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Exploring the Genetic Wealth of Sunflower (*Helianthus annuus* L.): A Comprehensive Review on Its Products and By-Products

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Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

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Review Article

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ABSTRACT

Sunflower stands out as a significant oilseed crop, pivotal not only in the production of edible oil and biofuels but also in the formulation of nutritious animal feed. Particularly noteworthy are the diverse opportunities presented by sunflower by-products. From the nutrient-rich sunflower oil cake to the versatile sunflower wax utilized in cosmetics and pharmaceuticals, the potential applications are manifold. Additionally, the burgeoning interest in sunflower-derived biofuels as sustainable alternatives to conventional energy sources highlights the crop's growing importance in modern agriculture. However, to meet the evolving demands sustainably, an in-depth analysis of sunflower cultivation practices and nutrient management strategies for optimal productivity is imperative. This

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review provides a comprehensive overview of sunflower cultivation techniques, processing methods, and avenues for value addition across various sectors. Renowned for its vibrant flowers and seeds brimming with high-quality oil, sunflower holds a significant economic value. Its oil, rich in beneficial unsaturated fatty acids and essential vitamins, has garnered acclaim for its health benefits, including cholesterol reduction and cardiovascular health promotion. Thriving primarily in warm climates and exhibiting resilience to drought conditions, sunflowers have witnessed a surge in demand for their sprouts, roasted seeds, oil, and even agricultural tourism ventures. With sunflower seeds and oil serving as essential components in integrated production systems, the scope for creating diverse food and non-food products continues to expand. By offering this comprehensive synthesis, this review aims to guide stakeholders towards maximizing the utilization of sunflowers across multiple domains.

Keywords: Sunflower; sustainability; products; resilience; fatty acids; essential vitamins; cosmetics; pharmaceuticals.

1. INTRODUCTION

Sunflower (*Helianthus annuus* L.) is well known as one of the main oil crops globally. Usually, the crop is indigenous to North America. However, the sunflower was first cultivated by Indians for its nutritional, medicinal value, and property to produce colors that can be used for paintings. Helianthus genus has 51 species throughout the globe among them 14 are annual and 37 are perennial. The average production of the sunflower is nearly 23 million ha in nearly 60 countries per annum. The crop is considered the 2nd largest hybrid crop and the 5th largest oilseed crop which is also used as a source of finance due to its economic value [1]. The production of the sunflower doubled between 2001 to 2014 (Fig. 1) from 21.4 Mt to 43.6 Mt. Europe, Russia, and Ukraine are the most dominant countries in terms of high production of the sunflower and its by-products [2]. On the other hand, the sunflower productivity in India has been drastically reduced over the times from 1972 to 2014. However, the area of production along with productivity of sunflowers have started declining persistently from 2006-07 onwards. The global output from sunflower production has reduced to almost 1/3rd during the last 10 years from about 15 lakh tons in 2005-06 to about 5.5 lakh tons in 2011-12.

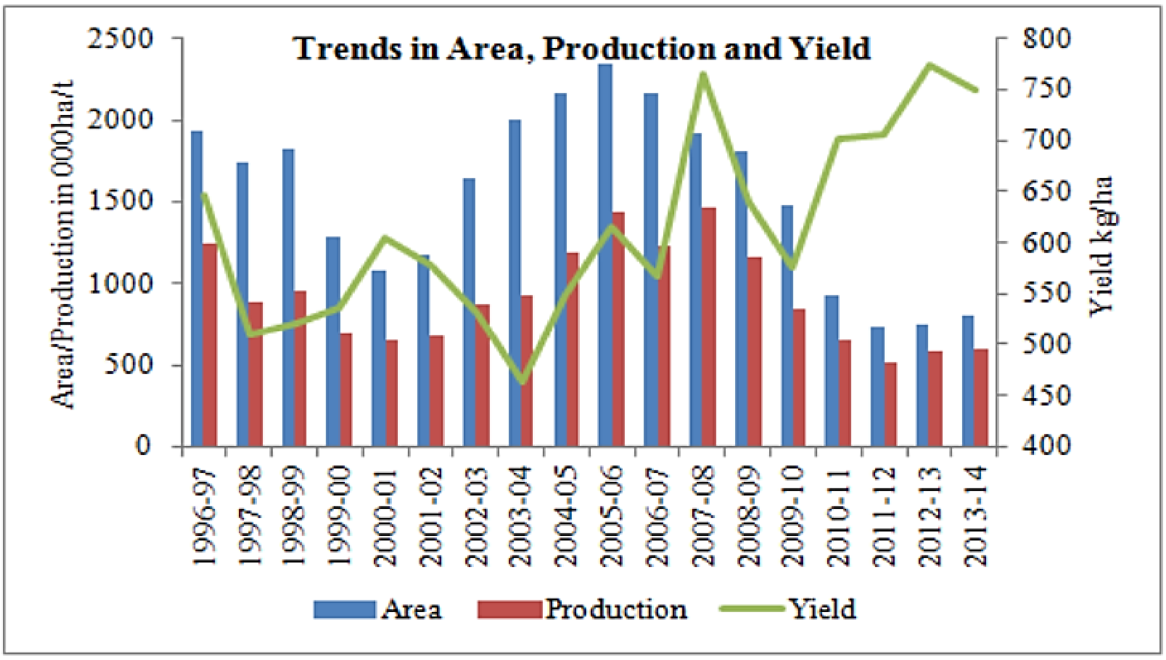

Fig. 1. The decreasing status of the yield of sunflowers from 1996 - 2014 in India. Source: [2]

Eventually, most of the varieties that are cultivated commercially are annual. The average height of the sunflowers is around 1-3 meters. The inflorescence of the sunflower involves a group of flowers including a capitulum/head. To reach the flowering stage the crop requires nearly 70 days from sowing day, on average 130 days are required for ripening the seeds and 10 days later of the ripening stage, the seeds are harvested. There are mainly two types of seeds available in sunflower, i.e., oil and non-oil type. Among them, oil-type seeds are found to be relatively smaller in size with a relatively thin shell contributing 20-25% of the seed weight. In general, the average weight of 1000 seeds may vary in the range of 30g-80g [3]. The shell of the sunflower is made of fibrous substances cellulosic materials and structural materials like lignin. 70% of the seed weight is contained by the kernel of the oil-type seeds in sunflower in which protein, carbohydrates, and mainly oils are found to be present. The average amount of oil content in the kernel is nearly around 55%. On the other hand, non-oil type sunflower seeds are of confectionary and bakery grade. These non-oil type sunflower seeds are also used for bird feed.

The components left over after the oil is extracted from sunflower seeds are known as sunflower by-products. These by-products have several applications in the food industry and feed industry. Sunflower oil produces oil meals, and press cakes, among other by-products, are high-protein diets for farm animals [4]. Similarly, other authors suggested the production of Sunflower press cake, a protein-rich feed additive based on sunflower oil meal and limestone flour are a few of the by-products of sunflower that have high prospects and utility [5]. The qualitative parameters of seeds of sunflower crops and the by-products can produce a protein-rich feed additive. Animals and poultry can be fed the supplement. On the other hand, the sunflower by-products are also used in the production of biofuels. several by-products such as husks of sunflower seeds can be used to produce fuel for power plants. Additionally, sunflower oil can be utilized as a feedstock for the synthesis of biodiesel [6]. Therefore, further investigation into the potential of by-products derived from sunflowers is necessary. The nutritional aspects of sunflower not only help to prepare various types of medicines but also can cure diseases and provide solutions against obesity and fat-related issues. Other than that, sunflower oil is also found to be capable enough to produce energy which can be an asset in terms of sustainable energy production. Hence, a brief discussion has been covered within this review paper, on how sunflower production can be enhanced through the efficient application of nutrients and the prospects of its by-products for mankind.

2. PRODUCTS AND BY-PRODUCTS OBTAINED FROM SUNFLOWER AND ITS USES

Sunflower, known primarily for its oil-rich seeds, offers a spectrum of valuable outputs beyond traditional cooking oil. The schematic depicts the extraction process, highlighting the steps involved in obtaining high-quality oil, which serves as a staple in culinary practices worldwide. Additionally, the figure showcases the utilization of sunflower by-products, such as oil cake and wax, emphasizing their significance in animal feed and cosmetic formulations, respectively. Sunflower oil cake stands out as a nutrient-rich feed ingredient, contributing to the nutritional needs of livestock and poultry. Meanwhile, sunflower wax finds application in the cosmetics industry, serving as a natural alternative in skincare products like creams, moisturizers, and lip balms. Furthermore, the figure underscores the emerging trend of biofuel production from sunflower seeds, showcasing its potential as a renewable energy source. By providing a comprehensive overview of sunflower products and by-products, Fig. 2 elucidates the multifaceted role of this crop in supporting agricultural sustainability and fostering innovation across various sectors.

2.1 Sunflower Oil

Sunflower oil has gained prominence in human diets owing to its rich, high-calorie nutritional content The oilseeds are primarily used as a means of obtaining vegetable oil, which exhibits specific physical and chemical characteristics [7]. It is now widely accepted that the chemical composition of sunflower oil has been extensively researched and documented. According to researchers, sunflower oil contains polyunsaturated fatty acids like ω-6 and ω-9, that protect against atherosclerosis [8]. Furthermore, it improves the performance of essential organs like the liver, gall bladder, and also kidney. Moreover, the inclusion of vitamin F in the oil helps prevent blood clotting. vessels and helps dissolve any existing atherosclerotic plaques [9]. According to Filho and Egea, 100g of sunflower seed `contains 15g of protein, 58g of fat, 24g of carbohydrate, 3g of ash, and 675 Kcal energy. The process of crushing sunflower seeds yields oil that is between 25% and 33% of the original weight of the seeds [10]. Using ethanol as a solvent in the Soxhlet extraction method leads to a reduction of 70% in waxes that tends to crystalize eventually, causing instability of the oil and yielding a minimum of 38% more tocopherols and phospholipids in the extracted sunflower oil [11]. The traditional process of extracting sunflower oil involves three stages. First, the seeds are prepared for extraction. Second, mechanical extraction is performed, yielding a press cake also known as an oilcake with an oil content ranging from 16% to 24%. Lastly, the oil is extracted from the press cake or expanded material, known as "collets," using a solvent. Finally, it is commonly accomplished through a counter-current mechanism, employing n-hexane as the solvent [12].

2.2 Sunflower Oil Cake

Oilcakes are residual materials obtained following the extraction of oil from seeds. They are categorized into two types: edible and non-edible [13]. Two varieties of cold-pressed sunflower oilcake have different functional, physical, and chemical characteristics [14]. Two different forms of sunflower cakes are mainly formed after drying and shaped into pellets and cakes. the pellet and the cake form are represented as SFOC/PE and SFOC/C. The material's color shifts from black to gray as it undergoes processing [15]. The stability of oilcake over an extended period mainly depends on maintaining an optimal moisture content [16]. A storage humidity level of less than 12% inhibits rapid mold growth [17]. Studies revealed that the moisture content for meal pellets is 8.75% and for meal cakes is 8.93%. Other authors reported that some other oilseed crops like sesame, soybean, flaxseed, and rapeseed have very similar values but relatively much lower values were observed in pumpkin and hemp [18,19,20]. Sunflower oilcake is produced for human consumption if the amount of protein (20-25%) and lipid (3-5%) ratio are equal [14]. If the amount is not equal and the fat percentage is higher, it is not good for human health. Typically, meal is incorporated into animal diets as feed due to its high protein content, increasing biomass [21,22,23]. Oil cakes are high in lipids and protein and thus are also good for feeding fish and omnivorous, but they are also high in fibre for ruminants. Research indicated that sunflower oilcake increased the amount of pig carcasses produced [24-25]. Physical and functional properties of different forms of sunflower oil cakes tabulated in (Table 1). A significant difference was observed between the two oilcakes in water holding capacity (WHC), with a p-value of less than 0.05 ($p<0.005$) [26].

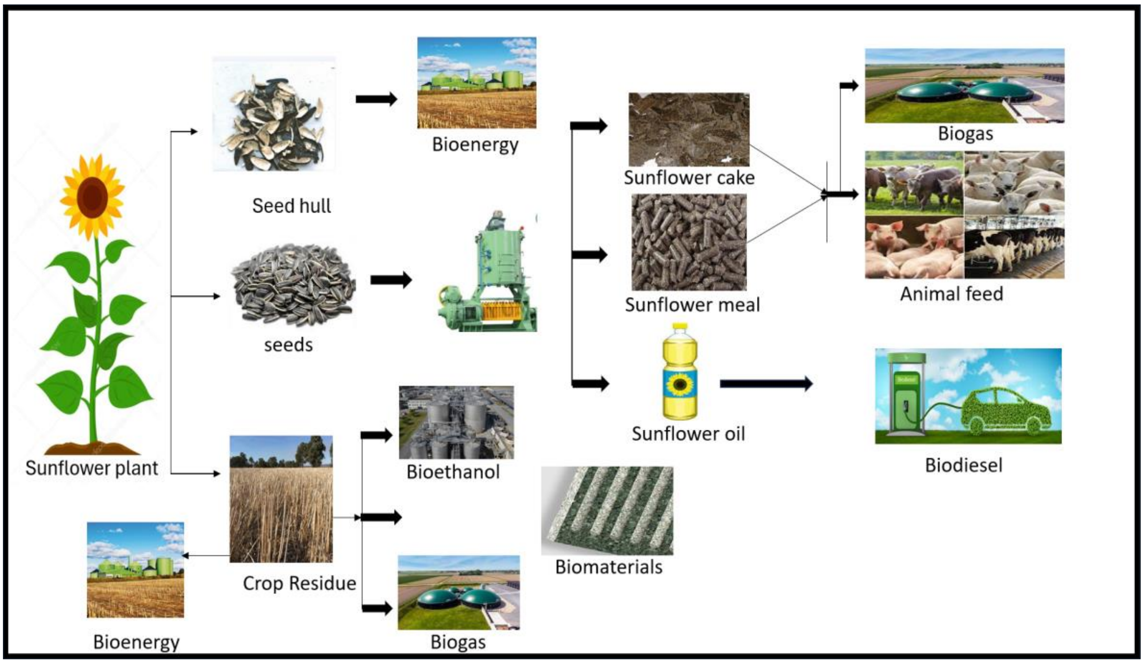

Fig. 2. Diagrammatic representation of the use of products obtained from sunflower

Table 1. Physical and functional properties of different forms of sunflower oil cakes

S. No.	Parameters	SFOC/PE	SFOC/C	Significance of the parameter
1	Moisture content	8.75 ± 0.10	8.93 ± 0.11	Moisture content is crucial for preserving the stability of oilcake over extended periods [16].
2	Water holding capacity (WHC)	2.58 ± 0.11	2.33 ± 0.07	This parameter plays a significant role in establishing the appropriate conditions for storage [26].
3	Bulk density (BD)	0.4196 ± 0.002	0.4204 ± 0.001	It holds significance in the food industry's packaging and handling procedures [16,27].
4	Emulsion stability (ES)	32.17 ± 1.15	30.62 ± 2.14	ES quantifies the rate at which water is separated from the emulsion over a while [16].
5	Oil holding capacity (OHC)	1.34 ± 0.13	1.18 ± 0.08	It is particularly important in various food processing and cooking applications, as it influences the texture, flavor, and overall quality of the final product.
6.	Swelling capacity (SC)	3.56 ± 0.06	3.19 ± 0.17	swelling capacity lies in its ability to indicate the capacity of a substance to absorb and retain water or other liquids also plays a role in assessing the absorbency, stability, and functionality of materials in industries

Results are given in the form of values ± standard deviation (S.D.) (source: [13])

2.3 Sunflower Meal (SFM)

Sunflower meal (SFM) is a by-product of the sunflower oil industry and is increasingly being incorporated into animal and poultry diets. [22]. SFM is an incredible source of protein. Sunflower meal complements soybean meal for nutritional needs and is a tasty source of protein and fibre with a high roughage factor [7]. SFM has the potential to serve as a replacement for soybean meal (SBM) in poultry diets [28]. SFM can be added to a non-ruminant animal diet in amounts ranging from 50-150 g/kg [29,30]. One of the main benefits of utilizing SFM in chicken is that it is less expensive than SBM and contains no harmful chemicals or any antinutritional elements that could reduce productivity [30,31]. In addition to its traditional use as cattle feed, SFM is increasingly recognized as a promising raw material for the synthetics of essential products, like emulsifiers, peptides, protein isolates, biomaterials, etc. They have large concentrations of phenolic chemicals that are currently underutilized and have antioxidant or antibacterial properties [32].

2.4 Sunflower Wax

Sunflower waxes typically occur on the coating of the hull of sunflower seeds, where they can be observed in concentrations to three percent, depending on the hybrid and seed source [33,34]. The amount of wax removed along with the oil is determined by the degree of dehulling and the extraction technique (solvent extraction or pressing, for example). The amount of wax formed in the oil can therefore differ depending on the type of seed, where it was sourced from, how much of the hull was removed, and the technique and temperature employed during the many stages of processing that produced the oil [34-36]. Sunflower wax is derived from the winterization process of sunflower oil. Winterization also known as dewaxing is the traditional technique that involves a slow crystallization and filter-mediated separation. The process entails first cooling the oil and agitating it gently to cause the waxes to crystallize. Next, the oil is filtered through a filter to eliminate the crystals from the oil [37]. Waxes typically exhibit low solubility. and can crystallize at room temperature, causing turbidity in refined oils. As a result, they are considered undesirable materials. There are two sources of sunflower wax, standard sources- seed hull and crude wax from oil refineries [11]. According to studies sunflower wax can be used to enhance the photochemical characteristics and efficacy of several products like moisturising cream, candles, coating, ointments, and lipsticks as a substitute for beeswax, mineral wax, and carnauba wax. It can also increase strength, viscosity, drug diffusion, etc. Since sunflower wax comes from a plentiful and renewable source, it can be regarded as an affordable and environmentally beneficial component [38].

2.5 Sunflower Stalk

The stalk of a sunflower is spherical or ribbed, filled with spongy tissue inside, and coated in scratchy hairs. The outside of the stalk is covered in bark. Ninety percent of the sunflower's volume is made up of the stalk. Bark weighs 350 kg per cubic meter, while spongy tissue weighs 29 kg per cubic meter. When the seed ripens, the leaves and the stalk attached to it undergo drying. The stalks consist of cellulose ranging from 34% to 42%, hemicellulose ranging from 19% to 33%, and lignin ranging from 12% to 30%. The stalks have an ash level that ranges from 3 to 13.2%. Stalks from sunflowers can be utilized as fertilizer, energy, and fodder. Sunflower stalks exhibit a melting temperature of ash similar to straw and lower than that of wood chips and maize stalks. This aspect should be taken into consideration when choosing heating equipment [6]. It is easy to divide the stalks into two sections: the pith (internal part, 10%) and the fibre (external part, 90%). We looked into the mechanical characteristics of paper pulp made from whole or depicted stalks that underwent thermo-mechanical treatment in a twin-screw extruder machine. The pulps are excellent for making cardboard since they scored highly on the CMT which is concora medium test and RCT which is the ring crush test [39]. Three-layer particleboards are another product that is made using sunflower stalks. Because these panels could be made in low densities, they might be used as packaging, furniture, decorative applications, and isolation panels. [40]. Moreover, sunflower Stalks can also be used as adsorbents for color removal from textile wastewater [41].

2.6 Sunflower Seed Hull

The hull of the sunflower seed is the only unused remaining portion. The utilization of the hull has been a significant industrial issue over the years. A substantial quantity of this byproduct is released during the oil's production. As a result, the factory needs to get rid of it because it requires a very significant volume for storage. Finding a truly profitable application for the hull is challenging due to its poor economic worth [42]. Moreover, this material has several uses like as heating, feeding cattle, extracting xyloses, producing furfural, fertiliser, and agglomerated panels. It is very beneficial as a mulch material for suppressing weeds. It is biodegradable and can be used as fuel [42,43].

2.7 lignocellulosic Biomass

Plant biomass, consisting of lignocellulosic material, represents the most readily abundant resource on the planet for the generation of biofuels. Plant components like cellulose, hemicellulose, and lignin usually make up these lignocellulosic materials. As the resources of fossil fuel are depleting day by day the demand for biofuels is gaining more and more importance as an attractive fuel [44]. Bioethanol which is the alternative to fossil fuel can be obtained by using sunflower biomass as raw material, but at first, pre-treatment is needed for the destruction of the lignocellulosic material [45] (Fig. 4). One liter of ethanol can be produced from 3.8 kilograms of primed sunflower stalks by using steam pretreatment, concurrent saccharification, and fermentation [6]. If the hydration level is higher in the biomass during harvest the wet biomass can be used for the production of biogas, but before fermentation, it needs to be prepared for physical, chemical, or mechanical, destruction.

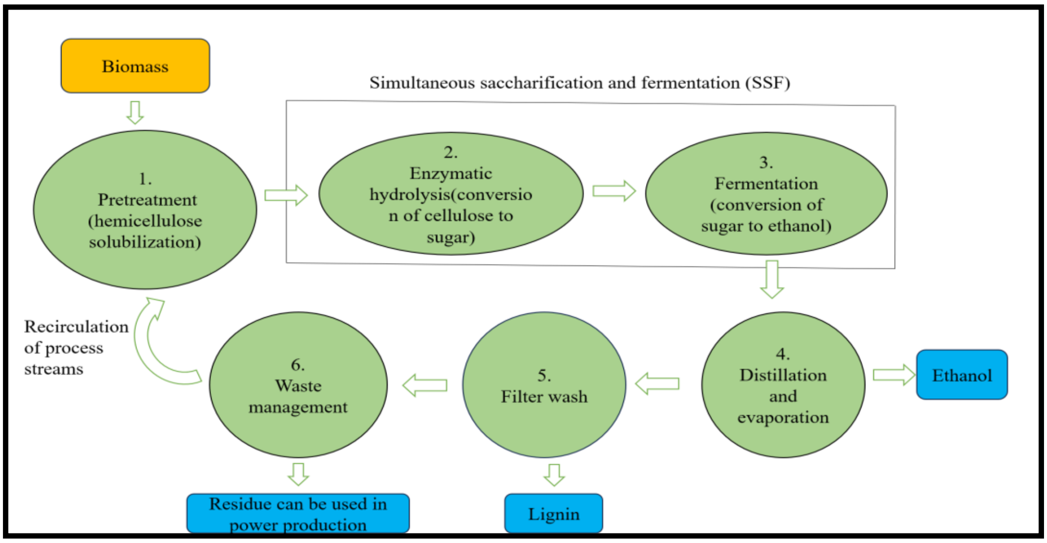

Fig. 3. Bioethanol production process from lignocellulosic biomass of sunflower

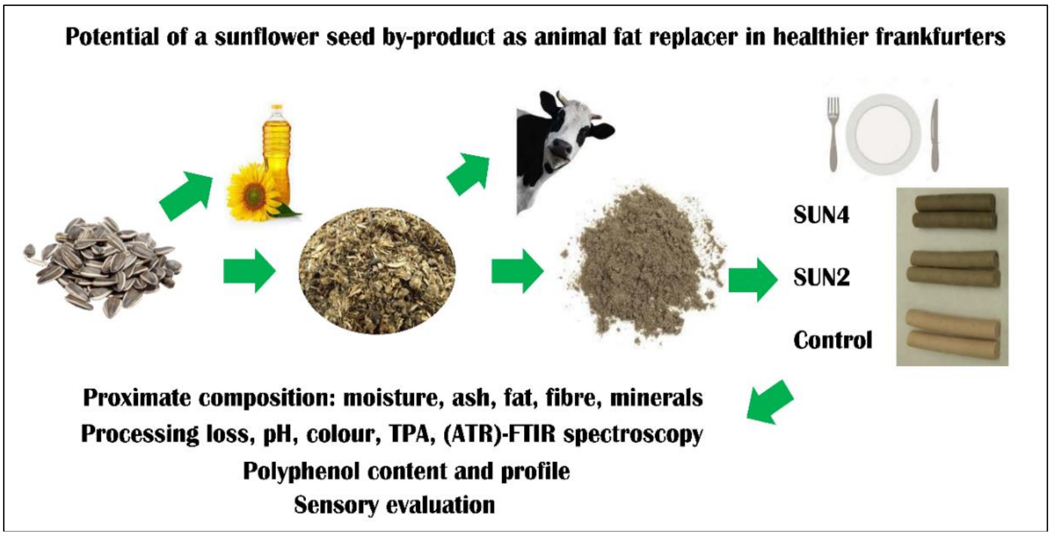

Fig. 4. Potential of a sunflower seed by-product as animal fat replacer [87]

Fig. 4 provides a comprehensive overview of the strategic framework for maximizing the potential of sunflowers in agricultural development. It highlights the multifaceted approach of the Smart Farmer concept, which integrates advanced management methodologies like the BCG model, the Internet of Things (IoT), and precision farming to enhance productivity and quality while minimizing waste. By leveraging tailored production decision-making systems, Smart Farmers can capitalize on market dynamics and regional nuances, fostering economic growth in alignment with Sustainable Development Goals (SDGs) and the broader sustainability agenda in agriculture. Moreover, the figure underscores the environmental and societal benefits of sunflower cultivation, emphasizing its role in promoting climate resilience and minimizing waste through the extraction of added value from sunflower by-products. Through strategic integration into agricultural systems, sunflowers not only unlock economic opportunities but also advance the SDGs, contributing to a more sustainable and equitable future.

3. PROSPECTS OF THE PRODUCTS AND BYPRODUCTS OF SUNFLOWER

The majority of nations produce oilseeds, which are mostly utilized to extract oil. In addition to its aesthetic value, the common sunflower is valuable economically. The flowers provide a yellow dye, the seeds are edible and contain oil, and the leaves are used as fodder. Cake made from sunflower oil is fed to livestock and fowl. Furthermore, the oil is a lubricant and is used in paints and soap. The seeds are often included in bird seed mixes and can be eaten raw, roasted, or mashed into nut butter [46].

The use and the nutritive value of sunflower oil and the different byproducts are unignorable. The nutritional composition of sunflower seeds is notable, comprising 33.85% proteins, 65.42% fats, and 18 essential mineral elements. Owing to their high lipid amount, they are mostly utilized as a provider of vegetable oils. The primary acids present in sunflower oil are oleic acid about 19.81% and linoleic acid about 64.35%, which are essential fatty acids not formulated by the human body and must be obtained through dietary intake. Sunflower oilcake has a very well-balanced amino acid profile and has higher levels of proteins (20.15% and 21.60%) and fibres (31.88% in pellets and 12.64% in cake form, respectively) [14] (Table 2).

In general, sunflower oil comprises four main types of fatty acids: high linoleic type, characterized by 69% linoleic acid (C18:2); high oleic acid type, with 82% oleic acid (C18:1); mid oleic acid type, containing 65% oleic acid (C18:1); and high stearic with high oleic acid type, which includes 18% stearic acid (C18:0) and 72% oleic acid (C18:1) [47]. Sunflower oil has a longer shelf life than high oleic sunflower oil since the rates of oxidation of the former oil were significantly lower at 40 °C in the dark [48]. This discovery confirmed that high oleic acid type sunflower oil surpassed many unsaturated oils in most oxidation tests, aligning with previous research findings [49].

Sunflower oil contains a significant amount of polyunsaturated fatty acids (PUFAs), while the content of saturated fatty acids (SFAs) is relatively low. This composition makes the oil a healthy choice for consumption. Low SFA in diet results in decreased total cholesterol and lowers the risk of cardiac arrest. The pellet and the cake form of sunflower oil cake have a protein content of about 20.12% and 21.60% respectively. The oil cake is also a high source of fibre. The fibre content in the Pettet form is 31.88% and in the cake is 12.64% [14]. Sunflower oilcake provides methionine, valine, leucine, isoleucine, tryptophan, cysteine, alanine, and phenylalanine as necessary amino acids [51]. In terms of vitamins and minerals, the most common ones are riboflavin, phosphorus, thiamine, pantothenic, and nicotinic acids [52].

Table 2. Nutritional composition of sunflower oil (100 gm)

S. No.	Elements	Amount in 100 gm
1	Energy	900 kcal or 3700 Kilojoule
2	Saturated fatty acids	11 to 12 gm
3	Mono-unsaturated fatty acids (MUFA)	24 to 27 gm
4	Polyunsaturated fatty acid (PUFA)	62 to 64 gm
5	Of which omega-6	62 to 64 gm
6	Of which omega-3	0 gm
7	Vitamin E	45 to 90 mg

Source: www.botanical-online.com [50]

Table 3. Nutrient composition of Sunflower Meal (SFM)

Crude Fibre%(CF)	Crude Protein%(CP)	Dry Matter%(DM)	Ether Extract%(EE)
28.73	29.72	89.32	12.53
18.40	32.60	90.23	-
25.21	33.14	-	2.77
23	31.40	89.09	-
11.54	32.30	90.20	18.78
21.20	30	88.00	2.50
27.23	33.52	91.48	3.11
22.18	31.81	89.72	7.93

For cattle, sunflower oil cake is an excellent source of fat and protein. It is a valuable addition to many cattle diets used for dairy purposes, as it can supply nitrogen in the form of rumen-degradable protein, that rumen microorganisms need. When compared to meals of canola and soybean, the protein present in sunflower meal exhibits higher ruminal degradability, often surpassing 60%. The protein percentage of the sunflower meal is approximately 60-65% for the kernel and 30-40% for the hull (shell). In sunflower meal, about 30 to 34% crude protein, 20 to 25% cellulose, and 8 to 10% lignin are present [53]. The results of multiple authors' chemical analyses of SFM's nutritional content are displayed in table 3. As a result, there was significant variation in the chemical composition of SFM; The crude fiber (CF) percentage varied from 11.54% to 28.73%, averaging 22.18%. Meanwhile, the values for crude protein (CP) ranged from 29.72% to 33.52%, and for dry matter (DM), they fell between 88.00% and 91.48%. Additionally, Table 3 shows that the ether extract (EE) concentration varied from 2.50 to 18.78%, averaging 7.93%.SFM is safe to add to chicken diets at relatively high levels without negatively affecting egg quality standards or productive performance [54- 56].

Wax is primarily an ester of fatty acid (FA) along with fatty alcohol which has around 36-50 carbon atoms [57]. Esters with carbon atom counts ranging from 36 to 48 made up the majority of crude sunflower oil waxes and a notable concentration was found in the C40–C42 fraction. Oil processing and marketing are hampered by waxes' tendency to Crystallization which causes turbidity as the oil cools. To achieve an obvious oil unaffected by low storage temperatures, wax is partly eliminated by refining during the winterization or dewaxing. The amount of wax in the oil is influenced by varied aspects such as variety, origin, methods of processing, extraction techniques like pressing or solvent extraction, etc. As a result, the overall wax concentration of refined sunflower oils can reach up to 0.06 weight percent while crude sunflower oils can range from 0.02 to 0.35 weight percent [58-60].

However, researchers suggest that biofuel is considered the major and most important by-product of sunflowers that can be used as a substitute for diesel and petrol. Although results from their research conclude that the production of bio-fuel from sunflower cannot meet the global demand as a substitute for the fuels that are used in automobile vehicles, however can be used in certain regions under a sustainable approach [61]. The findings from the research conducted in Italy suggest that the biodiesel potential, estimated at 95,000 tons per year, equates to saving 104,400 tons of CO2 equivalent per year of greenhouse gases and 26,500 tons of oil equivalent per year of fossil energy. Regarding the prospect, the authors reported two scenarios that involve the requirement of biodiesel to make a complete substitute of the traditional fuels that are used in auto-vehicles [62]. The data has been derived from European countries and were analyzed. The analyzed data indicates that while the 2010 target of replacing 5.75% of transportation diesel fuel was achievable, meeting the 2020 target of reaching a 10% replacement is not feasible. This is because local biodiesel production could only fulfill 4.78% of the diesel fuel requirement. Sunflower crops were used for the development of hydrocarbon biofuel with the help of a Zeolite Socony Mobil-5 (ZSM-5) catalyst under a fixed bed reactor in respectively three different temperatures such as 450^0 C, 500^0 C, and 550^0 C. The results from the experiment have displayed that the highest hydrocarbon biofuel yield can be obtained through the upgradation of sunflower meat oil at 500 °C. Eventually, the maximum profit of sunflower meat hydrocarbon biofuel was considerably 8.5% greater than the maximum profit of seed hydrocarbon biofuel. The experiment indicates that the reaction temperature significantly influences the distribution of uncondensed gas components. [63]. The temperature factor of the reaction has a direct effect on the yield and properties of hydrocarbon biofuel. However, the expenses associated with producing a unit of sunflower meat oil were significantly lower than those for producing sunflower seed oil. Therefore, it can be argued that sunflower meat may be a more cost-effective feedstock than sunflower seed for producing hydrocarbon biofuel.

4. SUSTAINABILITY AND FUTURE ASPECTS

The alternative use of agricultural waste materials as raw materials in the production of composites has been a hot topic of research nowadays. Effective alteration of that waste product can turn it into a by-product that can be productive as well as socio-economic. The waste is typically burned or disposed of in landfills, which pollutes the water, air, and soil eventually. Byproducts from vegetable oil processing units such as groats, flour, meals, and oil cakes are regarded as significant economic resources due to the low cost and high concentration of bioactive chemicals, which are readily found in huge numbers [64]. To ensure the well-being of future generations the circular economy concept is very famous among the food and agricultural industries recently, which emphasizes and interests the industries to use resources to its fullest and to obtain bioactive compounds from them [65-66].

It's been demonstrated that sunflower meal contains phenolic components such as chlorogenic acid, which functions as a natural antioxidant in food on the other hand it has potential use as biodegradable packaging material, thus its alternative use is profitable for the agribusiness industry [67,68]. Vegetable proteins are naturally occurring sources of high-quality nourishment and are found in oilseed plants, which are used to produce vegetable oil. Through the development and application of cutting-edge technologies that offer environmentally sustainable solutions for agriculture and the agro-industry, it is possible to produce a vast array of good-quality protein products which have implementation in the pharmaceutical and food industries [69]. In addition to being possible sources of plant protein, dietary fibre, and antioxidants, oilseed meals are typically high in chemicals that are good to health. Numerous research studies have documented the process of converting these by-products into food products with additional value, like meat and bakery goods, to improve their functional and nutritional qualities. These initiatives promote environmental zero-waste, foster the creation of innovative functional foods, and advance sustainability [26].

On the other hand, recent advances have been made in the use of biofuel from the byproducts obtained from the sunflower as well as other oil seed plants, due to their large output and high oil content, sunflower seeds are regarded as a significant renewable energy source [63]. Due to undesirable characteristics including a high freezing point and high viscosity, vegetable oil cannot be utilized directly as fuel. Transesterification, hydrocracking, thermal cracking, and catalytic cracking stand as common techniques employed to convert vegetable oil into biofuel. Transesterification is typically utilized to produce biodiesel, involving a process with alkali compounds and excess solvents. [70-71]. Several researchers have reported the transesterification of HOSUN oil (High Oleic SUNflower oil) as biodiesel. [72-73]. Higher stability biodiesel was created by HO oils than by regular oils. The economic feasibility of HOSUN oil-based biofuels would be dubious at this point, considering their comparatively high cost and restricted supply. Ultrahigh oleic sunflower oil containing 90% oleate in it, works as an excellent feedstock for the oleochemical industry [74]. Additionally, epoxidized HOSUN or its methyl esters have significant promise as crucial feedstocks for the oleochemical sector [75-77].

5. CONCERNS RELATED TO THE QUALITY CONTROL OF THE PRODUCTS

Although the contribution from the product and by-products of sunflower is enormous, there is still a concern related to the quality of it. The quality of the obtained material depends on various factors like processing, packaging, environmental factors, and management of it. Although Sunflower Meal (SFM) has an average crude protein level of 32.42%, the presence of polyphenolic compounds limits its application in animal and poultry feed. the main reason behind this is the presence of Chlorogenic Acid (CGA) in polyphenolic compounds. Several researches have shown that 70% of the SFM is CGA [78-79]. CGA is an essential part of hydroxycinnamates which helps plants in their antioxidant activities but it also significantly lowers sunflower protein's digestibility and bioavailability [80-81]. In 1999, Swick conducted research and hypothesized that the negative effects of CGA might be mitigated when SFM is used in the diet of livestock and poultry by the addition of methionine and choline supplements [82]. On the other hand, improperly dehulled sunflower cake is very high in fibre and unsuitable for pig and poultry nutrition. Protein content rises and fibre content falls during the dehulling process [83]. The quality and the stability of vegetable oil such as sunflower oil is disturbed by the presence of wax in it. Low-temperature solubility of waxes in oil results in turbidity upon crystallization. Winterization is the process by which the waxes can be removed from the oil through refining [84].

Moreover, there is a chance of microbial contamination in the byproducts. Fusarium spp. and Alternaria spp. may be the primary contaminants of the byproducts from sunflower oil production [85]. Such fungi produce toxic secondary metabolites like mycotoxin. These byproducts may harbor various heavy metals originating from both the raw materials and the production process. Despite this, they also offer nutritional benefits attributed to their content. [86]. Furthermore, while the majority of the byproducts of the vegetable oil processing units have physical, chemical, nutritional, and functional qualities, allergic reactions are still a problem for certain of these products, particularly the byproducts of soybean and rapeseed [87].

6. CONCLUSION

In conclusion, the prospects of sunflower by-products present a promising avenue for sustainable development and resource utilization. The various by-products derived from sunflowers, such as oil, meal, and hulls, offer diverse applications across industries ranging from agriculture to energy and beyond. Sunflower oil, known for its health benefits, remains a staple in the culinary world, while sunflower meal serves as an invaluable component in animal feed, contributing to livestock nutrition. Additionally, the potential for harnessing sunflower hulls for bioenergy production underscores the role of these by-products in fostering renewable energy solutions. However, the preservation period of high-fat press cakes is very limited, and the physical properties are also very poor. Therefore, the production of a protein-rich feed additive based on sunflower oil meal along with limestone flour, and sunflower press cake is suggested. The additive can be used to feed animals and poultry. The multifaceted benefits of sunflower by-products extend to environmental sustainability as well, as they provide alternatives to conventional resources, contributing to waste reduction and circular economy principles. As research and technology continue to advance, further innovations in processing and utilization methods may unlock even more possibilities for these by-products.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Kaya Y, Jocic S, Miladinovic D. Sunflower. Technological Innovations in Major World Oil Crops, Volume 1: Breeding. 2012:85-129.
2. Hulke BS, Kleingartner LW. Sunflower. Yield gains in major US field crops. 2014; 33:433-57.
3. Iegorov B, Kananykhina O, Turpurova T. Development of production technology of high-protein feed additive from by-products of sunflower oil production. Grain Products and Mixed Fodder's. 2022;22(2):17-23.
4. Rakita S, Kokić B, Manoni M, Mazzoleni S, Lin P, Luciano A, Ottoboni M, Cheli F, Pinotti L. Cold-pressed oilseed cakes as alternative and sustainable feed ingredients: A review. Foods. 2023;12(3): 432.
5. Egea MB, de Oliveira Filho JG, Bertolo MR, de Araújo JC, Gautério GV, Lemes AC. Bioactive phytochemicals from sunflower (*Helianthus annuus* L.) oil processing byproducts. InBioactive Phytochemicals from Vegetable Oil and Oilseed Processing By-products 2021 Nov 10 (pp. 1-16). Cham: Springer International Publishing.
6. Adeleke BS, Babalola OO. Oilseed crop sunflower (*Helianthus annuus*) as a source of food: Nutritional and health benefits. Food Science & Nutrition. 2020;8(9):4666-84.
7. Sarwar MF, Sarwar MH, Sarwar M, Qadri NA, Moghal S. The role of oilseeds nutrition in human health: A critical. Journal of Cereals and. 2013;4(8):97-100.
8. Aguilera CM, Ramırez-Tortosa MC, Mesa MD, Ramırez-Tortosa CL, Gil A.

Sunflower, virgin-olive and fish oils differentially affect the progression of aortic lesions in rabbits with experimental atherosclerosis. Atherosclerosis. 2002; 162(2):335-44.
9. Sarwar MF, Sarwar MH, Sarwar M, Qadri NA, Moghal S. The role of oilseeds nutrition in human health: A critical. Journal of Cereals and. 2013;4(8):97-100.
10. de Oliveira Filho JG, Egea MB. Sunflower seed byproduct and its fractions for food application: An attempt to improve the sustainability of the oil process. Journal of Food Science. 2021;86(5):1497-510.
11. Baümler ER, Crapiste GH, Carelli AA. Sunflower-oil wax reduction by seed solvent washing. Journal of the American Oil Chemists' Society. 2007;84(6):603-8.
12. Li Y, Fine F, Fabiano-Tixier AS, Abert-Vian M, Carre P, Pages X, Chemat F. Evaluation of alternative solvents for improvement of oil extraction from rapeseeds. Comptes Rendus. Chimie. 2014;17(3):242-51.
13. Cozea A, Ionescu NA, Popescu M, Neagu M, Gruia R. Comparative study concerning the composition of certain oil cakes with phytotherapeutical potential. Rev. Chim. 2016;67:422-5.
14. Petraru A, Ursachi F, Amariei S. Nutritional characteristics assessment of sunflower seeds, oil and cake. Perspective of using sunflower oilcakes as a functional ingredient. Plants. 2021;10(11):2487.
15. Bochkarev MS, Egorova EY, Reznichenko IY, Poznyakovskiy VM. Reasons for the ways of using oilcakes in food industry. Foods and Raw materials. 2016;4(1):4-12.
16. Rani R, Badwaik LS. Functional properties of oilseed cakes and defatted meals of mustard, soybean and flaxseed. Waste and Biomass Valorization. 2021:1-9.
17. Abdullah MH, Ch'ng PE, Lim TH. Some physical properties of Parkia speciosa seeds. InInternational Conference on Food Engineering and Biotechnology 2011 (Vol. 9, No. 1, pp. 43-47).
18. Popović S, Hromiš N, Šuput D, Bulut S, Romanić R, Lazić V. Valorization of by-products from the production of pressed edible oils to produce biopolymer films. InCold pressed oils 2020 Jan 1 (pp. 15-30). Academic Press.
19. Sinkovic L, Kolmanic A. Elemental composition and nutritional characteristics of cucurbita pepo subsp. Pepo seeds, oil cake and pumpkin oil. Journal of Elementology. 2021;26(1):97-107.
20. Sunil L, Appaiah P, Prasanth Kumar PK, Gopala Krishna AG. Preparation of food supplements from oilseed cakes. Journal of food science and technology. 2015;52: 2998-3005.
21. Serrapica F, Masucci F, Raffrenato E, Sannino M, Vastolo A, Barone CM, Di Francia A. High fiber cakes from mediterranean multipurpose oilseeds as protein sources for ruminants. Animals. 2019;9(11):918.
22. Alagawany M, Farag MR, Abd El-Hack ME, Dhama K. The practical application of sunflower meal in poultry nutrition. Adv. Anim. Vet. Sci. 2015;3(12):634-48.
23. Nang Thu TT, Bodin N, De Saeger S, Larondelle Y, Rollin X. Substitution of fish meal by sesame oil cake (*Sesamum indicum* L.) in the diet of rainbow trout (Oncorhynchus mykiss W.). Aquaculture Nutrition. 2011;17(1):80-9.
24. Jannathulla R, Dayal JS, Ambasankar K, Muralidhar M. Effect of Aspergillus niger fermented soybean meal and sunflower oil cake on growth, carcass composition and haemolymph indices in Penaeus vannamei Boone, 1931. Aquaculture. 2018;486:1-8.
25. Zentek J, Knorr F, Mader A. Reducing waste in fresh produce processing and households through use of waste as animal feed. InGlobal Safety of Fresh Produce 2014 Jan 1 (pp. 140-152). Woodhead Publishing.
26. Nevara GA, Giwa Ibrahim SA, Syed Muhammad SK, Zawawi N, Mustapha NA, Karim R. Oilseed meals into foods: An approach for the valorization of oilseed by-products. Critical Reviews in Food Science and Nutrition. 2023;63(23):6330-43.
27. Amza T, Amadou I, Zhu K, Zhou H. Effect of extraction and isolation on physicochemical and functional properties of an underutilized seed protein: Gingerbread plum (Neocarya macrophylla). Food Research International. 2011;44(9):2843-50.
28. Soliman AA. Evaluation of the productivity and performance of broiler breeder hens fed practical or vegetable diets containing high levels of barley and sunflower meal with multi-enzymes supplement during the pre-laying and laying periods (Doctoral dissertation, Ph. D. Thesis, Fac., of Agric. Alex. Univ., Egypt).

29. Lipiec A. Warto pokarmowa pasz bia kowych z ro lin oleistych. Prz. Hod. 1991;1:22-5.
30. Gheyasuddin S, Cater CM, Mattil KF. Effect of several variables on the extractability of sunflower seed proteins. Journal of food science. 1970;35(4):453-6.
31. El-Barbary A. Effect of sunflower seed meal *(Helianthus annuus)* as feed replacement for layer ration on some physiological parameters and reproductive performance (Doctoral dissertation, M. Sc. Thesis, Faculty of Agric., Alexandria University).
32. Hadidi M, Aghababaei F, McClements DJ. Sunflower meal/cake as a sustainable protein source for global food demand: Towards a zero-hunger world. Food Hydrocolloids. 2023:109329.
33. Morrison WH, Sojka RE, Unger PW. Effects of planting date and irrigation on wax content of sunflower-seed oil. Journal of the American Oil Chemists Society. 1984l;61:1242-5.
34. Carelli AA, Frizzera LM, Forbito PR, Crapiste GH. Wax composition of sunflower seed oils. Journal of the American Oil Chemists' Society. 2002; 79(8):763-8.
35. Recseg K, Kemeny Z, Kovari K, Denise J. Investigation of Non-Gliceridic Esters of Vegetable Oils. Olaj, Szappan, Kozmetika (Hungary). 1997.
36. Matthäus B. Oil technology. Technological Innovations in Major World Oil Crops, Volume 2: Perspectives. 2012:23-92.
37. Dijkstra AJ. Oil modification processes. Fats in food technology 2e. 2014:133-67.
38. Maru AD, Lahoti SR. Formulation and evaluation of moisturizing cream containing sunflower wax. Int J Pharm Pharm Sci. 2018;10(11):54-9.
39. Marechal V, Rigal L. Characterization of by-products of sunflower culture–commercial applications for stalks and heads. Industrial Crops and Products. 1999;10(3):185-200.
40. Bektas I, Guler C, Kalaycioğlu H, Mengeloglu F, Nacar M. The manufacture of particleboards using sunflower stalks (*Helianthus annuus* L.) and poplar wood (Populus alba L.). Journal of Composite materials. 2005;39(5):467-73.
41. Sun G, Xu X. Sunflower stalks as adsorbents for color removal from textile wastewater. Industrial & engineering chemistry research. 1997;36(3):808-12.
42. Cancalon P. Chemical composition of sunflower seed hulls. Journal of the American Oil Chemists' Society. 1971; 48(10):629.
43. Casoni AI, Gutierrez VS, Volpe MA. Conversion of sunflower seed hulls, waste from edible oil production, into valuable products. Journal of Environmental Chemical Engineering. 2019;7(1):102893.
44. Brazil OA, Vilanova-Neta JL, Silva NO, Vieira IM, Lima ÁS, Ruzene DS, Silva DP, Figueiredo RT. Integral use of lignocellulosic residues from different sunflower accessions: Analysis of the production potential for biofuels. Journal of Cleaner Production. 2019 Jun 1;221:430-8.
45. Ziebell AL, Barb JG, Sandhu S, Moyers BT, Sykes RW, Doeppke C, Gracom KL, Carlile M, Marek LF, Davis MF, Knapp SJ. Sunflower as a biofuels crop: An analysis of lignocellulosic chemical properties. Biomass and Bioenergy. 2013;59:208-17.
46. Jideani VA, Jideani AI, Jideani VA, Jideani AI. Ethnonutritional and ethnomedicinal uses of Bambara groundnut. Bambara Groundnut: Utilization and Future Prospects. 2021:49-60.
47. Flagella Z, Rotunno T, Tarantino E, Di Caterina R, De Caro A. Changes in seed yield and oil fatty acid composition of high oleic sunflower (*Helianthus annuus* L.) hybrids in relation to the sowing date and the water regime. European journal of agronomy. 2002;17(3):221-30.
48. Roman O, Heyd B, Broyart B, Castillo R, Maillard MN. Oxidative reactivity of unsaturated fatty acids from sunflower, high oleic sunflower and rapeseed oils subjected to heat treatment, under controlled conditions. LWT-Food Science and Technology. 2013 Jun 1;52(1):49-59.
49. Martín-Polvillo M, Márquez-Ruiz G, Dobarganes MC. Oxidative stability of sunflower oils differing in unsaturation degree during long-term storage at room temperature. Journal of the American Oil Chemists' Society. 2004 Jun;81(6):577-83.
50. Anonymous.. Nutritional composition of sunflower oil (100 gm) www.botanical-online.com; 2024.
51. Petraru A, Ursachi F, Amariei S. Nutritional characteristics assessment of sunflower seeds, oil and cake. Perspective of using sunflower oilcakes as a functional ingredient. Plants. 2021;10(11):2487.
52. Zoumpoulakis P, Sinanoglou VJ, Siapi E, Heropoulos G, Proestos C. Evaluating

modern techniques for the extraction and characterisation of sunflower (*Hellianthus annus* L.) seeds phenolics. Antioxidants. 2017;6(3):46.
53. Sredanović SA, Lević JD, Jovanović RD, Đuragić OM. The nutritive value of poultry diets containing sunflower meal supplemented by enzymes. Acta periodica technologica. 2012(43):79-91.
54. Tsuzuki ET, Garcia ED, Murakami AE, Sakamoto MI, Galli JR. Utilization of sunflower seed in laying hen rations. Brazilian Journal of Poultry Science. 2003; 5:179-82.
55. Casartelli EM, Filardi RS, Junqueira OM, Laurentiz AC, Assuena V, Duarte KF. Sunflower meal in commercial layer diets formulated on total and digestible amino acids basis. Brazilian Journal of Poultry Science. 2006;8:167-71.
56. Rezaei M, Hafezian H. Use of different levels of high fiber sunflower meal in commercial leghorn type layer diets. International Journal of Poultry Science. 2007;6(6):431-3.
57. Carelli AA, Frizzera LM, Forbito PR, Crapiste GH. Wax composition of sunflower seed oils. Journal of the American Oil Chemists' Society. 2002; 79(8):763-8.
58. Morrison WH. Rapid determination of wax in sunflower seed oil. Journal of the American Oil Chemists' Society. 1982; 59(7):284-5.
59. Rhazi L, Depeint F, Ayerdi Gotor A. Loss in the intrinsic quality and the antioxidant activity of sunflower (Helianthus annuus L.) oil during an industrial refining process. Molecules. 2022;27(3):916.
60. Ragaglini G, Triana F, Villani R, Bonari E. Can sunflower provide biofuel for inland demand? An integrated assessment of sustainability at regional scale. Energy. 2011;36(4):2111-8.
61. Barontini F, Simone M, Triana F, Mancini A, Ragaglini G, Nicolella C. Pilot-scale biofuel production from sunflower crops in central Italy. Renewable Energy. 2015;83:954-62.
62. Zhao X, Wei L, Julson J. First stage of bio-jet fuel production: non-food sunflower oil extraction using cold press method. AIMS Energy. 2014;2(2):193-209.
63. Cedola A, Cardinali A, D'Antuono I, Conte A, Del Nobile MA. Cereal foods fortified with by-products from the olive oil industry. Food Bioscience. 2020;33:100490.
64. Chamorro F, Carpena M, Fraga-Corral M, Echave J, Rajoka MS, Barba FJ, Cao H, Xiao J, Prieto MA, Simal-Gandara J. Valorization of kiwi agricultural waste and industry by-products by recovering bioactive compounds and applications as food additives: A circular economy model. Food Chemistry. 2022;370:131315.
65. Trento LR, Pereira GM, Jabbour CJ, Ndubisi NO, Mani V, Hingley M, Borchardt M, Gustavo Jr JU, de Souza M. Industry-retail symbiosis: What we should know to reduce perishable processed food disposal for a wider circular economy. Journal of cleaner production. 2021;318: 128622.
66. de Oliveira Filho JG, Egea MB. Sunflower seed byproduct and its fractions for food application: An attempt to improve the sustainability of the oil process. Journal of Food Science. 2021;86(5):1497-510.
67. Smeu I, Dobre AA, Cucu EM, Mustățea G, Belc N, Ungureanu EL. Byproducts from the vegetable oil industry: The challenges of safety and sustainability. Sustainability. 2022;14(4):2039.
68. Rodrigues IM, Coelho JF, Carvalho MG. Isolation and valorisation of vegetable proteins from oilseed plants: Methods, limitations and potential. Journal of Food Engineering. 2012;109(3): 337-46.
69. Li H, Yu P, Shen B. Biofuel potential production from cottonseed oil: a comparison of non-catalytic and catalytic pyrolysis on fixed-fluidized bed reactor. Fuel processing technology. 2009;90(9): 1087-92.
70. Demirbas AH, Demirbas I. Importance of rural bioenergy for developing countries. Energy Conversion and Management. 2007;48(8):2386-98.
71. Bouaid A, Martinez M, Aracil J. Long storage stability of biodiesel from vegetable and used frying oils. Fuel. 2007; 86(16):2596-602.
72. Ferrari RA, Pighinelli AL, Park KJ. Biodiesel production and quality. Biofuel's engineering process technology. 2011;1:221-40.
73. Roumanet PJ, Laflèche F, Jarroux N, Raoul Y, Claude S, Guégan P. Novel aliphatic polyesters from an oleic acid based monomer. Synthesis, epoxidation, cross-linking and biodegradation. European Polymer Journal. 2013;49(4): 813-22.

74. Pages X, Alfos C. 15th International Sunflower Conference Synthesis of new derivatives from vegetable sunflower oil methyl esters via epoxydation and oxirane opening. Oléagineux, Corps gras, Lipides. 2001;8(2):122-5.
75. Espinoza-Perez JD, Ulven CA, Wiesenborn DP. Epoxidized high-oleic vegetable oils applied to composites. Transactions of the ASABE. 2010;53(4): 1167-74.
76. Scotti R, Bonanomi G, Scelza R, Zoina A, Rao MA. Organic amendments as sustainable tool to recovery fertility in intensive agricultural systems. Journal of soil science and plant nutrition. 2015;15(2): 333-52.
77. Lucas PW, Corlett RT, Luke DA. Plio-Pleistocene hominid diets: an approach combining masticatory and ecological analysis. Journal of Human Evolution. 1985;14(2):187-202.
78. Pedrosa I, Saíz A, Arrazola J, Ferreirós J, Pedrosa CS. Hydatid Disease: Radiologic and Pathologic Features and Complications 1: (CME available in print version and on Rsna Link). Radiographics. 2000;20(3): 795-817.
79. Clifford MN. Chlorogenic acids and other cinnamates–nature, occurrence, dietary burden, absorption and metabolism. Journal of the Science of Food and Agriculture. 2000;80(7):1033-43.
80. Žilić S, Šukalović VH, Dodig D, Maksimović V, Maksimović M, Basić Z. Antioxidant activity of small grain cereals caused by phenolics and lipid soluble antioxidants. Journal of Cereal Science. 2011;54(3):417-24.
81. Swick RA. Considerations in using protein meals for poultry and swine. ASA Technical Bulletin. 1999;21:1-1.
82. Lazaro E, Benjamin Y, Robert M. The effects of dehulling on physicochemical properties of seed oil and cake quality of sunflower. Tanzania Journal of Agricultural Sciences. 2014;13(1).
83. Martini S, Añon MC. Crystallization of sunflower oil waxes. Journal of the American Oil Chemists' Society. 2003;80: 525-32.
84. Karaman S, Karasu S, Tornuk F, Toker OS, Gecgel U, Sagdic O, Ozcan N, Gul O. Recovery potential of cold press byproducts obtained from the edible oil industry: Physicochemical, bioactive, and antimicrobial properties. Journal of agricultural and food chemistry. 2015; 63(8):2305-13.
85. Adamse P, Van der Fels-Klerx HJ, de Jong J. Cadmium, lead, mercury and arsenic in animal feed and feed materials–trend analysis of monitoring results. Food Additives & Contaminants: Part A. 2017; 34(8):1298-311.
86. Rao M, Bast A, De Boer A. Valorized food processing by-products in the EU: Finding the balance between safety, nutrition, and sustainability. Sustainability. 2021;13(8): 4428.
87. Grasso S, Pintado T, Pérez-Jiménez J, Ruiz-Capillas C, Herrero AM. Potential of a sunflower seed by-product as animal fat replacer in healthier frankfurters. Foods. 2020;9(4):445.

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