CHIA SEEDS (Salvia hispanica L.) OIL: an overview - extraction, benefits and encapsulation

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ABSTRACT

Chia oil is rich in polyunsaturated fatty acids (PUFA), such as $\alpha$-linolenic acid and linoleic acid, which are essential for human health, since the human body is not able to synthesize these components. Therefore, it is important to know better the extraction of chia oil, its benefits, as well as maintaining the characteristics of this oil, in order to provide consumers with a good quality oil that can add nutrients to the diet. Here, we review recent advances in the extraction and evaluation of chia seed oil, as well as its health benefits and encapsulation techniques. The chia seed oil extraction studies provided higher extraction yields, which is industrially favorable. Currently, studies are focused on combining extraction techniques in order to obtain more significant results in view of the various methods that are available to determine the quality of the oil. Although chia oil has promising health benefits, already proven in animal studies, there is still a lack of clinical and human trials. Therefore, to better inform researchers, engineers and technologists, here we describe the studies of chia oil, showing the advances in extraction and, more recently, the use of encapsulation techniques for protecting oil.

Keywords: Chia, Fatty Acids, Components, Evaluation.
INTRODUCTION

The search for functional foods with beneficial health effects, in general, has been gaining interest in recent years either by consumers or by researchers and industry. Epidemiological and experimental evidence shows a strong correlation between the regular diet consumption of polyunsaturated fatty acids (PUFA) and lower incidence of cardiovascular diseases, diabetes, and other metabolic syndromes. Besides, dietary fortification of α-linolenic acid (ALA) and long-chain PUFA in laboratory animals have shown cardioprotective effects. This leads to studies of promising new sources of PUFA and omega-3, as well as studies of their consumption and application of these in foods (GAZEM et al., 2016).

There is much demand for oil, both for consumption and for industrial uses. This has led to the search for new sources of vegetable oil. Vegetable oils from oilseeds (e.g., pumpkin seed oil, soybean, linseed, and grape) account for about 80% of world production for edible purposes, while the remaining 20% is shared between animal feed and chemical process industries. Besides their use for food, most vegetable seed oils can be used in the production of soaps, paints, varnishes, lubricants, hydraulic fluids, inks, dyes, pesticides, and insecticides (UZOH; ONUKWULI; NWABANNE, 2014).

The high content of oil present in chia seeds (28 to 32%), as well as their richness in polyunsaturated fatty acids [mainly ω-3 fatty acids (linolenic acid, ~68%) and ω-6 (linoleic acid, 19%)] makes chia seed an attractive oil source (FERNANDES et al., 2019). The ratio of ω-6/ω-3 fatty acids is important because it presents potential health benefits. Since a diet based on an ω-6/ω-3 ratio below 1:1 is not recommended, to inhibit the transformation of linoleic acid in very-long-chain PUFAs, the chia oil is an alternative, as this ratio is, on average, 1:3 (MELLO; GARCIA; SILVA, 2017; SILVA; GARCIA; ZANETTE, 2016; TIMILSENA et al., 2017).

In addition to these fatty acids, oleic acid, palmitic acid, and stearic acid are also present in small quantities, as well as bioactive components such as tocopherols, polyphenols, carotenoids, and phospholipids. Thus, chia oil can be considered a gourmet oil, since it is recognized as a high-quality oil and appreciated for its taste, color, and healthy characteristics (IXTAINA et al., 2015).

Here, based on available reports in the literature, we provide important information on chia oil. Our objective was to perform a detailed survey addressing chia seed oil extraction, health benefits and encapsulation. This information will help in the production of high-quality chia oil.
FATTY ACIDS

Linolenic (ω-3) and linoleic (ω-6) fatty acids belong to two different groups of polyunsaturated fatty acids (PUFAs) that are not synthesized by humans but are indispensable for maintaining human health and, therefore, must be supplemented by dietary intake (MUDGIL, 2019). These fatty acids are essential because the double bonds, located on the third and sixth carbon atoms, cannot be produced by humans and, therefore, must be acquired through diet. Other essential PUFAs are then synthesized from linoleic and linoleic fatty acids, including arachidonic acid (AA) from linoleic acid and eicosapentaenoic (EPA) and docosahexaenoic (DHA) acids from linolenic acid (EL-BADRY; GRAF; CLAVIEN, 2007).

The ω-3 and ω-6 fatty acids are fundamental in the prevention and treatment of cardiovascular diseases, as well as having other important actions in hypertension, diabetes, arthritis, and autoimmune diseases. These fatty acids are also used in pharmacological therapy, potentiating the effect of certain drugs during the growth and development of children (AREDES et al., 2019; BILINSKI et al., 2019). These polyunsaturated fatty acids are mainly consumed from oils derived from fatty fish. However, a source that has gained potential prominence is chia seeds (FERNANDES et al., 2019).

CHIA SEEDS

Chia seeds (Salvia hispanica L.) are obtained from an herbaceous plant cultivated annually, belonging to the Lamiaceae family, being native to southern Mexico and northern Guatemala (IXTAINA; NOLASCO; TOMÁS, 2012). Chia is cultivated mainly in Mexico, Peru, Bolivia, Colombia, Ecuador, and Guatemala. In Argentina, this culture has become an important economic activity (mainly in the north of the country, in the provinces of Salta and Jujuy) (MARTÍNEZ et al., 2012).

Chia can be used in various ways, both in food and as an animal feed, and several studies are reporting the use of chia commercially. Chia seeds can be used whole, ground, in the form of flour, or soaked in water or dried. Also, their products of chia seeds can be consumed, such as pure oil or oil added in food, fibers through the chia mucilage and proteins through hydrolysates and protein isolates (HRNCIC et al., 2020).

Chia seed has about 28 to 32% of oil, which is rich in polyunsaturated fatty acids, especially omega-3 (linolenic acid, ~68%), greater than any known plant source, and omega-6 (linoleic acid, ~19%) (FERNANDES et al., 2019). Moreover, this oil presents other valuables components such as tocopherols, polyphenols, phytosterols, carotenoids, and phospholipids (FERNANDES et al., 2019; JULIO et al., 2019).
CHIA OIL

Chia oil is rich in ω-3 fatty acid content, containing more than any other known plant source (AYERZA; COATES, 2011). Flaxseed oil has long been said to be the richest source of linolenic acid (containing about 59%). Other sources of the linolenic acid include soybean oil (8%) (BELLALOUI; MENGISTU; KASSEM, 2013) and walnut oil (15%) (Martínez et al. 2015). The ω-6 fatty acid is found in vegetable oils such as soybeans (54%) (BELLALOUI; MENGISTU; KASSEM, 2013).

Chia oil, as other vegetal oils, does not contain cholesterol, which is an advantage over products derived from fish, which contain significant quantities of cholesterol. Unlike other sources of ω-3 fatty acid, chia seed has a low sodium content, which makes it an excellent food option for people who suffer from high blood pressure (BUSILACCHI et al., 2013).

Previous studies characterizing chia oil have mostly been conducted in Mexico (IXTAINA et al., 2010), Argentina (IXTAINA et al., 2011), and other South American countries (AYERZA; COATES, 2011). However, the knowledge of chia oil is centered in the Chilean region due to its geographical origin, which has significant impacts on the composition of the seed and the concentration of bioactive compounds (AYERZA; COATES, 2011).

BENEFITS OF CHIA OIL CONSUMPTION

Most studies that were made with chia seeds demonstrated their beneficial effects on human and animal health. The studies focus on assessing the nutritional benefit of the oil present in the chia seed and not just pure oil (ENES et al., 2020).

About human health, it has been shown that supplementation of 50 g of chia seed per day significantly increases the content of plasma linolenic acid, but does not reduce weight in the overweight (NIEMAN et al., 2009); the ingestion of 25 g daily of chia seed by healthy postmenopausal women significantly increases the levels of eicosapentaenoic acid (EPA) and plasma linolenic acid (JIN et al., 2012); daily diets of 35–37 g of chia seeds can be used by diabetics to control hyperglycemia and reduce systolic blood pressure (TOSCANO et al., 2014; VUKSAN et al., 2007). Nieman et al. (2015) found that the intake of 7 kcal kg$^{-1}$ of pure chia oil by athletes about 30 min before running resulted in a 3.4-fold increase in α-linolenic plasma levels but did not improve the performance of them.

The increase of plasma linolenic acid levels is of great importance as they aid in the performance of cell membranes, in brain functions, and in the nerve impulses transmission, as well as in the transfer of atmospheric oxygen to blood plasma, hemoglobin synthesis, and cell division. Already the increase in the levels of eicosapentaenoic acid contributes to the prevention of allergic, inflammatory, and cardiovascular diseases (KAUR; CHUGH; GUPTA, 2014).
A fact not yet proven, but raised by some authors, is that by the chia oil be characterized by a high polyunsaturated fatty acid/saturated fatty acid (PUFA/SFA) ratio, this makes it a highly favorable for the reduction of serum cholesterol and atherosclerosis, and the prevention of cardiovascular disease. Shen et al. (2018) obtained PUFA/SFA ratio of chia oil of 8.85 and these authors suggested that the incorporation of chia oil into the diet could bring great beneficial effects to the cardiovascular system due to the high content of PUFAs.

According to literature data, chia oil and chia seeds have different antioxidant potentials, confirmed by in vitro assays (MARINELI et al., 2014). In vivo, Marineli et al. (2015) evaluated the antioxidant potential of chia oil and chia seed in rats with diet-induced obesity. The authors verified that daily consumption of seeds and chia oil improved the plasma and antioxidant status of the liver, with a reduction of plasma lipid peroxidation, and promoted a protective effect against oxidative stress due to obesity. Gazem et al. (2016) examined the anti-inflammatory property of chia seed oil pure and in synergy with the other vegetable oils employing in vitro systems. There was an increase in anti-inflammatory activity as the dose of chia oil increased at a concentration of 10 to 40 μL/mL.

Besides, chia oil and chia seed are considered new sources of natural antioxidants due to their high content of tocopherols, phytosterols, carotenoids, and phenolic compounds (IXTAINA et al., 2011), which have the potential to protect consumers against many diseases and promote beneficial effects on human health. Chia oil might be an alternative source of ω-3 for vegetarians and people with fish allergies, since neither the oil nor seed have shown problems associated with other nutritional sources, such as flaxseed and marine products, including the taste of fish, weight loss of animals, and digestive problems (ALI et al., 2012).

Most early studies have focused on proving the benefits of chia seed in all its forms, but some studies have focused only on the benefits of oil through the diet of animals (GONZÁLEZ-MAÑÁN et al., 2012; VALENZUELA et al., 2014). Recently, Souza et al. (2020) verified that supplementation with chia oil in swiss male induced the browning process in subcutaneous WAT (white adipose tissue) and was even more beneficial to health when supplemented since the onset of obesity. WAT plays a key role in endocrine and metabolic functions, as it participates in regulating energy homeostasis and insulin sensitivity.

Chia oil shows bioactive potential and its regular use can reduce the risk of chronic diseases due to antioxidant, anti-inflammatory, hypoglycemic and hypolipemic effects. However, clinical and human trials with regard to safety, possible side effects and mechanism of action of their biomolecules are still lacking and, based on these studies, appropriate recommendations for the use of chia seed and oil products can be provided.
EXTRACTION METHODS OF CHIA OIL

Vegetable oils are usually extracted by mechanical pressing and extraction with organic solvents. The effectiveness of these methods depends on the moisture content of the seed and the temperature during the oil extraction process. Chemical extraction processes are dangerous and unacceptable because they employ solvents, such as hexane, which is harmful to the environment and human health.

One of the main objectives of chia oil research is to identify a suitable method to recover the oil from the seeds while preserving its quality. An ideal extraction method would be simple (extraction, deployment, operation, and control processes) and accessible to local producers.

In recent years, there has been much interest in the use of presses to recover oil (Martínez et al. 2012), although multiple methods are being used. The different extraction methods produce different oil yields, fatty acid qualities, fatty acid contents, total dietary fiber contents, and antioxidant activities (ALI et al., 2012). The choice of the extraction method will depend on the intended use of the oil (e.g., for pharmacological or food purposes).

EXTRACTION BY PRESSING

Pressing is one of the more traditional methods of oil extraction, which is done by crushing the seeds. Mechanical pressing can be carried out by a hydraulic, screw and roller press, and oilseeds recovery by this technique is typically between 86 and 92% of the oil after up to two passes. The organic segment of the edible oil industry prohibits the use of certain process technologies, especially the extraction of oil from petroleum solvents. This had led to increased use of pressing, which is commercially viable, low-cost, and relatively efficient (SINGH et al., 2002).

The pressing method of chia seed promotes better preservation of the antioxidant components (quercetin and myricetin) than solvent extraction. However, only partial recovery of the oil can be achieved (ALI et al., 2012).

Multiple studies have used a Komet screw press in a single step to extract chia oil and they reported the extraction parameters, such as seed moisture, velocity, temperature, and pressing speed (Martínez et al. 2012); compared the yield and quality and physical-chemical parameters with oil obtained by solvent-extraction (IXTAINA et al., 2011), and extraction with the use of supercritical fluids (DĄBROWSKI et al., 2017); or evaluated the efficacy of natural antioxidants alone and in combination during storage (BODOIRA et al., 2017).

Seed moisture is one of the most important parameters during extraction by pressing. Seed moisture of 10% is adequate for extraction. Martínez et al. (2012) found that oil yield increases with decreasing the seed moisture, obtaining a maximum yield (48%) when the
lowest moisture content (13.6%) was tested. The authors explain that increasing the moisture makes it difficult to extract oil due to the formation of an external chia mucilage that reduces the yield of obtained oil.

Dąbrowski et al. (2017) performed a hot-pressing extraction and obtained 26.3% yield, where before pressing, seeds were conditioned for 1 h at 110 °C. The yield increased to the cold pressing (24.1%), however, the fatty acid composition and phytosterols content did not differ significantly between the two techniques.

Recently, Özcan et al. (2019) determined the effect of microwave heating treatments in chia seed before the cold pressing. These authors verified that microwave heating led to considerable losses in the quality attributes of chia oil extracted from the seeds heated at different microwave watts. Thus, they concluded that although preheating may facilitate the extraction of chia oil, there is a loss of the bioactive compounds.

**EXTRACTION BY SOLVENTS**

Solvent-extraction protects the functional characteristics of the oil, such as water retention, absorptive capacity, and emulsifying stability, but reduces the oil’s antioxidant content. Also, because of the use of hexane, solvent extraction does raise some environmental and health safety issues (ALI et al., 2012).

Because of the above disadvantages, there have been few studies addressing chia oil extraction by solvents. Among the available studies, the solvents used are hexane (Ixtaina et al. 2011; Silva, Garcia, and Zanette 2016; Castejón, Luna, and Señorans 2017; Dąbrowski et al. 2017; Souza et al. 2017; Noshe and Al-bayyar 2017), acetone (DĄBROWSKI et al., 2017), petroleum ether (TIMILSENA et al., 2016), ethyl acetate, and isopropanol (SILVA; GARCIA; ZANETTE, 2016).

Ixtaina et al. (2011) obtained higher contents of tocopherols and greater extraction yields using hot extraction (Soxhlet) with hexane at 80 °C for 8 h (33.6% with Argentine seed and 26.7% with Guatemalan seed) compared to pressing extraction (24.8% with Argentine seed and 20.3% with Guatemalan seed). However, important quality parameters, such as the iodine index, saponification index, and unsaponifiable matter, did not differ between these techniques.

The use of solvent extraction provides a higher yield than the other techniques, this was proven by the study of Dąbrowski et al. (2017). The authors found similar yields (32.6% for hexane and 31.5% for acetone) using Soxhlet extraction, and higher contents when compared to cold and hot pressing (mentioned above) and supercritical extraction (29.9% at 70 °C and 23.9% at 90 °C). In this same line, Noshe and Al-bayyar (2017) found yield from 34.6%
(white chia seeds) and 35.6% (black chia seeds) for Soxhlet extraction and 9.5% (white chia seeds) and 9.0% (black chia seeds) for pressing.

EXTRACTION USING SUPERCritical FLUIDS

Vegetable seed oil is traditionally produced by extraction with hexane from ground seeds. Although the process is very efficient, there are some major disadvantages, including the incomplete elimination of the hexane after the extraction and the possible thermal degradation of the oil. As an alternative to solvent and pressing methods, the extraction of vegetable oils using pressurized fluids under sub- or supercritical conditions has been gaining interest (TRENTINI et al., 2017).

Supercritical fluid extraction (SFE) is a mass transfer process under conditions of pressure and temperature above the critical point of the solvent. This alters the density of the solvent and thereby increase the selectivity to the solute. Also, supercritical fluids have viscosity and diffusivity of the same order of magnitude as the gases. Based on these properties, supercritical fluids can be considered to move like gases and dissolve substrates similar to a liquid (MANTELL et al., 2013).

Other techniques may be associated with supercritical extraction to increase the final extraction yield as the application of ultrasonic energy, that increases the mass transfer coefficient and consequently accelerates the kinetics of the process causing a physical rupture of the material (RIERA et al., 2004); and use of co-solvents to improve the solubility of the desired compounds and/or increase the selectivity of the extraction (by changing the polarity of the supercritical fluid) (PATIL et al., 2018).

Few studies have addressed the extraction of chia oil through supercritical extraction, all of which concentrate on the use of carbon dioxide as the supercritical fluid, except for Scapin et al. (2017), who also used liquefied petroleum gas (LPG).

Ixtaina et al. (2010) found that extraction time and pressure had the greatest impact on oil yield. Uribe et al. (2011) found that pressure has a greater effect on yield than temperature does. Ixtaina et al. (2010) and Uribe et al. (2011) used similar conditions and concluded that: (a) the yield increases with the pressure at the temperatures tested; (b) at low pressure, the yield remains constant or decreases with increasing temperature; (c) at pressures greater than 30 MPa, the yield increases with temperature.

Guindani et al. (2016) found that, at extraction pressures greater than 20 MPa, the yield is higher at low temperatures (40 °C). This is because, at lower pressures, the mass-specific effect of the solvent exerts a greater influence on the solubility, whereas, at pressures greater than 20 MPa, the effect of the solute vapor pressure on solubility is dominant.
Scapin et al. (2017) concluded that LPG is a promising solvent for chia oil extraction, principally because of its high extraction speed, high yields, and high antioxidant activity of the extracted oil. However, both solvents (LPG and CO\textsubscript{2}) were efficient at extracting oil containing high levels of \(\alpha\)-linolenic acid and bioactive compounds.

Dąbrowski et al. (2017) obtained a higher yield than the other studies, however, for this, a higher extraction temperature was required. Besides, the authors compared with other techniques (Soxhlet using hexane and acetone, cold and hot pressing), although the extraction by Soxhlet using acetone was provided the highest yield, the use of supercritical with extraction 90 °C resulted in higher \(\alpha\)-linolenic content.

Fernandes et al. (2019) studied different conditions for extraction, such as different temperatures, different pressures, and different sample pre-treatments. The authors found that the use of pretreatment of chia seeds in 15 minutes in the ultrasonic bath associated with the addition of ethanol (in the concentration of 50%, m/m), leads to a considerable increase in the initial kinetics of chia oil extraction.

Villanueva-Bermejo et al. (2019), in a preliminary study, they studied the supercritical extraction of chia oil at temperatures of 40 and 60 °C, and pressures of 25 and 45 MPa. Subsequently, with the same parameters Villanueva-bermejo et al. (2020) performed modeling the experimental kinetics of oil from two sets of chia seeds.

OTHER EXTRACTION METHODS

Guindani et al. (2016), besides the supercritical extraction, used the maceration extraction method, with hexane, ethyl acetate and ethanol, and ultrasound-assisted extraction (UAE) extraction from industrial waste generated for extraction of commercial chia oil. These authors compared the results with the UAE extraction with hexane that provided yield values (10.6%) statistically equal to yields provided by maceration using ethanol (9.6%) and UAE using ethyl acetate (11.2%).

Zanqui et al. (2015) extracted oil chia by subcritical n-propane fluid, under different pressure (8, 10, and 12 MPa) and temperature (30, 45, and 60 °C) conditions, and compared to different conventional lipid extraction methods. These authors obtained 28.1% oil at 45 °C, 12 MPa and 60 min, and oil is less oxidized compared to oils obtained by Bligh and Dyer, Soxhlet, and Folch, Less and Stanley and has higher purity.

Rosas-Mendoza et al. (2017) and Mello, Garcia, and Silva (2017) investigated the use of UAE to obtain oil from chia seeds. Rosas-Mendoza et al. (2017) not used solvents and obtained a yield of 25% with 90 min of stirring. Already, Mello, Garcia, and Silva (2017) used ethyl acetate as the solvent and verified that the oil yield increased with the increase of the solvent to solid ratio, due to a higher driving force in the more diluted solution, such that the
extraction yields increased. With this, the authors concluded that oil maximum yield was obtained within 40 min, 50 °C, and solvent to seed ratio of 12 (mL/g), with a value of around 27%.

Castejón, Luna, and Señorans (2017) and Villanueva-Bermejo et al. (2019) extracted oil chia by pressurized liquid technique. Castejón, Luna, and Señorans (2017) used different solvents: ethyl acetate, hexane and ethanol, and different temperatures (60, 90, 120 and 150 °C); while Villanueva-Bermejo et al. (2019) used dichloromethane/methanol and ethanol, and different temperatures (40, 60 and 80 °C).

**ANALYTICAL METHODS FOR THE EVALUATION OF OILS**

Most of the methods used to evaluate the quality of oils have been standardized by bodies such as the International Union of Pure and Applied Chemistry (IUPAC), International Standard Organization (ISO), Codex Alimentarius, American Oil Chemists Society (AOCS), and the American Society for Testing and Materials (ASTM). However, each country might have specific official standards, such as the *Agência Nacional de Vigilância Sanitária* (ANVISA) in Brazil, and the European Commission.

The oxidation state of oils is important for their industrial application. Oils with a higher degree of instauration, such as chia oil, are highly susceptible to oxidation. The changes caused by oxidation are irreversible and include the loss of or development of flavor, loss of color and nutrients, and the accumulation of compounds that might harm the health of consumers. These lipid oxidation phenomena depend on diverse and extremely complex reaction mechanisms, including free radicals, photo-oxidation, and process related to lipoxygenase activity, all of which produce different oxidation products.

Multiple physical, chemical, and physical-chemical methods have been used to evaluate the quality of oils, such as peroxide, iodine, acid, saponification and refractive indexes (BODOIRA et al., 2017; FERNANDES et al., 2019; GUINDANI et al., 2016; SHEN et al., 2018; TIMILSENA et al., 2017); unsaponifiable matter (BODOIRA et al., 2017; NADEEM et al., 2017); fatty acid profile; moisture content (TIMILSENA et al., 2017); oxidized acid value; p-anisidine (Julio et al. 2015); tocopherols (Ixtaina et al. 2011; Ixtaina et al. 2015; Martínez et al. 2012; Bodoira et al. 2017; Dąbrowski et al. 2017; Noshe and Al-bayyar 2017); polyphenols (BODOIRA et al., 2017; DĄBROWSKI et al., 2017; GUINDANI et al., 2016; IXTAINA et al., 2011; MARINEILI et al., 2014); oxidative stability analysis (Rancimat or Omnion Instrument) (BODOIRA et al., 2017; DĄBROWSKI et al., 2017; SHEN et al., 2018; TIMILSENA et al., 2017); differential scanning calorimetry (DSC) (Souza et al. 2017; Timilsena et al. 2017); thermogravimetric analyzer
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(TGA) (TIMILSENA et al., 2017); fourier transform infrared (FTIR) (TIMILSENA et al., 2017); viscosity (FERNANDES et al., 2019; IXTAINA et al., 2010; TIMILSENA et al., 2017); color (IXTAINA et al., 2011; SHEN et al., 2018; TIMILSENA et al., 2017); pH (TIMILSENA et al., 2017); metals (IXTAINA et al., 2015); antioxidant activity (NOSHE; AL-BAYYAR, 2017); and relative density (GAZEM et al., 2016). Other analyzes, such as smoke-point, headspace, and sensorial analyses can also be used to assess the quality of oils. However, to our knowledge, these methods have not been applied to chia oil.

ENCAPSULATION OF CHIA OIL

Although the fatty acid profile of chia seed oil is nutritionally favorable, the high degree of unsaturation of ω-3 renders it susceptible to oxidation. Therefore, the incorporation of ω-3 fatty acids in foods is challenging because of their susceptibility to oxidation and the development of foreign flavors that affect the sensory properties of foods (IXTAINA et al., 2015). Encapsulation has been used to overcome the susceptibility of chia oil to oxidation. Micro and nanoencapsulation techniques were developed relatively recently. However, new methods have been rapidly developed. Most of the chia oil studies have focused on microencapsulation (by the spray drying technique), although nanoencapsulation techniques are now being investigated.

Multiple wall materials for microencapsulation of chia oil have been tested, including sodium caseinate and lactose (IXTAINA et al., 2015); hydroxymethylcellulose and maltodextrin (Martínez et al. 2015); whey protein concentrate and mesquite gum (ESCALONA-GARCÍA et al., 2016; RODEA-GONZÁLEZ et al., 2012); isolated soy protein and maltodextrin (GONZÁLEZ et al., 2016); whey protein concentrate, pectin, maltodextrin, and modified starch(NOELLO et al., 2016); whey protein isolate, maltodextrin and arabic gum (ALCÂNTARA et al., 2019); chia seed protein isolate and chia mucilage (TIMILSENA, 2016); sodium caseinate, lactose, maltodextrin, chia mucilage and chia protein-rich fraction (US-MEDINA et al., 2018); stearic acid (ROJAS et al., 2019); carnauba wax and sodium caseinate (GUIMARÃES-INÁCIO et al., 2018); sodium alginate (HECK et al., 2019); isolated soy protein (GAÑAN et al., 2020); and curcumin, maltodextrin and arabic gum (FIRTIN et al., 2020).

High encapsulation efficiency, low surface oil content, and higher core stability are key considerations for successful microencapsulation. Most of the studies above-mentioned reported encapsulation efficiencies of greater than 97% and a particle diameter less than 10.7 μm. Particle size is one of the most observed points among the authors, since reduction of microcapsules leads to improvements in the final perception of the formulations.

Campo et al. (2017) and Fernandes et al. (2021) have described a chia oil nanoemulsion using mucilage extracted from the chia seed as encapsulating material. Campo et al.
Fernandes et al. (2021) concluded through several formulations, that 0.375 g of chia mucilage and 0.233 mL of chia oil forms a nanoemulsion with better characteristics.

Teng et al. (2017) studied chia seed oil nanoemulsions by using microfluidization and spontaneous emulsification with polysorbate 80 (Tween 80) and sorbitan monooleate (Span 80), sodium caseinate, or sucrose monoesters as an emulsifier. These authors verified that chia seed oil nanoemulsion with all emulsifier studied can be fabricated by microfluidization, however, only chia seed oil Tween 80 and Span 80 can be fabricated by spontaneous emulsification, which suggests that the microfluidization method has a wider range of application than spontaneous emulsification for polyunsaturated fatty acids.

Although the encapsulation of chia oil has gained prominence, there are few studies that involve the application of these particles in food. Most micro and nanoencapsulation studies focus only on determining the best wall materials or the optimal encapsulation conditions for obtaining smaller particles and greater stability.

Heck et al. (2019) evaluated the volatile compounds and the sensory profile of burgers with 50% pork back fat replacement by microparticles of chia oil enriched with rosemary. The chia oil did not have a major impact on the volatiles profile of raw and cooked burgers for both the unencapsulated and microencapsulated forms, with an exception while rosemary was added. The direct incorporation of bioactive compounds from rosemary into chia oil was effective to solve oxidation sensory impacts. Therefore, it can be concluded that the lipid reformulation proposed is a promising alternative to incorporate healthy oils into cooked meat products.

Rojas et al. (2019) developed mayonnaises containing microencapsulated chia, pumpkin seeds and baru oils. The authors verified that mayonnaise contained chia microparticles presented higher ω-3 content and the results were similar for all the formulations tested in relation to the technological and sensorial characteristics, being the consumers were not able to differentiate the samples from the control sample (mayonnaise with no microparticles) for all tested oils.

Almeida et al. (2018) evaluated cookies containing free and microencapsulated chia oil. The cookies loaded with microparticles showed less puncture resistance than the other samples tested. The cookies supplemented with microparticles loaded with chia oil were sensorially well accepted. Chia oil showed oxidative stability during the cooking process when encapsulated in carnauba wax microparticles.

Cardoso et al. (2020) added microcapsules of chia oil to processed cheese. The authors found significant differences in taste acceptability in relation to the formulation with the
addition of free chia oil. In addition, the appearance, odor and color parameters showed no difference. Thus, the authors concluded that the microencapsulation process was able to mask the flavor of the oil, but the acceptability of both formulations was less than the control.

CONCLUSION AND FUTURE PERSPECTIVES

The review presented some studies involving chia oil, including various information that may be clarifying the reader about the origin of chia oil, the best forms of extraction, health benefits, forms of evaluation and protection, and results already found to take advantage of this oil.

Although chia seed oil extraction techniques are important, we now believe that methods of assessing oil quality associated with a combination of extraction techniques should be the focus of future research. This is because the purpose is to increase the extraction yield and to maintain the physical, chemical and bioactive characteristics of the oil. In this review, we present numerous extraction and evaluation techniques to ensure the quality of the oil so that it is efficient in terms of its health benefits and when inserted in a food.

The proven benefits make us interested in showing that this is a relatively new oil and that it has great potential for production and consumption. However, due to its high unsaturation, the use of micro and nanoencapsulation techniques becomes the best way for this oil to present greater oxidation stability for storage and addition in food.

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