells R, Clero E, Hercberg S, Boutron-Ruault MC (2005) Dietary fiber intake and risk factors for cardiovascular disease in French adults. Am J Clin Nutr 82:1185–1194
Li BQ, Fu T, Dongyan Y, Mikovits JA, Ruscetti FW, Wang JM (2000) Flavonoid baicalin inhibits HIV-1 infection at the level of viral entry. Biochem Biophys Res Commun 276(2):534–538
Lin KY, Daniel JR, Whistler RL (1994) Structure of chia seed polysaccharide exudate. Carbohydr Polym 23:13–18
Liu S, Stampfer MJ, Hu FB, Giovannucci E, Rimm E, Manson JE, Hennekens CH, Willett WC (1999) Whole-grain consumption and risk of coronary heart disease: results from the Nurses' health study. Am J Clin Nutr 70:412–419
Lowe ED, Gao GY, Johnson LN, Keung WM (2008) Structure of daidzin, a naturally occurring anti-alcohol-addiction

agent, in complex with human mitochondrial aldehyde dehydrogenase. J Med Chem 51:4482–4487
Lu Y, Foo LY (1999) Rosmarinic acid derivatives from *Salvia officinalis*. Phytochemistry 51:91–94
Lu Y, Foo LY (2001) Salvianolic acid L., a potent phenolic antioxidant from *Salvia officinalis*. Tetrahedron Lett 42:8223–8225
Lu Y, Foo LY (2002) Polyphenolics of *Salvia*—a review. Phytochemistry 59:117–140
Martínez-Cruz O, Paredes-López O (2014) Phytochemical profile and nutraceutical potential of chia seeds (*Salvia hispanica* L.) by ultra-high performance liquid chromatography. J Chromatogr A 1346:43–48
Matthaus B (2002) Antioxidant activity of extracts obtained from residues of different oilseeds. J Agric Food Chem 50:3444–3452
Menga V, Amato M, Phillips TD, Angelino D, Morreale F, Fares C (2017) Gluten-free pasta incorporating chia (*Salvia hispanica* L.) As thickening agent: an approach to naturally improve the nutritional profile and the in vitro carbohydrate digestibility. Foog Chem 221:1954–1961
Miller HE (1971) A simplified method for the evaluation of antioxidants. J Am Oil Chem Soc 48:91–105
Mongeau R, Brassard M (1982) Insoluble dietary fiber from breakfast cereals and brans bile salt and water holding capacity in relation to particle size. Cereal Chem 59:413–417
Montanher PF, Costa e Silva B, Bonafé EG, Carbonera F, dos Santos HMC, de Lima Figueiredo I, Maruyama SA, Matsushita M (2016) Effects of diet supplementation with chia (*Salvia hispanica* L.) oil and natural antioxidant extract on the omega-3 content and antioxidant capacity of *Nile tilapia* fillets. Eur J Lipid Sci Technol 118:698–707
Montonen J, Knekt P, Jarvinen R, Aromaa A, Reunanen A (2003) Whole-grain and fiber intake and the incidence of type 2 diabetes. Am J Clin Nutr 77:622–629
Muñoz LA, Cobos A, Diaz O, Aguilera JM (2012a) Chia seeds: microstructure, mucilage extraction and hydration. J Food Eng 108:216–224
Muñoz LA, Aguilera JM, Rodriguez-Turienzo L, Cobos A, Diaz O (2012b) Characterization and microstructure of films made from mucilage of *Salvia hispanica* and whey protein concentrate. J Food Eng 111:511–518
Olivos-Lugo BL, Valdivia-López MÁ, Tecante A (2010) Thermal and physicochemical properties and nutritional value of the protein fraction of Mexican chia seed (*Salvia hispanica* L.). Food Sci Technol Int 16:89–96
Palma F, Donde M, Lloyd WR (1947) Fixed oils of Mexico. Part 1. Oil of chia—*Salvia hispanica*. J Am Oil Chem Soc 24:27
Parnham MJ, Kesselring K (1985) Rosmarinic acid. Drugs Future 10:756–757
Pearce KN, Kinsella JE (1978) Emulsifying properties of proteins: evaluation of a turbidimetric technique. J Agric Food Chem 26:716–723
Peiretti PG, Meineri G (2008) Effects on growth performance, carcass characteristics, and the fat and meat fatty acid profile of rabbits fed diets with chia (*Salvia hispanica* L.) seed supplements. Meat Sci 80(4):1116–1121
Petruzziello L, Iacopini F, Bulajic M, Shah S, Costamagna G (2006) Review article: uncomplicated diverticular disease of the colon. Aliment Pharmcol Ther 23:1379–1391
Porras-Loaiza P, Jiménez-Munguía MT, Sosa-Morales ME, Palou E, López-Malo A (2014) Physical properties, chemical characterization and fatty acid composition of Mexican chia (*Salvia hispanica* L.) seeds. Int J Food Sci Technol 49:571–577
Reyes-Caudillo E, Tecante A, Valdivia-López MA (2008) Dietary fibre content and antioxidant activity of phenolic compounds present in Mexican chia (*Salvia hispanica* L.) seeds. Food Chem 107:656–663
Sandoval-Oliveros MR, Paredes-López O (2012) Isolation and characterization of proteins from chia seeds (*Salvia hispanica* L.). J Agric Food Chem 61:193–201
Sargi SC, Silva BC, Santos HMC, Montanher PF, Boeing JS, Júnior S, Visentainer JV (2013) Antioxidant capacity and chemical composition in seeds rich in omega-3: chia, flax, and perilla. Food Sci Technol (Campinas) 33:541–548
Scapin G, Schimdt MM, Prestes RC, Ferreira S, Silva AFC, da Rosa CS (2015) Effect of extract of chia seed (*Salvia hispanica*) as an antioxidant in fresh pork sausage. Int Food Res J 22:1195–1202
Segura-Campos MR, Ciau-Solìs N, Rosado-Rubio G, Chel-Guerrero L, Betancour-Ancona D (2014a) Physicochemical characterization of chia (*Salvia hispanica*) seed oil from Yucatan, México. Agric Sci 5:220–226
Segura-Campos MR, Solis NC, Rubio GR, Guerrero LC, Ancona DB (2014b) Chemical and functional properties of chia seed (*Salvia hispanica* L.) gum. Mexico. Int J Food Sci 2014:1–5
Steffen LM, Jacobs DR Jr, Stevens J, Shahar E, Carithers T, Folsom AR (2003) Associations of whole-grain, refined grain, and fruit and vegetable consumption with risks of all-cause mortality and incident coronary artery disease and ischemic stroke: the atherosclerosis risk in communities (ARIC) study. Am J Clin Nutr 78:383–390
Taga MS, Miller EE, Pratt DE (1984) Chia seeds as a source of natural lipid antioxidants. J Am Oil Chem Soc 61:928–932
Timilsena YP, Adhikari R, Kasapis S, Adhikari B (2016) Molecular and functional characteristics of purified gum from Australian chia seeds. Carbohydr Polym 136:128–136
Tolba R, Guosheng W, Aicheng C (2011) Adsorption of dietary oils onto lignin for promising pharmaceutical and nutritional applications. BioResources 6(2):1322–1335
Trowell HC, Southgate DAT, Wolever TMS, Leeds AR, Gassull MA, Jenkins DJ (1976) A. dietary fiber redefined. Lancet 307:967
Vázquez-Ovando A, Rosado-Rubio G, Chel-Guerrero L, Betancur-Ancona D (2009) Physicochemical properties of a fibrous fraction from chia (*Salvia hispanica* L.). LWT—Food Sci Technol 42:168–217
Vuksan V, Whitham D, Sievenpiper JL, Jenkins AL, Rogovik AL, Bazinet RP, Vidgen E, Hanna A (2007) Supplementation of conventional therapy with the novel grain Salba (*Salvia hispanica* L.) improves major and emerging cardiovascular risk factors in type 2 diabetes. Diabetes Care 30:2804–2810
Vuksan V, Jenkins AL, Dias AG, Lee AS, Jovanovski E, Rogovik AL, Hanna A (2010) Reduction in postprandial glucose excursion and prolongation of satiety: possible explanation of the long-term effects of whole grain Salba (*Salvia Hispanica* L.). Eur J Clin Nutr 64:436–438

Wall R, Ross RP, Fitzgerald GF, Stanton C (2010) Fatty acids from fish: the anti-inflammatory potential of long-chain omega-3 fatty acids. Nutr Rev 68:280–289

Weber CW, Gentry HS, Kohlhepp EA, McCrohan PR (1991) The nutritional and chemical evaluation of chia seeds. Ecol Food Nutr 26:119–125

Whelton SP, Hyre AD, Pedersen B, Yi Y, Whelton PK, He J (2005) Effect of dietary fiber intake on blood pressure: a meta-analysis of randomized, controlled clinical trials. J Hypertens 23:475–481

Wu YJ, Hong CY, Lin SJ, Wu P, Shiao MS (1998) Increase of vitamin E content in LDL and reduction of atherosclerosis in cholesterol-fed rabbits by a water-soluble antioxidant-rich fraction of *Salvia miltiorrhiza*. Arterioscler Thromb Vasc Biol 18:481–486

Yagi A, Fujimoto K, Tanonaka K, Hirai K, Takeo S (1989) Possible active components of Tan-Shen for protection of myocardium against ischemia. Planta Med 55:51–54

Yao LH, Jiang YM, Shi J, Tomas-Barberan FA, Datta N, Singanusong R, Chen SS (2004) Flavonoids in food and their health benefits. Plant Food Hum Nutr 59:113–122

Yeh H, Su N, Lee M (2005) Chemical compositions and physicochemical properties of the fiber-rich materials prepared from shoyu mash residue. J Agric Food Chem 53:4361–4366

Zandi K, Teoh BT, Sam SS, Wong PF, Mustafa MR, Abubakar S (2011) Antiviral activity of four types of bioflavonoid against dengue virus type-2. Virol J 8:560–571

Zhang HJ, Li LN (1994) Salvianolic acid I: a new depside from *Salvia cavaleriei*. Planta Med 60:70–72

Zhao BL, Jiang W, Zhao Y, Wu JH, Xin WJ (1996) Scavenging effects of *Salvia miltiorrhiza* on free radicals and its protection for myocardial mitochondrial membranes from ischemia-reperfusion injury. Biochem Mol Biol Int 38:1171–1182

Zhu W, Jia Q, Wang Y, Zhang Y, Xia M (2012) The anthocyanin cyanidin-3-*O*-β-glucoside, a flavonoid, increases hepatic glutathione synthesis and protects hepatocytes against reactive oxygen species during hyperglycemia: involvement of a cAMP–PKA-dependent signaling pathway. Free Radical Bio Med 52:314–327

Zou ZW, Xu LN, Tian JY (1992) Antithrombotic and antiplatelet effects of rosmarinic acid, a water-soluble component isolated from radix *Salviae miltiorrhizae* (danshen). Yao Xue Xue Bao = Acta Pharm Sin 28:241–245