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Chia Seeds as Potential Nutritional and Functional Ingredients: A Review of their Applications for Various Food Industries

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Abstract

Chia seeds, being the golden seeds of the 21st century, have a great potential for the food industries, because of their exceptional nutritional composition and functional properties, have been successively incorporating in the formulating of nutritious products, thus, classifying them as novel food ingredients. The current demand of producing nutritionally enriched and specially designed food products for gluten intolerant, celiac, diabetic, obese and cardiac patients, have taken a greater speed toward exploring the utilization of chia seeds. Therefore, a review about the industrial potential of chia seeds has been performed by focusing research studies belonging to various industries, such as, baking, dairy, oil, meat, extrusion and packaging industry. The studies were mostly conducted with the proportions ranging from 2.5-20% of either intact chia seeds, chia flour, chia mucilage or chia seed oil separately or in combinations. In all the studies, the resultant product has increased nutritional content, particularly PUFAs but may face some technical limitations as the chia seed content increases. However, among all studies it was observed that the 2.5% incorporations of either intact chia seeds, chia flour, chia mucilage or combinations, apart from meeting EU allowance limits, tend to produce products without any detrimental effect on quality parameters and resulted in developed product with high purchase intent.

Keywords: Chia seeds; Food; Food History; Food Industry; Food Safety; Nutrition.

Introduction

The Lamiaceae family is blessed with one of the most popular annual herbs Salvia hispanica L. naturally grown in Southern Mexico and Northern Guatemala, whose seeds generally called chia seeds have been widely used by the food industries (Grancieri et al., 2019; Amato et al., 2015). It had been under cultivation for thousands of years and was widely used in folk medicines and traditional beverages by Aztec and Mayans during the pre-Columbian period (Ayerza & Coates, 2005). The higher linoleic and linolenic acid, soluble and insoluble dietary fibre, phytochemicals, minerals, vitamins and phenolics in its seeds have made it a centre of focus for food processors in making nutritious and healthy food products particularly in the manufacturing of bread, energy bars, dietary supplements, and even animal diet. Also, the increased incidences of CVDs, cholesterol, cancer, diabetes and obesity have made chia seeds a paramount solution toward their reduction among the population. (Borneo et al., 2010; Capitani et al., 2012; Coorey et al., 2012; Ixtaina et al., 2011; Munoz et al., 2012a). The seed composition which is on average varies from 30-33% fat, 6% moisture, 15-25 % protein, 18-30 % fibre and 26-41 % carbohydrate make chia seeds an important ingredient in food as well as medicine (Ixtaina et al., 2008).

History

Since 3500 BC, chia seeds remained a source of food and medicine in Mexico, but for some 500 years, the use of these seeds had been declined. Mostly, it had been thought that the Spanish domination for 289 years, which have banned its use, was alonely responsible for all the causes, but sound evidence had not been able to support this assumption. Also, according to (Sosa et al., 2017), there are three more possible causes of such decline. These are (1) reduction in Mexican population, (2) introduction of other food crops such as wheat, barley, corn etc. and animals from Europe, and (3) the resultant shift in diet pattern, due to these newly available food sources. Although the history of chia seeds were first explored by (Ayerza & Coates, 2006; Sosa-Baldivia et al., 2018) for the first time classified historical journal of chia seeds around 5 Era, (1) Pre-hispanic Era (3500 BC-1521 AD), (2) Colonial Era (1550-1810), (3) Post-Colonial Era (1810-1900), (4) Modern Era (1900-2010); and (5) Chia Bloom (2010-2017). In the pre-hispanic Era, the chia seeds had been used as food and medicine in different cultures particularly Teotihuacans who were the first to use them. These seeds are also offered to Gods as a part of the religious tribute. At the start of 1500 AD, the Mexican culture had adopted chia seeds as per Mendoza Codex records (Mohd

Ali et al., 2012) Colonial Era was characterized by Spanish domination; thus, significantly causing chia seeds to become almost extinct from Mexico (Ayerza, 2014). However, some areas of Mexico remained to cultivate chia seeds and its tradition owing to the lower influence of Spanish and because these regions are mountainous and lack easy access to water and land (López, 2010). Such retention of chia cultivation had resulted in positive consequences during the post-colonial era during which Mexico gained independence. Also, (Urbina, 1887) proved that chia seeds didn't grow in Spain. This together with other researches on genetics and agronomic practices provided a source of attraction for USDA (Maisch, 1882; A. Sosa et al., 2016). As a result, in the modern era, projects launched and research teams from USA & Argentina began to visit Acatic, Jalisco and Mexico for getting awareness and training about chia and its agronomic practices (Ayerza & Coates, 2006). In addition, during the year 2009, European Parliament classified chia to be the novel food item by passing a Regulation with EC No. 258/97. All these efforts provided a resource bank that took chia toward the blooming period. All over the world, chia seeds got attention and offered researches over a wide range of applications starting from food, medicine and to other food and non-food industrial products (FSAI, 2015). Being used in 30 countries, the future of chia seeds is very promising. The reason lies in its unique constituents and their possible health and technological advantages (Gleeson et al., 2014; Mohd Ali et al., 2012).

Nutritional Value

Chia seeds; the golden seed of the 21st century, which are richly packed with carbohydrates, proteins, fats, fibre, vitamins, minerals and polyphenols, have been acknowledged by the European parliament to be the novel food source (Orona-Tamayo et al., 2017). It has 26-41% carbohydrates, 30-35% fat mostly PUFAs (ω-3 & ω-6) while 10% saturated fats, 15-24% non-gluten protein and about 18-30% fibre (Ullah et al., 2016). Also, the seeds provide Ca, P and K about 6 times, 11 times and 4 times more than milk (Coates & Ayerza, 2009). Protein potion mainly consists of globulins, albumins, glutelin and prolamin with their percentages to total protein content about 52-54%, 17.3-18.6%, 13.6 and 17.9% respectively. one of the important characteristics that have made chia a very valuable alternative and indeed a solution for celiac and gluten intolerance patients is its absence of gluten. The fibre portion that is over 35% in most seed varieties is equivalent to the RDA of an adult. Besides these macro and micronutrients, a wide range of polyphenolics with high antioxidant capacity are present in about 0.88-1.6 GAE/g of chia seeds/flour (Capitani et al., 2012; Reyes-Caudillo et al., 2008) Among these antioxidants, tocopherols, gallic, caffeic, chlorogenic, ferulic, and rosmarinic acids are present in significant amounts. Isoflavones such as daidzin, glycitin, genistin, glycitein, and genistein are also packed in chia seeds having ranges between 0.005-0.0066 mg/g of chia seeds (Martínez-Cruz & Paredes-López, 2014).

Oil Industry

Several studies were carried to extract oil employing solvent extraction, supercritical fluid extraction and pressurized liquid extraction. Temperature, time and pressure are the three factors affecting oil extraction of Mexican and Argentinian varieties. In the former variety, the recovery was 92.8% under conditions such as 80 °C for 300 min at 45MPa whereas in the latter one, about 82-97% recovery was obtained under the same conditions except for temperature and time usually about 60 °C for 138 min. For achieving maximum extraction yield, temperature and pressure need to be high enough. Using supercritical fluid extraction, the yield of around 7.2% and 10.6% were obtained as the weight of oil extracted per weight seeds (Guindani et al., 2016; Uribe et al., 2011). Moreover, the solvent ethanol in combination with cosolvent ethyl acetate used for extracting residual oil from chia seed cake increases yields by 2.5 %. However, ethyl acetate can be used singly to achieve 27.2% yield via extraction backed by the application of ultrasounds (Tolentino et al., 2014). Besides this, traditionally used solvents i.e. propane, hexane or petroleum ether are also used for chia seed oil extraction via the Soxhlet process (Amato et al., 2015; Segura-Campos et al., 2014). Although different studies carried extraction via various methods the percentage of α-linolenic acid and linoleic acid in the oil remained the same as mentioned before (Dąbrowski et al., 2017). The oil extracted in turn can be utilized as such or to produce a wide range of fatty products.

Edible Oil

The oil content of chia seeds influenced by factors such as cultivation, climatic condition, geographical region and extraction method varies from 25-35% (Borneo et al., 2010). The fatty acid profiling revealed chia seeds to be enriched with polyunsaturated fatty acids (PUFA), particularly linoleic and linolenic acid, with percentages 15-20 and 60-65, respectively (Porras-Loaiza et al., 2014). Such a rich presence of ω-3 and ω-6 fatty acids, owing to current health outcomes, have attracted their applications for both food and medicinal purpose.

Mayonnaise

Mayonnaise is an oil in water type food emulsion with high caloric content mainly made from oils, water, egg yolk, and vinegar (Rahmati et al., 2014). The egg yolk acts as an effective emulsifier. However, The increasing demand for PUFA rich, fat less and eggless food products have left the food processors to look for other suitable ingredients (O'Sullivan, 2017). The three in one features of chia seeds, i.e. high PUFAs, fat mimicking and egg mimicking characteristics of chia seeds, have provided all needed for producing such mayonnaise. Firstly, (Fernandes & Mellado, 2018) employed fat and egg replacing property of chia seeds by using its freeze-dried mucilage. Egg substituted mayonnaises have scored, more in terms of overall quality, almost near commercial mayonnaises than oil substituted ones. However, the mayonnaise with oil substitution up to 45% reduces 50% fat, along with high stability whilst egg substitute up to 35%, only 0.94% fatty reduction and emulsion lower stability has seen which is inconsistent with the aim of the study. Rojas used micro-encapsulated chia seed along with pumpkin seeds and Baru oil to increase the PUFA content of Mayonaise (Rojas et al., 2019). The mayonnaise has attained an increase in PUFAs, along with higher thermal stability and protection from oxidation due to the presence of polyphenolics in chia seeds.

Beverage Industry

Under the current demand for natural functional beverages along with omega-3 fatty acid fortification, chia seeds possess a great potential in the formulation of such beverages (Koner et al., 2019; Panse et al., 2019). Also, the richness of minerals and vitamins in chia seeds make them suitable ingredients, for solving micronutrient deficiencies in developing countries, where people frequently suffer from diet-related maladies, owing to lack of adequate protein, dietary fibre, iodine, calcium, iron and other nutrient intakes, which are responsible for body functioning (Ahmad & Ahmed, 2019; Prathyusha et al., 2019). Chia seeds had been used in making traditional beverages, but very scarce work has been done considering the incorporation of chia seeds in beverages (Cornelis, 2019). Generally, beverages contribute 80% of the total water intake and are associated with reducing the risk of several chronic diseases, namely; diabetes, cardiovascular diseases, cancer and obesity, except for carbonated, sweetened and alcoholic beverages (Cornelis, 2019). Since 3500 BC, it had been used to prepare traditional beverages by Aztecs. Moreover, a refreshing and nourishing prepared during that time had been considered the base recipe which gave rise to 'chia Fresca nowadays consumed in Mexico, Arizona and California (Sahagun, 1999; Coates, 2011). However, the incorporation of chia seeds to prepare beverages has been done very scarcely. (Battalwar & Shah, 2015), prepared two types of beverages i.e. fruit punch and smoothie by using 8 g and 4 g chia seeds respectively. The main aim of the study is to look for sensory acceptability in terms of colour, taste and consistency, which although less as compared to the standard sample; but wasn't significant. Similarly, (Dyakonova & Stepanova, 2016), prepare smoothies by incorporating 0.5-2 g chia seed but along with walnut to increase the content of n-3 fatty acids. The incorporation has resulted in 100% stability for a period of 24 h along. Also, the prepared smoothie is recommended for all age groups, particularly for chronic CVD patients, by fulfilling 30% needs of n-3 and n-6 in a healthy individual. Besides these two pieces of research, two patents also have been prepared using chia seeds. Firstly, in 2009 by (Minatelli et al., 2009) and secondly in 2019 by (Lu, 2019). The former has prepared patent beverages with increased nutrients and is stable without requiring any additional thickening agent because of the thickening effect provided by its seed mucilage, whereas the latter aimed at replacing tapioca with chia seeds in preparing 'Bobar', which is a popular drink of Asian region. Also, the problems regarding tapioca digestability, choking hazard in some people because of its texture and vulnerability to toxin formation has led to such replacement. The patent drink with chia seed besides its nutritional enrichment also exhibit a similar chewiness as desired in tapioca bobar. Moreover, the easy digestibility and rapid nutrient release of chia seeds with no need to mill or ground have made them attractive ingredients for the bobar. However, chia bobar has not been marketed yet and need attention for an industrialist to recognize its applicability. Whilst, researcher have focussed their intentions over the preparation of beverages using whole chia seeds, one study have been recently done by (Stefani et al., 2019), using 0.1% chia seed mucilage as a structure in preparing n-3 enriched orange juice. Linseed oil was nano encapsulated using chia seed mucilage for the purpose. Also, regarding consumer acceptability, there is no significant difference between the pure orange juice, and the n-3 enriched orange juice. The juice besides enrichment with n-3 exhibit good bioaccessibility and protection against linseed oil oxidation.

Dairy Industry

Milk, the chief ingredient of the dairy industry, has been recognized as healthy food for a long time (IDF, 2019). By 2021, the volume of the dairy sector is estimated at around 234 metric tons globally (Statista, 2018). For the Year 2019, milk production, Which is an important driver of the whole industry with a growth rate of 1.9%, has been anticipated about 859 million tonnes (FAO 2019). Among the major products, butter, cheeses, and fresh dairy products (such as yoghurt, which have attained dominance in almost every part of the world) have forecasted production values of about 13.593, 26.193, and 103 Million tons respectively by 2026 (OECD & FAO 2017). Resultantly, the incorporation of chia seeds in the formulation of these major products has been highlighted by researchers, nutritionists, and food technologists. However, there are a few research articles published indicating the potential application of chia seeds in the manufacturing of dairy products such as yoghurt, cheese, and Ice-cream. Kwon, et al. (2019) fortified yoghurt with chia seed water extract and chia seed ethanol extract in amounts 0.05 and 0.1% respectively. The study showed significant improvement in viscosity, syneresis, water holding capacity, fermentation rate, LAB growth, and radical scavenging activity. In addition to these quality parameters, the ethanolic chia extract resulted in the inhibition of hydrogen peroxide formed by lipopolysaccharides present in human colon cells. Goat milk cheese prepared by using chia seed oil around 3-5g/L has positively influenced cheese yield and α-linolenic acid content without affecting bacterial growth, coagulation, and ripening of cheese (Munoz-Tebar, et al., 2019). Chia seed mucilage has been shown to act as total replacers of emulsifiers and stabilizers in the formulation of ice-creams, which in turn have improved texture, overrun and melting characteristics of ice-cream but the darkness of colour (Campos, et al., 2016).

Packaging Industry

The current trend to develop safe, nutritious and healthier food through environment-friendly practices have made the replacement of conventional packaging with biodegradable edible films (Avila-Sosa, et al., 2016). These films are continuous matrices made from lipids, polysaccharides, proteins, and combinations (Seyedi, et al., 2014). However, gelatin, a natural animal-derived polymer, has been used for this purpose because of its excellent properties in hindering oxygen and forming film matrix (Ahmad, et al., 2012). Two ways are indicating the potential application of chia seeds in formulating bio-degradable edible films with or without essential oils. Whether the film is coated with essential oils or not, plasticizers played major roles in influencing the mechanical stability of these films (Khazaei, et al., 2014). Of the plasticizer usually used for the purpose, glycerol comes out to be the most suitable for polysaccharide-based films (Ghasemlou, et al., 2011).

Non-EO coated films

The development of bio-degradable films through chia seed is achieved mostly by its mucilage, while only a few studies have indicated the use of whole chia seeds. The development of glycerole plasticized film, using chia-mucilage, and whey protein, in ratio 1:3 and at pH 10, resulted in higher tensile strength, elongation at break, and water barrier properties (Munoz, et al., 2012b; Rodea-Gonzalez et al., 2012). Dick et al. (2015), prepared films using 1% chia mucilage and glycerole as a plasticizer with concentrations of 25%, 50% and 75%. He found that increasing the concentration of plasticizer, the higher will be the water vapour permeability and elongation at the break, while lower will be tensile strength and Young's modulus. Chia flour along with maize starch exhibit improved film characteristics as compared to previous studies (Dick., et al., 2016). Although elongation at break was still lower, these films possessed nutritional properties, owing to the incorporation of chia flour.

EO coated films

The development of EO coated edible films have been started recently to lessen the use of chemical additives, thereby protecting the food against microbial spoilage and increasing its shelf life (Alves-Silva, et al., 2013; Cortes-Camargo et al., 2019). There are enough researches conducted on the addition of essential oils in films made from polysaccharides, lipids and proteins, while very few have indicated their longer retention (Pelissari, et al., 2009). Although these EO edible films have provided a very valuable means in mitigating spoilage caused by microorganisms, there are some problems such as loss of oil during preparation and gravitational phase separation. Therefore, chia seeds owing to their exceptional mucilage properties have solved this problem (Capitani et al., 2012). Capitani et al. (2016a), who prepared clove films using chia seed mucilage and its protein fraction about 1-3% as polymer concentration, found that increasing the concentration of clove essential oil would enhance anti-microbial properties against some important pathogens such as Escherichia coli and Staphylococcus aureus. Although these films are thermally stable up to 350°C, the higher the concentration of essential oil the lower will be tensile strength and elongation at break. Moreover, the film with improved characteristics has 2% chia mucilage. Similarly, oregano essential oil has been successfully used to prepare anti-microbial edible film using chia seed mucilage and gelatin with almost longer retention of the antimicrobial activity against both gram-positive and gram-negative bacteria (Luo, et al., 2019). Moreover, these films besides, their improved mechanical properties, show similar results reported by Capitani et al. (2016b) for elongation at break, and tensile strength, as the incorporation of chia mucilage is increased.

Meat Industry

The most important and indeed, the premium source of protein provides essential amino acids in enough amount to human beings for years. Globally, meat has been categorized as beef/veal, mutton, poultry and pork with their production during the year 2018 about 70.93, 14.87, 123.12 and 120.48 Million tons, respectively (OECD and FAO, 2018). Meat products are normally categorized into 4 groups, namely whole meat products consisting of animal carcass, formed or re-structured meat products consisting of meat chunks or pieces, grounded meat products such as patties, kabab and emulsified meat products such as sausages and bologna usually prepared from finely minced meat slurry (Petracci, et al., 2013). Besides, the utilization of whole meat, processed meat products are more dominant and much liked by consumers. However, these products are often modified using techno-functional ingredients to maintain their shelflife, reduce formulation cost and maintain consumer image (Barbut, S. 2017). Under the current status of labelling products with a "clean label", indicating the product free from any synthetic additive, the development of processed meat products using natural ingredients are gaining consumer acceptance (Asioli, et al., 2017). Chicken nuggets: a very popular snack food among youngsters, fortified using 10% chia seed flour have a higher amount of dietary fibre and PUFAs, particularly ω-3 fatty acid while lower moisture, saturated fats and water activity without compromising both technological as well as sensory parameters (Barros, et al., 2018). One of the major factors affecting the quality of meat products is lipid oxidation that is associated with considerable losses (Falowo, et al., 2014). Thanks to chia seeds for their extraordinary antioxidant potential due to the richness of polyphenols that have shown excellent results in preventing the oxidation of pork sausage without compromising sensory attributes (Silva, et al., 2015). Similarly, Zaki (2018), who prepared camel meat burgers using chia seeds about 1, 3 and 5% also found these incorporations significantly reducing lipid oxidation under refrigerated storage without affecting sensory properties. Low-fat meat products although have been a global demand for the last decades due to a higher risk of cardiovascular diseases are often limited because of their hard texture, low juiciness, and worse flavour (Mallika, et al., 2009). The fat mimicking property of chia seeds have been successfully utilized to formulate these low-fat products with improved sensory and physiochemical properties almost similar to adding fat for a similar purpose (Ding, et al., 2018). Moreover, the lipid oxidation as indicated earlier also gets lowered particularly at 1% chia substitution. While research has focussed their attention on land animals, a study has been found on marine species named Cyprinus carpio or common carp indicating fortification with chia seeds flour up to 8% and providing valuable projections for future research (Santillan-Alvarez, et al., 2017). Further, the product containing 4% chia seed flour has improved cooking yield, hardy texture and higher protein and fibre content than commercial products. In addition to these in vitro studies conducted over the meat, in vivo studies have also been done on substituting chia seeds in feeds of pigs, broiler, rabbit, to enhance meat quality, nutrition and consumer acceptance (Ayerza, et al., 2002; Ayerza &

Coates, 2009; Meineri, et al., 2010; Peiretti & Meineri, 2008).

Snack Industry

The higher prevalence of obesity and cardiovascular diseases (hereinafter CVDs) alone causing 1/3rd of the global deaths are chiefly associated with the consumption of ultra-processed foods that are normally rich in sugars, salt and saturated fat (Benjamin, et al., 2018; Lawrence & Baker, 2019). Almost 10% intake of these ultra-processed increases the risk of CVDs, coronary heart, and cerebrovascular diseases by the same 10% (Srour, et al., 2019). In addition to fat, sugar and refined starches; major ingredients, are significantly increasing the risk of diabetes, gluten intolerance, usually because of their high gluten and glycemic index thus, consumers are demanding snacks with the low glycemic index, absence of gluten and richness of PUFAs particularly ω-3 fatty acids. The ω-3 fatty acids which are normally present in marine species and leafy vegetables in considerable amounts are indeed highest in chia seeds about 69% of the total fatty acids (Kulczynski, et al, 2019). Resultantly, researches have begun on the development of chia substituted snacks to improve the product quality both in terms of nutrition and acceptability. Gluten-free chips containing 5% chia seed flour have met commercial acceptability along with increment in protein, dietary fibre, ω-3 fatty acids and antioxidant activity and almost negligible effect during the baking process (Coorey, et al., 2012). Although the chips which are substituted with more than 5% chia seed flour have a higher content of the aforementioned nutrients, they attain lower values against sensory parameters and acceptability. Likely, Rendon-Villalobos et al. (2012), who have used chia seeds flour to produce fibre rich corn tortillas with lower glycemic index owing to lower digestibility, also have found 5% substitution most preferred one both in terms of sensory evaluation. Besides this, these chia substituted tortillas have higher nutrients and antioxidants as compared to other low GI foods.

Extrusion industry

The marvellous applicability of chia seeds have also been assimilated by extrutionists but a few.

Puffs

The incorporation of grounded chia seeds ranging from 5-20 % for manufacturing of extruded corn puffs has resulted in a reduction of mechanical energy, expansion ratio, hardness and the total colour (Byars and Singh, 2015).

Pasta

Pasta is a widely used processed food after bread that is manufactured from cereals such as patent wheat flour and semolina. Although a rich source of energy owing to the richness of carbohydrates, it is however low in dietary fibre, vitamins and minerals. For this purpose several studies have been carried over fortification of pasta with either leaves or flour of sorghum, Algae, Oregano, Carrot, amaranth, Parsely and Peas (Borneo & Aguirre, 2008; Prabhasankar, et al., 2009; Boroski, et al., 2011; Khan, et al., 2013; Biney and Beta, 2014; Padalino. Et al., 2014; Seczyk, et al., 2016). In all these studies slight changes have been observed but the fortified products have met quality and consumer acceptance. Chia seeds concerning their richness in dietary fibre, PUFAs, protein, antioxidants have attracted the attention of researchers toward exploring their processing potential in making nutritious pasta. Aranibar, et al., (2018) has prepared pasta by utilizing partially de-oiled chia flour in proportions of about 2.5%, 5% and 10%. During the study, pasta was evaluated against nutritional and technological aspects by considering parameters such as texture, colour, microstructure, protein, fibre content, polyphenol content, antioxidant activity and sensory evaluations by semi-trained judges. About 5-10% incorporation of both chia seeds and their mucilages enhance physiological properties such as thickening and nutritional properties such as higher phenolic content and lower glycemic index (Menga, et al., 2017). Substituting 10% grounded chia seed would increase macro as well as micronutrients namely Ca, Mg, P, Cu, Zn and Fe by 2.2, 2, 1.4, 2, 1.5 and 3.5 times respectively (Naumova et al., 2017). Also, the substitution has made pasta shelf-stable for up to 15 days without affecting the colour, nutrient content and microcrystalline structure of the pasta. In addition to nutritional parameters; celiac disease and gluten intolerance which have resulted from long-term consumption of gluten protein, have led the consumer to take a shift from normal gluten pasta toward gluten-free pasta as the only available solution to these diseases is lifelong avoidance from gluten products (Caruso, et al., 2013; Pellegrini & Agostoni, 2015). Consequently, researches have been conducted on the development of gluten-free pasta but are limited by the fact that these gluten-free pastas have a higher content of saturated fat while lower other essential nutrients (Steffolani, et al., 2014). This has happened usually because they developed from refined flour or starches without subjecting these to fortification with essential nutrients. Chia seeds concerning the absence of gluten and exceptional nutrient content, have triggered the development of nutritionally enriched gluten-free pasta.

Noodles

Whilst, researchers have developed gluten-free pasta, the development of gluten-free noodles with almost similar objectives as discussed pasta earlier, have also been done recently but very scarce. Levent (2017), who prepared gluten-free noodles by incorporating chia seed flour up to 30% w/w found such incorporation significantly increased protein, fat, phenolic content and antioxidant activity by 1.7, 5.5, 2 and 2.6 times respectively. Moreover, this 30% chia seed flour could cover RDA of important minerals Ca, P, K, Mg, Fe and Zn by 22, 24, 19, 32, 25 and 19% respectively. However, this incorporation causes a reduction in surface smoothness and scores of speck and appearance in raw noodles and of chewiness in cooked noodles; therefore, 20% chia seed flour would be most suitable owing to negligible adverse effects regarding sensory properties.

Baking Industry

The prevalent dietary diseases such as obesity, diabetes, gluten intolerance and other problems related to the GI tract owing to long term consumption of less fibrous foods, have led bakers to manufacture various bakery products by incorporating chia seeds to make low-fat gluten-free bread, biscuits, cakes and other bakery products. Whilst, nutritional aspects have been discussed in most studies, the processing parameters such as pasting characteristics, rheology, visco-elasticity and physiochemical interactions regarding the production of baked foods with chia have been covered by a few studies (Goyat et al., 2018).

Bread

Bread, which is the staple food for several people worldwide need to be formulated with new ingredients with comparatively paramount nutritional and health benefits. Regarding chia substitution, enormous research has been conducted over both commercial bread and some of its variants like pita bread, pan bread and tortilla. Mostly, the research objectives are based on nutritional improvement while to a lesser extent on other technological aspects. A Korean study on quality characteristics of bread about 3% incorporation of grounded chia has shown very different results than other studies thus making it to be a single study indicating high specific volume and lower firmness than bread without chia incorporation (Lee, 2013). Also, the bread has a more sensory acceptance score than bread without chia. Similarly, Zettel et al. (2015) also found lower crumb firmness than bread without chia by using chia gel 1-3%. However, the gel has less impact on the overall bread quality as more gel would make bread soft and sticky.

Gluten bread

In areas where gluten intolerance or celiac disease is not a problem, the development of chia fortified bread without being subject to gluten-free, have also been done to produce nutritionally enriched bread. Pizarro et al. (2015) who studied substitution of chia seed flour up to 20% along with vital gluten up to 4% for observing technological, nutritional and sensory changes, have found that up to 10% of chia seed flour bread with improved characteristics can be developed (Huerta et al., 2016). Increasing the content of chia seed flour increases fat particularly PUFAs, protein and fibre but there can be limitations such as low specific volume, high firmness and lower viscosity almost similar to those reported for chia seed flour in gluten-free bread by Steffolani et al. (2014). However, the problem can be solved by adding vital gluten content up to 2%. Likely, Sayed-Ahmad, et al. (2018), also focused upon fortifying bread using 2-6% chia seed flour and chia seed cake along with vital gluten incorporation. Although bread with both chia incorporations has indicated lower firmness like Korean study and increase in nutrient content particularly chia seed cake which has resulted in more carbohydrates, protein and fat than chia seed flour, the sensory acceptability is lower by 10% when compared to bread without chia seeds. Moreover, the study hasn't evaluated quality parameters such as loaf volume, bread softness.

Low saturated fat bread

The prevalent demand for bread with lower saturated fats and higher PUFAs by cardiac patients could be resolved through chia substitution because of its higher PUFA content usually 83%, thus, making it to be the richest among other edible oil seeds. While the development of nutritionally enriched bread is focused, the bread with improved nutrition depending upon particular conditions such as for obese person have also done (Liu, et al., 2007). However, restoration of quality and other attributes related to the high-fat product are major challenges regarding the formulation of these low-fat products (Worrasinchai, et al., 2006). Since, the fats play vital roles in bread manufacturing such as promoting dough aeration, providing lubrication during the mixing, improving the product texture, increasing loaf volume and delaying starch retrogradation, the chia seed because of its high mucilage could provide fat mimicking effect, thereby replacing fat to a considerable degree without any major effect on its consumer acceptance (Verdu, et al., 2017; de Lamo & Gomez, 2018). Giaretta et al. (2018), prepared bread by using chia seed 20% along with Kinako flour to reduce saturated fat while increasing PUFAs and lower ω-3/ω-6 ratio. The study indicated higher retention of PUFAs particularly ω-3 about 92.44% without being affected by high-temperature processing. Fernandes & Salas-Mellado (2017), upon preparing bread by replacing fat with chia mucilage up to 25%, 50%, 75% and 100%, found that chia mucilage can replace up to 56.6 % fat. Also, these low-fat bread have passed against the technological and sensory parameters except with a slight impact on specific volume and crumb firmness. However, the bread with 75% and 100% fat replacement by chia mucilage dried at 50°C achieved higher scores about 89.5 and 93.79 respectively. Thus, these higher scores further confirmed their industrial applicability as defined by Dutcosky (1996) who said that the bread with scores between 61-80 against quality could be regarded as regular and with scores between 81-100 as good quality bread. Moreover, the low water activity of these low-fat bread significantly reduces microbial growth due to water absorption by chia mucilage. The value of bread colour which has been over 7 add further fuel to their acceptability as colour is an important parameter that consumer has in mind while buying. Similarly, Coelho & Salas-Mellado (2015) also found that a lower amount of chia seed about 7.8% would produce bread with an overall quality score of 92.1 and the same above 7 scores against sensory evaluation like Fernandes & Salas-Mellado (2017). However, limitations are there such as increased firmness and colour of the crust. Additionally, the lower specific volume has been observed but that differs from commercial bread by 0.3%. Gas retention; a significant indicator of high loaf volume, has often been seen in bread substituted with either chia seeds or chia flour, but Verdu, et al. (2017) has not only solved but increased gas retention by incorporating 5% chia seed flour together with 13% wheat bran. The formed bread has a very close similarity to refined wheat bread in terms of specific volume that is affected in most studies described earlier. Additionally, the sensory score was more than 7 like Fernandes & Salas-Mellado (2017).

Gluten-free Bread

Although a wide range of ingredients has been used for making nutritionally rich gluten-free bread, the bread made by proportioning 10% chia seed flour with Tartary buckwheat flour has proved to be the most excellent recipe for making nutritionally rich gluten-free bread (Costantini, et al., 2014). Steffolani et al. (2014), who has also prepared gluten-free bread but used chia seeds along with its flour separately. The product upon its organoleptic evaluation revealed contrasting results. The bread containing chia seed up to 15% as compared to bread with chia flour and without chia substitution, have shown improved characteristics regarding dough, bread and sensory acceptability. The pasting parameters such as pasting viscosity, peak viscosity and final viscosity are higher in the case of chia seed while lower for flour. The only significant difference found regarding dough characteristics is a lower pasting temperature for chia seed while a decreased setback for chia flour. Prehydrated chia seeds don't have any significant effect on the bread attributes (Svec, 2015). Regarding fermentation, gas production was faster in bread without chia, moderate in bread with chia seeds and intermediate in bread with chia flour. Bread properties such as specific volume, weight loss and firmness are more pronounced in the case of bread with chia flour than with chia seeds. The lower specific volume in the case of chia flour was due to lower retention of moisture. On the other hand, chia seeds because of their mucilage content have a high specific volume but not more than bread without chia. The lower firmness in bread with and without chia seed is due to the inverse relation between specific volume and firmness. The colour was darker in the case of chia flour due to the interaction of its components in crust formation while the components of chia seed remain intact without taking part in crust formation. Huerta, et al. (2016), collectively evaluate gluten and gum free bread prepared with chia seed flour 2.5-7.5% for nutritional and physical characteristics. Like other studies, lower incorporation of chia seeds about 2.5 has less impact on the sensory and technological aspect of the bread. A bread developed by Sandri, et al. (2017) indicated that bread with chia seed flour percentages 5%, 10% and 14% like other studies also have negligible impact on loaf volume, crumb firmness and moisture and has acceptability scores of about 7.9-8.7 on a scale of 10.

Variant bread

Chinese steamed bread

Chinese steamed bread is a well-known staple food of Chinese and other Asian countries. However, the high glycemic index of commercially available steamed bread has resulted in improving its nutritional profile by reducing refined starches by chia seeds thus increasing its suitability for diabetic patients. The bread prepared using intact chia seeds has better retention of nutrients as compared to ground seeds which may interact with other bread ingredients and processing conditions such as fermentation, steaming and high baking temperature (Zhu, 2016). Thus, Zhu & Chan (2018), who prepared bread by using intact chia seed has resulted in nutritional improved bread with lowering glycemic index by 25%. The bread besides its overall sensory acceptance and the lower glycemic index has a significant impact on specific volume and firmness. However, the study indicated that at a lower concentration of about 2.5%, chia seeds have less impact on specific volume and firmness.

Pan bread

Pan bread mostly consumed in china also seek nutritional fortification like common commercial bread due to emerging and disease-specific consumer demand. For this purpose, various materials such as cellulose and gums have been used for either reducing fat or increasing PUFAs (Martinez-Cervera, et al., 2015). Regarding pan bread, only Zettel & Hitzmann (2016), found that the fat mimicking property of chia gel can replace fat up to 25% with improved bread quality. The pan bread besides being low in fat also has a high specific volume, yeast activity, extensibility and crumb softness than bread without chia.

Pita bread

Pita bread is mostly consumed by Asians and Africans and has lower crumbs (Al-Dmoor, 2012). The bread also has a lower glycemic index and less impact on its nutrient content because of its high-temperature short-time processing (Indrani, et al., 2011). Just like pan bread, only Salgado-Cruz et al. (2017), for the first time prepared pita bread using chia seed mucilage. However, the bread indicated a higher value of the estimated glycemic index in bread with chia mucilage than without mucilage.

Cakes

Cakes are sweet baked products characterized by their soft and dense crumb with wider acceptability all over the world. The product is normally prepared with an equal amount of fat, sugar and flour along with eggs (Cauvain, 2017). However, these ingredients about the high prevalence of obesity, diabetes, cardiovascular diseases and celiac disease need to be replaced with other ingredients without affecting sensory and technological properties. Thus, studies were conducted on the replacement of these ingredients by ingredients from multiple sources (Min, et al., 2010; Roman, et al., 2015; Majzoobi, et al., 2016; de Souza, et al., 2018). However, chia seeds also won acceptability toward incorporating chia seeds in the cake for a similar purpose. Borneo et al. (2010) were the first to use chia seed gel for replacing fat as well as egg up to 75% in both cases. However, fat reduction up to 25% besides sensory acceptance have a lower impact on technological properties such as cake volume but no visible increase or decrease in volume of cake with 25% replacement of eggs by chia seed gel has been observed. . Similarly, up to 25% replacement of hydrogenated fat with chia seed mucilage in pound cake has no significant alteration in quality parameters regarding cake texture and structure (Felisberto, et al. (2015). In contrast, Pizarro, et al. (2013), found that up to 15% chia seed flour in combination with 20% hydrogenated vegetable fat would result in cakes with increased nutrition particularly ω-3 fatty acid content, technological attributes and purchase intent. hydrogenated vegetable fat is used to overcome the lower specific volume and high firmness. Also, up to 50% incorporation of chia seeds, the cake is produced with almost slight compromisation of the technological aspects (Fernandes & Salas-Mellado, 2017). However, the sensory acceptance, as well as purchase intent, is more if chia mucilage dried at 50°C is added to the cake.

Biscuits

Biscuits, the concentrated source of energy owing to a higher presence of saturated fat and sugar, also have been attracted modifications in their formulation by replacing these conventional ingredients to reduce the burden of non-communicable diseases such as obesity, cardiovascular diseases, diabetes, and celiac disease, which are often linked to a higher intake of fat, sugar and gluten. Resultantly, studies conducted over the use of gums and flour from other cereals, pseudocereals and legumes (Fradinho, et al., 2015; Kaur, et al., 2015; Di Cairano, et al., 2018; Diaz, et al., 2019; Gharaie, et al., 2019). The versatile composition of chia seed has made it a single ingredient to be used for preparing fat-free, gluten-free biscuits along with improved nutrition and a lower impact on consumer acceptability. For this purpose, there can be two approaches either using chia seeds alone or in combination with other ingredients like Ivan et al. (2017), who along with chia use teff as an improver for making wheat-barley cookies. The cookies are prepared by proportioning 5-10% chia seed and teff with wheat-barley flour having a ratio of about 70:30 and 50:50. The result indicated higher extensibility of cookie dough along with masking of barley of taste. Similarly, Gfetoyat et al. (2018), also prepared cookies by using chia seed flour along with quinoa seed flour about 5-15% for both flours. The cookies, as compared to non-substituted ones, have increased nutrients, particularly ω-3 fatty acid and polyphenols, thus enhancing their shelf life. Also, the cookies scored 6 on a 9-hedonic scale. However, crumb firmness was higher in these substituted cookies. Besides, these above studies, indicating the use of chia seeds along with other ingredients, Mesias et al. (2016), has only used chia, by observing the risk/benefit analysis of various concentrations from 0-20% over wheat flour. The study, for the first time, evaluates nutritional quality along with safety aspects. It has been observed that increasing the chia seed flour increases nutrients, but it may also increase processing contaminants such as acrylamide, hydroxymethylfurfural, furfural, and dicarbonyl compounds, such as methylglyoxal and glyoxal. Also, the lipid oxidation was more in biscuits containing chia seeds, thus reducing their shelflife.

Safety Aspects of Chia seeds

No doubt chia is a superfood, but "access of everything bad" fits all foodstuffs. Thus, the European parliament after declaring it a novel food in 2009 under (EC) No 258/97, set safety limits after 4 years in 2013 such that chia seeds can be used raw no more than 15g/day and no more than 10% in processed foods. However, American guidelines recommended consumption of chia seeds about 48g/day (Carrillo, et al., 2018). The reason behind establishing safety limits by Europeans is due to the increase in processing contaminant acrylamide in a bakery produced processed at 190°C and also of some rare cases reported regarding allergenic reactions to chia consumption (Turck, et al., 2019). Table 1 will indicate the usage limits of chia seeds.

Products	Chia seeds	Limit
Bakery Products	Whole seed	5-10%
Fruit and vegetable Juice	Whole seed/ grounded	10% or 15g per day
RTE Sterilized cereals/ pseudocereals/pulses	Grounded	5%
Dairy products	Whole seed	1.3 g/100g
Fat based products	Chia seed oil	2 g/day
Food Supplyments	Whole seed	2 g/day

Table 1: Usage limits of chia seeds.

Source: Commission Implementing Regulation (EU) 2018/1023

Conclusion

The miraculous compositional profile of chia seed has made it a very valuable ingredient for the food industry, provided that it is, used in specified proportions. The high content of healthy fats, absence of gluten protein, high fibre content, the richness of vitamins and minerals and presence of polyphenolic compounds have extended its uses for producing a wide range of food items both for the general healthy population and also for diseased patients suffering from, diabetes, celiac disease, gluten intolerance, obesity and cardiac problems. In terms of nutrition, indeed, all studies confirmed an increase in nutritional content whereas, in terms of quality, few studies have checked the influence of chia seeds on quality aspects of resultant food products. The various means by which chia seeds can be used include intact or raw chia seeds (whether or not prehydrated), chia seed flour, chia seed oil, and chia seed mucilages. Various industries possess the space to incorporate chia seeds such as baking, dairy, meat, oil, beverage, extrusion, snack and packaging industry. Most work has been conducted regarding the baking sector, while a few regarding dairy, extrusion, beverage, snack industry and packaging industry while very little work has been conducted regarding oil-based food products and the meat industry. In the researches, 1-20% of chia incorporations have been seen as it would increase the nutritional value of the food product as the content of chia seed increases while the higher concentration is detrimental to the commercial quality parameters. However, 2.5%, as seen in most studies, would produce products with higher nutrition, along with the least compromisation of technological quality. Additionally, the allowance limit set forth by Europen regulations makes such chia incorporations promising without any adverse effects. Also, these chia-fortified products met higher purchase intent and consumer acceptability. Therefore, because of this extraordinary potential of chia seeds for both food and non-food products, they have been titled, the golden seed of the 21st century.

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