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Sonu
M.Tech Scholar, Department of Processing and Food Engineering, College of Technology and Engineering, Maharana Pratap University of Agriculture and Technology, Udaipur; Rajasthan, India

SK Jain
Retd. Professor, Department of Processing and Food Engineering, College of Technology and Engineering, Maharana Pratap University of Agriculture and Technology, Udaipur; Rajasthan, India

Deepak Rajpurohit
Professor & PI, AICRP on PHET, Department of Processing and Food Engineering, Maharana Pratap University of Agriculture &Technology, Udaipur, Rajasthan, India

Sarla Lakhawat
Department of Food Science and Nutrition, Maharana Pratap University of Agriculture &Technology, Udaipur, Rajasthan, India

Jasvinder
Ph.D Scholar, Department of Processing and Food Engineering, College of Technology and Engineering, Maharana Pratap University of Agriculture and Technology, Udaipur; Rajasthan, India

Ronit Verma
M.Tech Scholar, Department of Processing and Food Engineering, College of Technology and Engineering, Maharana Pratap University of Agriculture and Technology, Udaipur; Rajasthan, India

Ranajit Patil
M.Tech Scholar, Department of Processing and Food Engineering, College of Technology and Engineering, Maharana Pratap University of Agriculture and Technology, Udaipur; Rajasthan, India

Kamlesh Kumar Meena
Assistance Professor, College of Dairy and Food Technology, Maharana Pratap University of Agriculture and Technology, Udaipur; Rajasthan, India

Corresponding Author:
Deepak Rajpurohit
Professor & PI, AICRP on PHET, Department of Processing and Food Engineering, Maharana Pratap University of Agriculture &Technology, Udaipur, Rajasthan, India

Utilization of sunflower seeds in functional food product development: A review

Sonu, SK Jain, Deepak Rajpurohit, Sarla Lakhawat, Jasvinder, Ronit Verma, Ranajit Patil and Kamlesh Kumar Meena

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Abstract
Sunflower seeds (*Helianthus annuus*) have gained attention in recent years due to their rich nutritional profile and potential role in functional food product development. This review highlights the compositional, nutritional, therapeutic, and technological attributes of sunflower seeds that make them suitable for various health-promoting food applications. Rich in essential fatty acids, high-quality protein, dietary fiber, antioxidants (notably vitamin E and selenium), and bioactive compounds, sunflower seeds contribute significantly to cardiovascular health, immune support, and disease prevention. The review explores the comparative nutritional profile of sunflower seeds with other oilseeds and grains, emphasizing their superior polyunsaturated fatty acid content and antioxidant potential. The paper also discusses the various methods of processing sunflower seeds—including roasting, oil extraction, and flour production—and their use in developing fortified, gluten-free, and protein-enriched products such as biscuits, laddoo, missi roti, and breads. Furthermore, sunflower meal and oilcake, often considered by-products, are identified as valuable protein sources for human consumption and animal feed. Sensory evaluation studies show promising results when sunflower seed derivatives are blended with other flours. Shelf life and storage conditions are reviewed, stressing the importance of packaging and environmental factors on product stability. Despite some limitations in protein extraction techniques, sunflower seeds hold substantial promise for use in functional and nutraceutical products, especially in the context of personalized nutrition and plant-based diets.

Keywords: Sunflower seeds, functional foods, nutritional composition, plant-based protein, sunflower oil, bioactive compounds, gluten-free products

1. Introduction

There are more than 70 species of Helianthus in the world. The plant's size and resemblance to the sun are the sources of its name, "sunflower." The term also comes from the revolving around the sun. Sunflowers are distinguished by their enormous, round, yellow inflorescence flower head (which bears achenes that mature into seeds), long taproot, hairy stalks, and broad, rough, coarsely serrated leaves that face the sun directly. In the sixteenth century, Spanish explorers brought it to Europe from its original temperate regions in North America, when temperatures often ranged from 20 to 25 °C. Sunflowers' flora exhibits their aesthetic and attractive qualities in a variety of sizes and colors, ranging from cream to yellow depending on the cultivar Vilvert *et al.* (2018) [63]. The oilseed crop sunflower (Helianthus annuus) is indigenous to North America. It is grown all throughout the world, and the majority of its products are sold as animal or culinary feed Yegorov *et al.* (2019) [69] .Kernels and seed coverings, sometimes known as hulls, make up sunflower seeds. Sunflower hulls are typically regarded as a waste by-product and make up 21-30% of the seed weight Seiler *et al.* (2016) [49].

1.1 Nutritional importance and health benefits of functional ingredients

One of the major oilseed crops cultivated worldwide, sunflowers provide high-quality oil and dietary fiber that are vital to human health Khan *et al.* (2015) [32]. An excellent source of plant protein is sunflower seeds, which provide 6 grams, or 12% of the Daily Value, per ounce. Because it eliminates free radicals, which are dangerous chemicals that can cause atherosclerosis, vitamin E is an antioxidant that may help prevent heart disease. Among entire foods, sunflower seeds are the richest source of vitamin E.

Vitamin E can be found in excess in sunflower seeds. The Recommended Dietary Allowance for vitamin E is 76% of what is found in just one ounce of sunflower seeds. As an antioxidant that works in tandem with vitamin E, selenium shields cells from harm that could result in cancer, heart disease, and other illnesses. An ounce of sunflower seeds contains 6 grams of plant protein, or 12% of the Daily Value. By removing dangerous chemicals known as free radicals, which can cause atherosclerosis, vitamin E, an antioxidant, may help prevent heart disease. The finest whole food source of vitamin E is sunflower seeds. 76% of the Recommended Dietary Allowance for vitamin E may be found in just one ounce of sunflower seeds Aishwarya *et al.* (2014) [3]. Sunflower is grown all over the world primarily for its protein and oil content. The distribution of amino acids in sunflower seed proteins is favorable. Additionally, sunflower seeds include a significant number of tocopherols, minerals, and vitamins Skorić *et al.* (2009) [52]. The most important thing for every person is their health. A broad approach is required in the current environment of increasing health problems in order to control the range of factors that contribute to the development of different illnesses. The benefits of oil seed crops for promoting health and preventing disease have been emphasized recently. The significant health benefits of sunflower seeds have also drawn attention Muhammad Anjum*et al.* (2012) [41].

1.2 Overview of sunflower seeds and their potential in food industry

Sunflower is grown all over the world primarily for its protein and oil content. The distribution of amino acids in sunflower seed proteins is favorable. Additionally, sunflower seeds include a significant number of tocopherols, minerals, and vitamins Skorić *et al.* (2009) [52]. acid (C18:1), fatty acids lower total and Low Density Lipoprotein cholesterol, which lowers the risk of coronary heart diseases Chowdhury *et al.* (2007) [14]. which has anti-inflammatory, cardioprotective, and anti-tumor properties by neutralizing free radicals, scavenging them, and preventing oxidative damage to cellular and molecular components. Sunflower seeds appear to hold promise for treating chronic inflammatory diseases such as rheumatoid arthritis, osteoarthritis, and bronchial asthma because of the anti-inflammatory properties of tocopherols. Sunflower seed oil is advantageous in lowering atherosclerosis and, consequently, issues like coronary artery disease and stroke because of the significant effect that vitamin E has on the cardiovascular system [Singh *et al.* (2005), Dutta *et al.* (2003)] [51, 19]. There is no statistically significant relationship between sunflower seeds' antioxidant value of 0.153, antioxidant activity of 72.9, oxidation rate ratio of 0.271, and antioxidant activity coefficient of 279.7 and total phenolic extracts Velioglu *et al.* (1998) [59]. Maintaining the body's nerve and muscle tone depends on magnesium. Given its high magnesium content, sunflower seeds may be beneficial for bronchial asthma, migraines, muscle cramps, and high blood pressure. Another significant component of sunflower seeds, selenium, is integrated into the active site of numerous proteins, such as glutathione peroxidase [an antioxidant enzyme]. It has been discovered to lower the risk of prostate cancer because of its antioxidant activity Vogt *et al.* (2003) [65]. Sunflower is still a nutrient-dense food source for people. Numerous phytochemicals, including antioxidants, flavonols, phenolic acids, procyanidins, phytosterols, amino acids, dietary fiber, potassium, arginine monounsaturated, and polyunsaturated fatty acids, have been found to be abundant in sunflower seeds, according to studies [Alagawany *et al.* (2015), Guo *et al.* (2017)] [5, 25].

1.3 Chronological development of sunflower seeds

Numerous studies have been conducted on the nutritional and functional qualities of sunflower seeds, which are among the greatest sources of vegetable proteins (Venktesh and Prakash, 1993) [62].

Additionally, it has been studied that certain substances, including selenium, can lower the risk of developing certain cancers (WCRF, 1997) [67].

Numerous studies have shown that certain polyphenols found in sunflower seeds, including caffeic, chlorogenic, and ferulic acids, have a strong antioxidative potential that is advantageous from a technological and biofunctional perspective Velioglu *et al.* (1998) [59].

Velasco *et al.* (2002) [61] found that the average tocopherol content of 669.1 mg kg-1 seed was composed of 2.0 percent gamma-tocopherol, 5.6 percent beta-tocopherol, and 92.4 percent alpha-tocopherol. assortment of commercial hybrids.

Sunflower seeds are good source of these minerals provided the mineral content of sunflower seeds as follows. Calcium (78 mg), iron (5.25 mg), magnesium (325 mg), phosphorus (660 mg), potassium (645 mg), sodium (9 mg), zinc (5 mg), and copper are all present in 100 g of seeds 1.80 mg, 53.0 mcg of selenium, and 1.95 mg of manganese, USDA (2008) [58].

For the dehulled kernels, the total phenolics content (TPC), which was calculated by adding together the amounts of each component separately, varied between 2938.8 mg/100 g and 4175.9 mg/100 g dry matter (DM) and from The TPC from sunflower kernels varied by around 30%, whereas the equivalent shells varied by about 52%, ranging from 40.8 mg/100 g to 86.0 mg/100 g DM. As anticipated, the sunflower kernels' TPCs were up to 100 times greater than the shells' (Weisz *et al.*, 2009) [68].

2. Nutritional Composition of Sunflower Seeds

2.1 Macronutrients

Among the nutrients included in 100g of sunflower seeds are 5.5% moisture, 19.8% protein, 52.1g fat, 1g fiber, 17.9g carbohydrate, 620kcal of energy, 280 mg calcium, 670 mg phosphorus, and 5 mg iron Gopalan *et al.* (2007) [22].The vital amino acids, vitamin B, minerals, and strong antioxidants found in sunflower meal make it an intriguing nutritional food for people and a composite feed for animals Wanjari *et al.* (2015) [66]. According to the findings, all types cultivated during the dry season had high levels of oleic acid, with plants that received a lot of sunlight but little rainfall and relative humidity at seeding having the greatest levels. In this case study Farid *et al.* (2015) [20].

2.2 Micronutrients

There have also been reports of the presence of several important amino acids in sunflower products, including aspartic acid, glutamic acid, serine, histidine, glycine, threonine, arginine, alanine, tyrosine, cysteine, valine, methionine, phenylalanine, isoleucine, leucine, lysine, and proline Karangwa *et al.* (2015) [30]. Minerals such as calcium, copper, iron, magnesium, manganese, selenium, phosphorus, potassium, sodium, and zinc are abundant in sunflower seeds, as are vitamins E, B, folate, and niacin. Sunflower seeds' medicinal potential has generally been demonstrated to be effective in treating colds and coughs, acting as a diuretic and expectorant, replacing quinine, and preventing malaria Islam *et al.* (2016) [29].

2.3 Bioactive compounds
In this case study Sukkasem *et al.* (2013) [54], experiments were conducted and found that, they planted sunflower seeds during two growing seasons—the dry and the rainy-to examine the effects of planting dates, temperatures, genotypes, moisture, solar radiation, and other environmental conditions on the amount of oleic acid in the seeds. Temperature, rainfall, sun radiation, and relative humidity readings were recorded, and the seeds' oleic acid content at maturity was assessed. Although the processed sunflower seeds are low in carbohydrate, they are rich in fatty acids, proteins, and dietary fiber. They are also a good source of vitamins, minerals, and antioxidants Shahbaz *et al.* (2018) [50].

2.4 Comparative profile with other seeds and grains
According to study Farid *et al.* (2015) [20], linoleic acid accounted for 43% of the fatty acid content of pumpkin and 61.68% of that of sunflower oil. After linoleic acid, which contributed 35% to pumpkin and 27% to sunflower, oleic acid took the second-largest share. Environmental conditions have a significant impact on sunflower's oil content and fatty acid. The two main important factors are soil moisture content and average daily temperatures. Sunflower growth requires a variety of conditions, including healthy seeds, moderate rainfall, and fertile soil. Among the three most important oilseed crops grown worldwide today-sunflower, rapeseed, and soybean—sunflower has emerged as a significant supplier of high-quality edible oil that is crucial for cooking Pal *et al.* (2015) [44]. Sunflower seeds are a promising source of protein that can be used in food preparation in place of soybeans, whose output is limited de Morais Oliveira *et al.* (2016) [17]. There are a number of essential and fixed oilseeds from which edible oils have been derived, including sunflower, canola, soybean, cotton, groundnut, peanut, linseed, flax, sesame, rape, jatropha, jojoba, and castor seeds. While fixed oils are made from the seeds of oil plants and are edible and have a high nutritional value, essential oils are volatile and typically extracted from the non-seed sections of plants and used to make flavors, deodorants, perfumes, antiseptics, and medications Blasi *et al.* (2018) [12]. Sunflower cultivation may be more competitive with other crops like maize, soybeans, and sorghum in some nations, such as South Africa and India Vijayakumar *et al.* (2016) [64]. Sunflower seed flour enhances dietary protein content and provides value when combined with other cereal crops. Linoleic acid (55-70%) makes up a larger portion of the oil produced from sunflower seeds than oleic acid (20-25%). High antioxidant content and an anti-cholesterol and low-density lipoprotein propensity were demonstrated by sunflower seeds. Additionally, compared to other oilseeds such as safflower seed (28.2%), sesame (25.5%), fax (22.4%), cottonseed (18.1%), peanut (13.1%), and soy (3.5%), it has a higher percentage of polyunsaturated fatty acids (31.0%) Saunders *et al.* (2013) [48].

3. Health Benefits of Sunflower Seeds
3.1 Cardiovascular health
Sunflower seeds and oil's nutritional makeup determines their functional qualities; they are also useful in avoiding or managing human conditions like diabetes, cancer, high blood pressure, high cholesterol, and coronary heart disease Katsarou *et al.* (2015) [31]. Atherosclerosis, rheumatoid arthritis, asthma, osteoarthritis, colon cancer, diabetes, sudden heat sensation in menopausal women, high blood pressure, stroke, heart attack, cardiovascular disease, and migraine headaches are all significantly decreased by consuming foods high in vitamin E and magnesium Bashir *et al.* (2015) [8]. In this case study Akrami *et al.* (2018) [4] they compared the effects of eating 25 milliliters of flaxseed and sunflower seed oil daily on blood pressure, lipid peroxidation, serum glucose, and lipid profiles in patients with metabolic syndrome were. While there was no decrease in fasting blood sugar, there was a notable drop in levels of triglycerides, low density lipoprotein cholesterol (10.8% in sunflower seed oil and 5.6% in flaxseed oil), and the total cholesterol. Subjects in both groups saw a decrease in weight as well, however those who just consumed flaxseed oil saw a decrease in their waist circumference. Consuming sunflower oil aids in preserving the body's levels of cholesterol and low-density lipoprotein, which is beneficial for treating ailments including arthritis, acne, and hair loss. Due to its easy accessibility and health benefits, sunflower oil is the favored oil throughout most of Europe, Mexico, and some South American countries. Sunflower oil extracts, which make up 1%-4% of the total mass of chlorogenic acid, are good phenolic antioxidants. Additionally, it contains phytosterols, which aid in changing the production of cholesterol and lowering serum cholesterol levels through cholesterol excretion Zoumpoulakis *et al.* (2017) [70]. Sunflower seeds' high protein content and nutritional composition may help increase the amount of protein in people Dadalt *et al.* (2016) [16].

3.2 Antioxidant properties
Based on its status as a significant functional food with several health advantages, the antioxidant content can be evaluated. Therefore, it might be regarded as a therapeutic dosage for the treatment, avoidance, and regulation of frittering illnesses linked to reactive oxygen systems Cao *et al.* (2019) [13]. Some scientists with a deeper understanding of the nutritional and bioactive compounds of sunflowers have focused their research primarily on this topic due to the presence of natural compounds in plants. Previous studies have reported high antioxidant activity and other nutritional value in sunflower [Alagawany *et al.* (2015), Karangwa *et al.* (2015),Malik *et al.* (2018)] [5, 30, 38].

4. Processing of Sunflower Seeds for Food Applications
As composite functional foods, sunflower seeds can be roasted, baked, boiled, or processed into flour Grasso *et al.* (2019) [23].

4.1 Sunflower seed by product
The biggest by-product of an industry's sunflower seed oil extraction process is sunflower meal. In addition to being a great source of protein for human consumption, it is also used as a supplement in ruminant and nonruminant feeds to improve relative biomass generation, animal development, and milk production. Leucine, valine, isoleucine,

tryptophan, alanine, phenylalanine, and other essential amino acids, as well as sulfur-containing amino acids like cysteine and methionine, are abundant in it. Minerals and vitamins like phosphorus, thiamine, nicotinic acid, pantothenic acid, riboflavin, and biotin aid in the development and growth of muscles Laguna *et al.* (2018) [36]. Because of its high fiber content and lower levels of protein and metabolizable energy, it is occasionally seen as having less nutritional value than rapeseed, cottonseed, and soybean meals. Additionally, one of the leftovers from the extraction of sunflower seeds is oil cake. It has 50% protein, which is necessary for animal feed supplements. It has a high fiber level that is comparable to 72% soybean oil cake. In South Africa and other nations like Tanzania, sunflower cake serves as the primary ingredient in animal feed. Tanzania typically exports sunflower cake to India and Kenya in exchange for cash because of their tiny cattle and little industry Mmongoyo *et al.* (2017) [39]. The main byproducts that are left behind after the oil is extracted from the seeds are oilcakes. Before being stored, the water is then removed by air drying them. They are occasionally formed into two shapes: pellets and flour, which is ground material. Press-cake, meal, and oil meal are all interchangeable with this phrase. In terms of appearance, sunflower meal has the original raw material's flavor and fragrance, free of musty, moldy, rancid, or alien odors. It shifts from black to gray Bochkarev *et al.* (2016) [10].

4.2 Oil extraction

Sunflowers are preferred over other oilseed crops because they produce roughly 87% of vegetable oil. It is a cost-effective and promising crop that has numerous advantages for improving valuable market goods, generating revenue, and reducing poverty. However, its full potential has not been fully realized along food value chains due to severe weather and a dearth of viable seeds available to farmers. If effectively utilized, the yield can be investigated to the fullest extent as a substitute for the current oil crops, including peanuts, soybeans, rapeseed, palm oil, and palm kernel oil Bassegio *et al.* (2016) [9]. Oil-producing plants are the primary source of oilseeds. The production of the four main oil crops in the world—sunflower, oil palm, soybean, and rapeseed-mustard—per metric million tons is shown in Table 1. In order to generate revenue from home production and to support the global economy, the need for edible and non-edible oils continues to rise in undeveloped, developed, and developing nations. The capacity of sunflower oilseeds to yield significant and high-quality oil is their most advantageous feature. Research on using bioinformatics and biotechnological techniques to cultivate sunflowers for the highest possible output of seeds and oils is still ongoing Aremu *et al.* (2016) [6]. Sunflower oil is typically categorized as a nonvolatile oil that is produced by processing sunflower seeds. It is frequently utilized as a primary ingredient in food preparation processes including frying and the creation of emollient cosmetics Lai *et al.* (2017) [35].

5. Application in Functional Food Product Development

In this case study Srivastava, S. and Verma, D.K. (2014) [53], in order to create three value products—"Laddoo," "Biscuit," and "Missi roti" evaluated the nutritional profile of sunflower seed flour and added it at 15%, 25%, and 35% levels. Sunflower seeds increased the nutritious value of the products. The laddoo had a higher proportion of energy (683.35 kcal), fat (40 g), calcium (134 mg), phosphorus (465.25 mg), and iron (5.53 mg) than biscuits, which contained protein (17.41 g), energy (551.15 kCal), fat (22.82 g), calcium (132.75 mg), phosphorus (368.55 mg), and iron (4.03 mg), except for protein (14.79 g). Of the three items, the biscuit contained the highest levels of protein, calcium, and phosphorus (18.52 g, 151.8 mg, and 487.47 mg), but the lowest levels of fat (21.32 g). Many households use the oil extracted from processed sunflower seeds for cooking, and it is also utilized as a raw material in the food sector to make butter, margarine, bread, and snacks Kottapalli *et al.* (2020) [34].

5.1 Fortified and Gluten-Free Products

Gluten ingestion is the cause of the disease in genetically predisposed individuals. However, it should be mentioned that eating gluten might lead to other conditions besides celiac disease. A significantly greater number of illnesses, such as gluten hypersensitivity or allergy, are referred to by the broad phrase "gluten-related disorders." The number of patients undergoing treatment for these conditions who are required to follow a gluten-free diet continues to rise [da Costa Borges *et al.* (2021), Salehi *et al.* (2019)] [15, 47]. Compared to traditional cereal goods, it contains fewer active components. It is typically characterized by a larger concentration of accessible carbs and fat but much lower levels of protein, minerals, vitamins, and dietary fiber [Foschia *et al.*, Korus *et al.* (2012)] [21, 33]

5.2 Blending with other flours

Bread created from mixes of these flours with buckwheat flour had intermediate volume values, but rice bread had a substantially higher volume than corn bread. As a result, the qualities of the fundamental ingredients that are utilized in the recipe could be crucial. The existence of gas bubbles trapped in the porous crumb skeleton, which is mostly made up of denatured proteins, gelatinized starch, and functional additives, is linked to the characteristics of the crumb's porous spatial structure and, consequently, the bread volume in the case of gluten-free bread Diowksz *et al.* (2008) [18]. When sunflower meal protein isolate (SMPI) was added to wheat bread at a 12% supplementation level (along with thick sourdough starter), no discernible changes in bread volume were observed. The type of flour used also affects how much gluten-free bread is made. In past research Różyło *et al.* (2015) [46].

6. Functional and Sensory Evaluation of Sunflower Seed Products

When building different agricultural machinery and equipment for tasks like planting, harvesting, cleaning, quality assessment, categorization, dehulling, milling, packaging, storing, and oil extraction, the physical attributes of the seeds are crucial Araujo *et al.* (2018) [7]. Dimensional, gravimetric, compressive, and frictional (angle of reaction and static friction) are the four categories into which physical attributes can be divided Ortiz-Hernandez *et al.* (2020) [42]. Dimensional properties such as length, width, thickness, area, volume, sphericity, equivalent diameter, and projected area provide details on the shape. Rather, gravimetric properties include mass, bulk density, actual density, and porosity Igbozulike *et al.* (2019) [28].

6.1 Methods of evaluating sensory properties (taste, texture, color)

Examined how adding sunflower meal (SFM) to find bread produced a darker brown product as compared to the control sample. The SFM-supplemented bread's crumb, on the other hand, had lower values of parameters a* and b* than the control bread. When comparing the SC-enriched gluten-free loaves to the control sample, the color evaluation results clearly show a considerable darkening of the crumb Gumul *et al.* (2020) [26]. Since the temperature inside the bread is lower and has less effect on color change, the color of the crumb typically resembles the color of the additions. The parameters a*, b*, and C* increased as a result of the fortification. Analysis of gluten-free bread treated with sunflower protein concentrate (SPC) revealed the similar trend of alterations in crumb color characteristics Zorzi *et al.* (2020) [71]. Added 10% DC to plain flour to produce bread with better sensory qualities Bhise *et al.* (2014) [11]. demonstrated the improved technological qualities, greater digestible protein content, and favorable consumer acceptance of biscuits made with ordinary flour enhanced with 10% DC. Likewise, additional by-products, such as strawberry seed cake or apple cake, were incorporated into the recipe [Korus *et al.* (2012), Gumul *et al.* (2021)] [33, 24]. Demonstrated that adding DC to muffin batter at varying concentrations (15 and 30%) resulted in dark brown cupcakes and that the 15% DC variation had higher sensory quality than the 30% supplementation. Data from the literature indicates that adding de-oiled sunflower cake (DC) to bakery goods has a comparable impact Mohammed *et al.* (2018) [40].

6.2 Functional properties: water/oil absorption

Van Alfen, N. K. (2014) [59] used the gravimetric method to determine the moisture content. Samples weighing around 2 g were dried until there was no discernible weight loss. The procedure was conducted using a laboratory drier (POL-EKO, SLN 15 STD) at a temperature of 130 °C. The rapeseed displacement method was used to measure the volume of bread. The adopted method was used to determine the bread's moisture content AACC International (2000) [1]

7. Shelf Life and Storage Stability

7.1 Factors affecting shelf life of sunflower-based products

Lower relative humidity and temperature settings have been found to be ideal for the better conservation of conventional seeds, such sunflowers, because they permit a low degree of chemical activity in the seeds and maintain their vigor and ability to germinate Marcos Filho *et al.* (2005) [37]. While high temperatures result in increased respiration and the depletion of stored reserves, high relative humidity conditions can cause the embryo's metabolic activity to resume Aguiar, I. B. (1995) [2].

7.2 Moisture content, rancidity (oil stability), packaging effects

Maintaining the seeds' viability and vigor greatly depends on the kind of storage container they are kept in Guedes *et al.* (2012) [56]. To preserve the seeds' original moisture content, the storage packaging should aid slow down the breakdown process by reducing respiration Tonin *et al.* (2006) [57].

8. The drawbacks of conventional & extraction methods

Plant-based proteins must be isolated and fractionated intact in order to reach their full potential. This is a significant issue since plant proteins are more difficult to extract and purify than animal proteins. Proteins have up till now been widely isolated and purified via precipitation and acid/alkali treatment. However, studies reveal that when proteins are treated with alkali, lysinoalanine, a hazardous amino acid, is produced Hou *et al.* (2017) [27]. Additionally, the extreme conditions used in the alkaline extraction-isoelectric precipitation wet extraction and fractionation processes for creating plant protein isolates result in widespread protein denaturation and aggregation, which negatively impacts functioning Pelgrom *et al.* (2013) [45]. Furthermore, natural phenolic chemicals may bind with plant proteins during processing, changing the proteins' nutritional and functional qualities Ozdal *et al.* (2013) [43]. Temperature, pressure, shear, freezing and thawing, pH, ions, electrostatic, covalent, noncovalent, hydrophobic, electric field, electromagnetic field, surface tensions, hydration, and solvent force are some examples of the extrinsic factors, also referred to as stressors in the process. The thermodynamic state of the protein, together with its structural and conformational properties, will be altered by such process-induced disruptions. The protein's size, surface charge, hydrophobic/hydrophilic ratio, and molecular flexibility, for example, might all be altered. All things considered, the alteration may enhance or produce completely new protein functionality Sun-Waterhouse *et al.* (2014) [55].

9. Conclusion

Because sunflower seeds have a well-balanced amino acid profile, there is a growing need for an alternative plant protein source, which presents an opportunity for their use as a protein source. Sunflower seeds offer a unique combination of essential nutrients, bioactive compounds, and health-promoting properties, making them a valuable ingredient in the development of functional food products. Their high content of quality proteins, essential fatty acids, antioxidants like vitamin E and selenium, and dietary fiber supports cardiovascular health, immune function, and the prevention of chronic diseases. The review highlights their potential application in a wide range of food products, including gluten-free and fortified formulations, due to their favorable nutritional profile and sensory acceptability. Additionally, by-products like sunflower meal and oilcake, often overlooked, serve as excellent sources of plant-based protein and contribute to sustainability in food systems. Despite certain technological challenges in protein extraction and formulation, ongoing advances in food processing and biotechnology present promising opportunities for maximizing the utilization of sunflower seeds. Their inclusion in functional and nutraceutical food applications aligns well with the growing consumer demand for plant-based, health-oriented diets. Further research into optimizing processing methods and improving product stability will enhance their application in future food innovations.

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