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Oilseeds industry by-products used as functional food ingredients

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Abstract
Oilseeds are a rich source of proteins, fats, carbohydrates, vitamins, minerals, and phytochemicals and are suitable for usage as a functional food ingredient. Oilseeds are a highly nutritious food that is rich in medically and physiologically beneficial elements. The oil is the main product that is extracted from the oilseeds. Oilseeds are rich in phenols, flavonoids, isoflavonoids, phytosterols, and phytic acid which are helpful in the treatment of cancer chronic disease, and heart diseases. The oilseeds are used to extract oil from seeds and are used for the production of byproducts including hulls, cakes, meals, salad oils, shortenings, margarine, and cooking oil. The presence of phytochemicals in the oilseeds is defined as functional food ingredients present in raw or processed form. In industries, various oilseed extraction methods are adopted such as mechanical pressing, solvent extraction, hydraulic pressing, supercritical fluid, microwave, and ultrasound extraction. Apart from primary products, many secondary products are also formed which have high nutritional value. The byproducts of oilseeds can be used as the material for functional foods. The main functional foods obtained from oilseeds are proteins, fatty acids, vitamins, and some minerals. Industries mainly approach different oilseeds byproducts for the formulation of kernel meals, hulls, cake, butter, snacks, confectionaries, and many other products. Different byproducts of oilseeds have attracted the limelight in the market consisting of great nutritional benefits. Further, more research and development are required to identify beneficial components in the oilseeds, as well as to fabricate new, innovative byproducts that can be used as value-added food products in the future. Widespread research is mandatory to improve the usability of oilseed as a functional food ingredient.

Keywords: Oilseeds, bioactive compounds, functional foods, by-products, phenolic acids, nutritional value

1. Introduction
Functional foods are food that provides additional nutrition to health other than basic nutrition. Functional foods are described as food ingredients that provide health benefits and nutrition to consumers. These functional food ingredients are composed of flavonoids, polyphenolics, phytosterols, tocopherols, fibers, and minerals. Etc. These ingredients are added during processing and function as health-beneficial ingredients. Functional foods are used in varietal food preparations because of the presence of healthy food ingredients. These food ingredients provide essential elements which are required by the body for normal functioning. They also provide additional elements that boost the immune system and enhance the functioning of the internal body system. The functional ingredients are not only extracted from plant-based sources but also from animal and microorganisms products (Dewapriya and Kim, 2014 [32]; Mahomoodally *et al*., 2021) [52]. The plant-based sources are mostly preferred because of their improved benefits, efficiency, and role (Carović-StanKo *et al*., 2016) [24]. Oilseeds characterize as a form of functional food ingredients as they are composed of phenolics, flavonoids, lignans, oleochemicals, and tocopherols. These components of oilseeds impart antioxidant activity which provides oxidative stress to the body and also reduces the risk of cancer proliferation. Oilseeds are a rich source of fat, protein, fiber, ash, vitamins, minerals, and carbohydrates. Oilseeds are a diverse group of food that a have a high amount of oil content present in seeds. Among major Oilseeds, soybean ranked first in production with 351.32 million tons, rapeseeds with 71.28 million tons, sunflower with 47.8 million tons, and groundnut with 43.05 million tons (Carović-StanKo *et al*., 2016) [24]. Humans have used oilseeds since the stone age because of their nutritional and pharmaceutical values (Kole, 2007) [48]. The country is the largest producer of oilseeds and provides 7% of global oil production and has a 14% share in the area. The oil industries extract oils from oilseeds and use them for multiple applications (Yusoff *et al*., 2015) [92]. They are majorly grown for the production of oil rich in seeds.

The amount contained in grains of wheat is about 1-2%, soybeans 20%, and about 40% in sunflowers and rapeseeds. Oilseeds are utilized to produce oils and fats and also byproducts such as margarine, salad oils, and shortening. The oils also have utilization in soap, detergents, lubricants, coatings, and cosmetics for industrial products. Other value-added products from oilseeds are oilcake, meals, salad oil, and cooking oil. Etc. These value-added oil products are rich in fibers, proteins, minerals, vitamins, and antioxidants. Soybean seeds are a good substitute for protein consumption and have the presence of functional properties. These ingredients enhance the nutritional requirement of the product and help to prepare low-cost value-added products. These oilseed meals are edible and used as food ingredients for human consumption and the fabrication of food formulations (Helkar *et al*., 2016) [42]. These byproducts are not only protein rich source but also concentrated source of energy. At the end of the complete production process in the food industry, in addition to the desired main product, high amounts of many different by-products are generated (Paraman *et al*., 2015) [66]. For example, bagasse, peels, trimmings, stems, shells, bran, and seeds are obtained as by-products from fruits and these usually account for more than 50% yield (Torres-León *et al*., 2018) [88]. These by-produces have social, economic, and environmental effects. In terms of environmental effects, these are related to greenhouse gas emissions, and socially, food wastage is one of the most significant issues (Scherhaufer *et al.*, 2015) [80]. Plant oils are a rich source of protein and fats which are important ingredients in the food industry (Helkar *et al*., 2016) [42]. During the extraction process, not only are oils obtained from oilseeds but many by-products are also generated. Oilseed cakes are one of the significant byproducts obtained during this process (Arrutia *et al*., 2020) [12]. In addition, the processing of plant-based items is easier as compared to other sources. Plant seeds are rich in multiple ingredients which provide essential and non-essential elements to the human body. These seeds provide many ingredients which have functional properties to improve human health and increase the nutritional value of the food (Helkar *et al*., 2016) [42]. These oilseeds byproducts are gaining attention because of the demand for healthy vegetable oils from consumers. The oilseeds are utilized as cake food for human consumption due to their increasing importance among the population and food recipes and have appealing nutritional profile on these by-products because of the presence of secondary metabolites and protein. The production of oilseed byproducts offers an opportunity to add value and also fills gap of protein demand by consumers. The present study focuses on the utilization of oilseeds for production of byproducts as functional food ingredients.

2. Oilseed types and their nutritional profile

Oilseeds are classified as major and minor oilseeds based on their production. Major oilseeds are including rapeseed, soybean, groundnut, sesame, sunflower, safflower, castor, linseed, and niger whereas the minor oilseeds involve palm and coconut oil. Other oils such as cotton seed oil, and rice bran oil are also available in small quantities. Oilseeds are a rich source of protein, fat, fiber, vitamins, carbohydrates, minerals, and vitamins (Ajila *et al.*, 2012) [6]. Table 1. Describes the nutritional composition of different types of major and minor oilseeds. Out of which 7 are edible oilseeds such as rapeseed, groundnut, soybean, sunflower, sesame, safflower, and niger, and 2 are non-edible ones such as linseed and castor. India also ranks first in the production of major oilseed crops such as safflower, sesame, niger, and castor. For the production of major oilseeds, India stands first for groundnut production, second for rapeseed, and fifth for soybean production (Smeu *et al.*, 2022) [83]. India's oilseed and edible oil production have been exposed to the international market level because of the effect of policy options such as minimum support price and market intervention policies. These oilseeds need to target the international market as they do not cause the desired changes that ensure the needs and target of market production (Sylvester *et al*., 2014) [86]. Rapeseed as a major crop contains 40% of rape oil and has 18% of vegetable oil demand around the world. Groundnut and soybean as the major crop that contains 60% of oil in production. Groundnut is the major oilseed crop of India and causes half of the oilseeds production in the country. Oilseeds are a good source of protein and also a concentrated source of energy is obtained from them. The protein present in oilseeds is used as oil-intact seeds and also as a meal. The minor oilseed crops have 5-10% of oil production and have utilization in the pharma, food, and soap industries. Soybean involves 18-22% of fat and also has polyunsaturated fatty acids (PUFA), monounsaturated fatty acids (MUFA), and other fatty acids such as oleic, and stearic acid (Young *et al*., 2010). Peanut oil has 50% of monounsaturated fatty acids, and 14% of saturated fatty acids. Sunflower seeds have 194% of polyunsaturated fatty acids (Smeu *et al.*, 2022) [83]. Unsaturated fatty acids are good as they remove bad cholesterol which in turn avoids the chances of obesity, atherosclerosis, and avoid heart diseases. Fatty acids carry the fat soluble vitamins and have antioxidant activity which lowers the oxidative stress in the body. Oilseed fats are utilized as functional food ingredients. Oilseeds are a rich source of protein and are an important source for the preparation of nutritionally based products. Soybean as important oilseed has 20-25% of protein whereas groundnut contains 22-26% of protein and is the richest source of arginine (Shahidi, 2009) [81]. Rapeseed involves 34.50% protein, 39.88% albumins, 46.25% glutelins and sesame oilseed has 20% protein with albumin 8.6%, and glutelin 6.9%. Linseed as oilseed contains 21% of protein with albumin 20-42%, globulins 26-58%. Also, oilseed contains fat soluble vitamins such as vitamin A, E, and K and also water-soluble vitamins such as B1, B2, B3, B6, and C but doesn't have vitamin B12 (Smeu *et al*., 2022; Shahidi, 2009) [83, 81]]. The vitamins serve an important role in the functioning of nerves, digestive system, skin, and protection of diseases. Minerals present in oilseeds are Ca, Mg, Zn, Mn, P, K, Fe, and Cu worked as cofactor for enzymes. Furthermore, oilseeds also have phytochemicals such as polyphenols, carotenoids, phytosterols, tocopherols which are beneficial for human health. Oilseeds are used as functional ingredients for production of food products such as extruded food, bakery goods, and confectionaries. The productivity of oilseeds causes variation in the trend of the annual production of oilseeds because of environmental policy and priority considerations in India (Young *et al.*, 2010).

Table 1: Nutritional composition of different types of major and minor oil-seeds

Oil-seed seeds	Major/minor	Moisture (%)	Protein (%)	Lipid (%)	Fiber (%)	Ash (%)	References
Sunflower	Major	-	18-20	40-45	32-36	3.1	Aishwarya and Anisha, 2014 [5]
Groundnut	Major	7.4	24.7	46.1	2.83	1.48	Ayoola *et al*., 2012 [18]
Sesame	Major	0.2-3.5	20	52-63	4.2-11.4	1.4-5.93	Nweke *et al*., 2011 [61]
Mustard	Major	9.5	25	33-45	12-15	9.6-12	Abul-Fadl *et al.*, 2011 [2]
Soybean	Major	13-14	36-56	19	5	5	Wijewardana, Reddy and Bellaloui, 2019 [90]
Niger	Major	1-11	10-25	30-40	10-20	-	Duc *et al*., 2019 [34]
Rapeseed	Major	12	36-38	1-2	10-12	6-8	Palaniappan *et al.*, 2017 [65]
Safflower	Major	43-29	12-17	34	20-33	3.45-4.21	Al-Surmi *et al*., 2016
Linseed	Major	7-11	20	40	30	4	Tripathi *et al*., 2013
Castor	Major	6.1-8.4	21-48	1.9-50	2.5-24.5	5.66-6.49	Panhwar *et al*., 2019
Oil palm	Minor	4.53	24.6-26.7	47.3-49.4	6-24.9	6.44	Sahad *et al*., 2015 [75]
Coconut palm	Minor	7.51	25-30	30-40	4.27	7.70	Obasi *et al*., 2012 [62]

3. Oilseeds utilization as byproducts

Oilseed byproducts are composed of proteins, fats, minerals, and vitamins and act as a functional ingredients for consumers. These by-products add nutrition to food and act as a functional ingredients. Different oilseeds byproducts are available in the industries. These includes:

3.1 Cooking oil

Cooking oil or vegetable oils are a great substitute for animal fat and are utilized as a functional food ingredient. The vegetable oils contain monosaturated fatty acids (MUFA), and polyunsaturated fatty acids (PUFA), and are used as health value-added products for consumers. The selection of cooking oil has to be done suitably as it is precisely related to the consumer's health (Young *et al.*, 2010). Cooking oils include canola, mustard oil, rice bran oil, and groundnut oil as they are composed of 3 and 6 fatty acids which are essential fatty acids as they are good for health. These fatty acids are not synthesized in the body but are taken from outside by consumption of food. Likewise, groundnut, sunflower, and cottonseed have 6-fatty acids. Palm oil is good for use as vegetable oil because of its good cooking properties and taste. Mustard oil is also good for cooking and frying due to the presence of monosaturated fatty acids, and polyunsaturated fatty acids (Bejar *et al.*, 2011) [21].

3.2 Shortenings

Shortenings are fat fabricated from animal sources such as butter, and lard. etc. as they are used mostly for the production of bakery goods. Different vegetable oils utilized for the formulation of shortenings are cottonseed, palm, soybean, and sunflower oil. Blends of two-more oils are measured finest for the preparation of shortenings. Shortenings are good in baked goods as these goods provide moisture and tenderness to products. The shortenings are used for the production of a variety of products such as confectionaries, snacks, baked goods, and deep frying products (Aluyor and Ori-Jesu, 2008) [9].

3.3 Margarine/Salad oils

Margarine is a product composed of 80% of oil. The vegetable oils such as palm, soybean, sunflower, cottonseed, and corn oil are utilized for the preparation of margarine. Margarine is used as a substitute for butter and is also utilized for bread, biscuits, cakes, and icing. Margarine created from vegetable oils is used as a functional food due to the presence of plant sterols which limit the cholesterol level in the body (Aluyor and Ori-Jesu, 2008) [9]. Sunflower oil blending with oleic content and other fats was used for the production of plastic margarine. Margarine contains 20-40% of fat and is prepared by utilization of vegetable oils. Groundnut oil is utilized as a food salad oil and is good for human consumption (Ribeiro *et al.*, 2022) [73].

3.4 Hulls

Hulls and shells are the byproduct of oilseeds processing and act as an antioxidant. They are utilized as animal feed as they contain phenolic compounds. Hulls are utilized as feed, and fuel as they have phenolic compounds, flavonoids, catechins, and epicatechins. Sunflower oilseeds have a high amount of caffeic acid as they are extracted from aqueous ethanolic extraction after saponification (Ribeiro *et al.*, 2022) [73].

3.5 Oil cakes/meals

Oil cakes and meals are byproducts extracted from oilseeds. Mechanical and solvent extraction methods are utilized for the production of oilcake and meals. The mechanical method causes 6-7% oil content extraction whereas solvent extraction extracts less oil (Calder and Kew, 2002) [23]. The oilseeds cakes present in the market are rapeseed cake, soybean cake, cottonseed cake, groundnut cake, sunflower seed cake, safflower seed cake, and flaxseed cake. Etc. Oilseed cakes and meals are used as protein concentrates, isolates, and defatted oilcake, and meals are utilized for improving the oilcake in the diet of undernourished people. They are used for the fabrication of breakfast cereals, bakery goods, supplements, and extruded products (Aluyor and Ori-Jesu, 2008) [9].

3.6 Oilseeds byproducts

Oilseeds are the byproduct extracted from the seed portions and have great utilization in industries for the production of different oil byproducts. The major components of food items are proteins and water (de Castro *et al.*, 2017) [28]. Both of these components interact with each other to provide functional properties to the food items. Their interactions affect the properties of food products, including swelling capacity, oil holding capacity, holding capacity, and oil absorption capacity (Bejar *et al.*, 2011) [21]. These properties are considered functional properties and affect the overall effects of food on the health of its consumers. These are also important for food preservation, storage, texture, and many other critical industrial operations (Neethirajan and Jayas, 2011) [58]. Table 2. Represents seed oils and their primary and secondary byproducts. Different oilseeds used for the production of by-products are sunflower, groundnut, pumpkin, and sesame seeds. The details of different oilseeds and their functional groups are given below:

3.6.1 Sunflower oilseed

The sunflower belongs to the *Asteraceae* family, and it is called sunflower due to its resemblance to the sun (Giacomelli *et al.*, 2010) [40]. Sunflower seeds are one of the commonly produced crops and seeds. It has two types of seeds: confectionary purpose seeds and oil-producing seeds. These seeds are rich in dietary fibers, unsaturated fatty acids, antioxidants, flavonoids, amino acids, proteins, and vitamins (Adeleke & Babalola, 2020; Aslaksen *et al.*, 2007) [3, 16]. The other minerals include calcium, iron, magnesium, manganese, zinc, and many others. The fatty acids include linoleic and oleic. The flavonoids include luteolin, quercetin and apigenin. The amino acids make up 20% of total ingredients and include cysteine, phenylalanine, leucine, glutamic, tyrosine, and methionine (Petraru *et al.*, 2021; Raß *et al.*, 2008) [68, 72]. Sunflower oilseeds act as an excellent functional food containing many ingredients with functional properties. It has linolenic acid, which is a polyunsaturated fatty acid. It is the precursor of omega 3, necessary for antithrombotic and immune-modulating activities inside the human body. In addition to the main ingredients, it has many by-products and precursors for many other ingredients. For example, it has proteins and different phenolic -products (J. G. de Oliveira Filho & M. B. Egea, 2021) [29]. In addition, it has ALA, which is the precursor of docosahexaenoic acid and eicosapentaenoic acid. This compound plays a vital role in regulating human body function due to its different properties, including anti-inflammatory, hypo-triglyceride, and hypotensive. Lastly, it has by-products related to vitamins and tocopherols categories which are excellent functional ingredients and essential for the human body due to their high biological and nutritional value. Vitamin E is an excellent antioxidant and immune stimulant (Franco *et al.*, 2018) [39].

3.6.2 Groundnut oilseed

Groundnut oilseeds are also known as peanut oilseeds and Arachis oil, which are highly nutritious because of their excellent composition. It is rich in vitamins, unsaturated fatty acids, and polyunsaturated fatty acids. Peanut oil and oilseeds are used throughout the world. It has many by-products, including proteins, fatty acids, phenolic compounds, and vitamins. Peanut oil has more than 32 proteins as part of its ingredients, and among them, many are extracted as by-products. It has different vitamins, including riboflavin, Niacin, thiamine, and pantothenic acid, which act as functional ingredients in different food items (Arya *et al.*, 2016) [13]. In addition, different phytochemicals are obtained during the oil extraction process from peanuts. These phytochemicals include resveratrol, campesterol, and β-sitosterol, which have anti-tumor, anticancer, and anti-proliferative abilities. The presence of these functional groups ensures the prevention of breast, colon, and prostate cancer. Many triglycerides are produced as by-products from peanut oilseeds which have atherogenic potential and help prevent cardiovascular diseases (Akhtar *et al.*, 2014) [8].

3.6.3 Pumpkin seed oil

Pumpkin oilseeds have a versatile range of ingredients that have multiple types of functional properties. It has many vitamins, polyunsaturated fatty acids, monounsaturated fatty acids, and other mineral compounds. It is popular in the market due to its benefits in hair growth, skin nourishment, and health improvement. It is commonly used for the treatment of urinary tract infections. It generates many alcohols during the extraction process, and phenols are by-products with strong antioxidant properties (Saavedra *et al.*, 2015) [74].

3.6.4 Sesame seed oil

Sesame oilseeds are among the most sought oil and oilseeds because of their anti-inflammatory, antioxidant, and anti-proliferative. It is rich in dietary fiber, proteins, carbohydrates, and vitamins. It has linoleic acid, oleic acid, stearic acid, palmitic acid, and many other vitamins. In addition to primary products, many by-products are produced during the extraction process. These by-products include phytosterols, sesamol, lignans, and sesamin (Asghar *et al.*, 2014) [14]. Phytosterols have functional properties to reduce the chances of cardiovascular diseases and prevent cholesterol accumulation in the intestine. Sesamol is an excellent antioxidant that helps prevent many chronic diseases (Jayaraj *et al.*, 2020) [46]. The other by-products help reduce inflammation, blood sugar levels, and stress levels.

3.6.5 Rapeseed oil

Rapeseed oil is used for cooking purposes because of its light flavor, texture, and high smoke point. It is used in baking, grilling, and stir-frying. etc. It is also used in salads, sauces, and marinades. The presence of fatty acids in rapeseed oil has beneficial oil on human health. The rapeseed oil has the presence of bioactive constituents and other bio-peptides which are used for the production of different byproducts for utilization for consumers and add value addition to food industries (Jayaraj *et al.*, 2020; Abdul-Hamid and Luan, 2000) [46, 1].

Table 2: Seed oils and their primary and secondary by-products

Seeds	Oil	By-products	References
Palm kernel	Palm kernel oil	Fatty acid distillate and palm kernel meal	Ibrahim, 2013 [45]
Soybean	Soybean oil	Hulls, soybean meals	Paraman *et al.*, 2015 [66]
Rapeseed	Rapeseed oil (Canola)	Phenolic, Canola meal	Wang *et al.*, 2010 [89]
Sunflower	Sunflower oil	Sunflower cake, hulls, meals	Josemar *et al.*, 2021
Groundnut	Groundnut oil	butter, snack products, confectionaries	Zhao *et al.*, 2012 [93]
Palm	Palm oil	Mesocarp fiber, shell, empty fruit bunches	Solomon, 2011 [85]
Olive	Olive oil	Olive oil cake	Ballesteros *et al.*, 2001 [19]
Corn	Corn oil	Cornmeal	Lyu *et al.*, 2021 [51]

4. Bioactive compounds of oilseed byproducts

Bioactive constituents are important constituents in food and are responsible for disease-averting properties. The bioactive compounds contain phenolic, flavonoids, phytosterols, carotenoids, and polyunsaturated fatty acids. These constituents are utilized as antioxidants and also for reducing cholesterol absorption, and blocking bacterial toxins. Etc. Bioactive constituents are active compounds that enhance

good health. These active compounds prevent heart, cancer, and other diseases. Different bioactive constituents available in oilseeds are phenolic, flavonoids, glucosinolates, lignan, tannins, and indoles. Oilseeds are a type of rich source of phytosterols (Roche *et al.*, 2016). Phytosterols are categorized as sterol-type plants that are counted among lower-density lipoproteins (LDL) (Calpe-Berdiel *et al.*, 2009; Ammerman *et al.*, 2002) [11]. They absorb intestinal cholesterol. Phytosterols have anti-carcinogenic and anti-inflammatory effects. They have protective effects such as anti-bacterial, anti-oxidative, anti-tumor, and anti-inflammatory properties in the human body. They also help to extend the shelf life of vegetable oils and act as an emulsifier. Phenolic is hydroxyl groups containing aromatic hydrocarbon groups. They are the major type of secondary metabolites and act as defense compounds against plants (Akbarirad *et al.*, 2016). Oilseeds have utilization in different industries because of the presence of fibers, vitamins, minerals, and active constituents. Phenolics act as a natural antioxidant in processed foods. They have anti-oxidative, anti-tumor, and anti-inflammatory properties. Carotenoids are renowned as special pigments which have the role to give red, green, and yellow colors to plant parts and they have antioxidant properties against cancers, cardiovascular diseases, and skin diseases (Ramadan and Mörsel, 2002; Fadavi *et al.*, 2006) [37]. Tocopherols are lipophilic antioxidants. Tocopherols are plant phenolics that provide antioxidant and nutritional properties to oilseeds. These tocopherol inhibits the cholesterol level and exhibits anti-inflammatory, antihypertensive activities. Polyphenolic compounds are used for the development of human health. The phenolic compounds are known as secondary constituents as they act against free radicals and oxidative stresses and provide antioxidant activities. They protect vegetable oils against oxidation. They serve as an antioxidant and regulate metabolic processes related to inflammations and cancers. Flavonoids are rich in groundnut and soybean seeds and have antioxidant, and anti-inflammatory properties (Ashaolu, 2020) [15]. These active constituents have antioxidant, antimicrobial, anti-tumor, anti-inflammatory, anti-radical, and anti-bacterial activities that provide health benefits and target good market share. The sesame seeds and oil have lignans present such as sesamin, sesamolin, sesaminol, and tocopherol isomers. Which are serve as antioxidant activity and also resistant to oxidative rancidity. Table 3 represents the bioactive compounds of oilseeds and their properties.

Table 3: Bioactive compounds and properties of oilseeds

Oilseeds	Byproduct compounds identified	Amount	Analysis technique	Bioactive properties	References
Sunflower seeds	Phenolic acids, Flavonoids	11.57-15.44 g CGA eq/100 g	HPLC-MS (ESI) analysis	Antioxidant activity, Development of functional foods, Active and bioactive food packaging, Anti-inflammatory, Antimicrobial, Anti-tumor	de Oliveira Filho and Egea, 2021 [29]; Nandha *et al.*, 2014
Groundnut seeds	Polyphenolics	428.1-739.8 µg gallic acid equivalents/g	Folin-ciocalteau and high-performance liquid chromatography	Antioxidant activity, Emulsifying activity, Emulsifying stability, Foaming capacity	Nile, and Park, 2013
	Flavonoids	145.3 mgRE/ 100 g			
	Proteins	25.80 g			
Linseed	Lignans	11.37-33.31 mg/g	HPLC analysis	Antioxidant activity, Free radical scavenging activity, Preventive function in atherosclerosis	Kasote *et al.*, 2013
	Phenolic acids	109.93-246.88 mg/100g			
	Phytosterols	56.52-125.12 mg/g			
Safflower seeds	Phenolic	272.20-525.30 mg GAE/kg	HPLC analysis	Antioxidant activity, Regulate the process of devlopemnt	Szydłowska-Czerniak., 2010 [87]
	Sitosterol	92.51-121.83 mg/100g			
Rapeseed	Phenolic	3.78±0.05 mg EE/g	HPLC-DAD-ESI/MS analysis	Antioxidant activity towards the oxidation of liposomes and LDL particles, Radical scavenging activity	Szydłowsk *et al.*, 2010 [87]
Niger	Phenolic compounds	22.4-27.9 mg GAE/g	HPLC analysis	Antioxidant activity, Antiradical activity	Solomon, 2011 [85]
Soybean	Polyphenols	4.94-6.22 mg of gallic acid equivalants/g	HPLC-DAD-ESI/MS	Antioxidant activity, Anti-inflammatory, Xanthine oxidase, and tyrosinase inhibitory activities, Anti-diabetic, Anti-obesity	Pathak *et al.*, 2019
	Isoflavones	80.7-213.6 mg/100g			
Mustard	Glucosinolates	103.3 GLS, µmol/g	(TPC), DPPH-and ABTS-radical scavenging activities	Antioxidant activity, Antimicrobial activity, Provides their olfactory and pungent properties	Olgun *et al.*, 2017
	Phenolic compounds	7740±820 mg GA/kg defatted seeds			
Sesame seeds	Phytosterols	400-413 mg/100 g	DPPH, ABTS and FRAP	Antioxidant activity, Emulsifying activity, Emulsifying stability, Foaming capacity	Pathak *et al.*, 2019; Pathak *et al.*, 2014 [67]
	Polyunsaturated fatty acids	41.7 g			

5. Oil extraction process

The extraction of oil from the oilseeds is a lengthy process and many steps are involved. The main steps are cleaning, treatment, drying, dehulling, size reduction, flaking, and extraction of oil. Before storing the plant, it should be cleaned thoroughly. The leaves, twigs, stems, and other materials in oilseeds must be removed (Pradhan *et al.*, 2011). The different methods used for oilseeds extraction are solvent and mechanical extraction as conventional methods and supercritical fluid extraction, ultrasound, microwave, and enzyme-assisted extraction are non-conventional extraction methods. Oilseed moisture content is frequently lowered to reduce degradation during the storage and increase subsequent processing efficiency (Kundu *et al.*, 2001). Before the oil extraction from oilseeds, their outer husk or shell must be removed (Carbonell- Barrachina *et al.*, 2009; Young *et al.*, 2010). Dehulling further enhances the production capacity and the capacity of the equipment. In cooking oils, these substances are undesirable and must be eliminated during the purification process. Dehulling step reduces the fiber amount of the meal while increasing the protein content. Before oil extraction, more than half of the oilseeds are lowered in its size to make it easier for removing the hull. Seed size reduction is done by cracking mills. Before the solvent extraction, oilseeds can also be flaked. Flaking causes the cell morphology of the seed to tear, reducing the distance that the solvent must cross to reach the oil within the cells of oilseeds. To release oil from the cells, inactivate enzymes, and denature proteins, oilseeds are roasted or tempered. The cooking step also improves the elasticity of seeds, allowing for more efficient squeezing (Adepoju *et al.*, 2014; Kumar *et al.*, 2017). Different methods of extraction of oilseeds for processing of different oilseed by-products are evaluated in Table 4.

5.1 Solvent extraction

Solvent extraction implies the preferable dissolving of the oil, by combining oilseeds with a liquid solvent. The efficiency of the extraction is determined by the oilseed processing before extraction, the temperature, and the manner of operation. The hexane solvent is mostly used as an organic solvent in the oil extraction industry because of its efficiency in oil recovery, recyclability, inexpensive, and low boiling point (Sarkar *et al.*, 2017) [79].

5.2 Mechanical extraction

Mechanical force is used to extract the oil. The mechanical process alone doesn't remove all the oil from seeds it required chemical extraction to remove the rest of the oil from seeds. Mechanical extraction needs mechanical devices such as presses and screws to remove oil from oilseeds. It does not extract oil by physical force (Kumar *et al.*, 2017). The expeller pressing is used for small-scale farm operations. The canola, sunflower, safflower, and flaxseed are extracted from expeller pressing. The low cost of expeller pressing so, its utilization is more in developing countries. The extraction of the oil depends upon the type of organic solvent and also the extraction method. Organic solvents are good and yield more oil as compared to ethanol and methanol for the extraction process (Adepoju *et al.*, 2014).

5.3 Supercritical fluid extraction

Supercritical fluid extraction is the latest technology from the last few decades for the extraction of oil from oilseeds. The latest method is supercritical fluid extraction which is known for its highly selective yield. It uses the critical temperature of different products to extract the desired components. It is mostly used for organic products. Despite high yield and selectivity, this technique is not commonly used because of the usage of flammable solvents and its high cost. It costs double that of the conventional plant (Sanchez-Camargo *et al.*, 2014; Williams, 2005) [76, 91]. Carbon dioxide and sulfur dioxide are used for fluid extraction. It is used for oil extraction oil from different seeds such as canola, soybean, sunflower, grape, walnut, and apricot seeds. During the extraction process, the pressurized carbon dioxide was mixed with solid raw material which extracts the particular component. The critical point for extraction is 31 ℃ and 7.38 MPa where gas and liquid phases come together to have a homogenous fluid phase beyond the supercritical fluid region. This method has high diffusivity, low viscosity, faster extraction times, and surface tension (Mushtaq *et al.*, 2020) [57].

5.4 Accelerated solvent extraction

Accelerated solvent extraction is also known as pressurized solvent extraction and is a modern extraction process. The oil is extracted from seeds by utilization of organic and aqueous solvents at elevated temperatures and pressures (Al-Widyan and Tashtoush, 2002 [10]; Athar and Nasir, 2005) [10, 17]. The elevated pressure inhibits the boiling at a temperature above the normal boiling point of solvent but the presence of high temperature enhances the extraction rate of oil. This method is good for flaxseed hulls and wheat germs (Gunstone and uses, 2011) [41].

5.5 Enzymatic extraction

The enzymatic extraction is used for the extraction of oil from plant materials. The advantage of this process is its environmentally friendly nature and also it is harmless. It does not produce harmful volatile and organic compounds. In this method, enzymes are used to extract the oils from seeds. Combination with other methods provides more good results in oil extraction. As a disadvantage, this method is time-consuming (Lavenburg *et al.*, 2021) [49].

5.6 Microwave-assisted extraction

The microwave extraction method is used for the extraction of oilseeds as this method has low-cost production, a shorter time, less solvent requirement, and a higher extraction process. This is a cheap method and is the most used conventional method for oil extraction. This method is used for the extraction of plant materials (Akanni *et al.*, 2005) [7].

5.7 Ultrasound extraction method

The ultrasound method is the conventional method used for the extraction of oils. The ultrasound process causes cavitation and releases the oil from cell matrices. The high sound waves are used for ultrasound processing. This method involves good oil yield and preserves the quality of the oil. This method when combined with other methods is good for yielding high oil. The combination of oilseeds extraction methods such as microwave, enzyme, and ultrasound technology enhances the oil extraction (Shimakawa *et al.*, 2003) [82].

Table 4: Different methods of extraction of oilseeds for processing of different oilseed byproducts

Methods	Advantages	References
Mechanical pressing	Simpler method Better adaptability Best quality Flexible production	Huang *et al.*, 2019 [44]; Soetaredjo *et al.*, 2008
Solvent extraction	Fast method Easy adaptability Large production capacity Low energy consumption	Durrani *et al.*, 2011 [35]
Hydraulic pressing method	Convenient method Fast production Technologically advanced	Huang *et al.*, 2019 [44]
Supercritical fluid extraction	Highly selective Low viscosity Higher diffusion rate	Sanchez-Camargo *et al.*, 2014 [76]
Enzymatic extraction	Environmental friendly Harmless method	Huang *et al.*, 2019 [44]
Microwave-assisted extraction	Low-cost production Shorter time Less solvent requirement Higher extraction process	Sanz-Serrano *et al.*, 2021 [78]; Huang *et al.*, 2019 [44]
Ultrasound extraction	High yield of oil Higher extraction process	Sanz-Serrano *et al.*, 2021 [78]; Huang *et al.*, 2019 [44]

6. Functional compounds from oilseed byproducts

Due to the high nutritional value of oilseeds byproducts many bioactive and functional compounds are extracted from them. Multiple types of compounds like phenols, fats, polyestrous, and polyphenols are obtained during different oil extraction methods from oilseeds. Table 5 defined the functional ingredients of oilseeds byproducts and their properties. These functional ingredients from oilseed byproducts help to nourish skin, improve internal body functions, reduce the chances of tumor generation and help to improve overall health. Usually, these products are divided into two categories: saponifiable and unsaponifiable fractions of functional compounds of oilseeds.

6.1 Saponifiable fraction of functional compounds from oilseed byproducts

This is the major fraction of the product derived during the extraction process. It makes up 90-98% of the oil yield (Díaz *et al.*, 2019) [33]. One of the major compounds from this category is triglycerides with double binds and long heavy chains. These compounds also have a single bond; thus, these belong to both saturated and unsaturated fatty acids. Their unsaturated form has both cis and trans-configurations. Commonly obtained compounds are unsaturated fatty acids. Afterward, compounds from the omega nomenclature are abundant, including omega-3, omega-6, and omega-9 (Cox and García-Palmieri, 2011) [27]. Most oilseeds, including coconut (Marina *et al.*, 2009) [54], almonds (Barku *et al.*, 2012) [20], groundnut, and caster, are saponifiable. In contrast, mineral oils are not saponifiable. Seeds of oils are rich in fatty acids, and through saponification, the content of fatty acids is decreased, which converts them into functional ingredients. For example, palm oil contains about 44% palmitic acid (Odia *et al.*, 2015; Kao and Chen, 2006) [63, 47]. This saponifiable fraction consists of by-products like wax, glycerides, triglycerides, and phospholipids are also important for the human metabolic system.

6.2 Unsaponifiable fraction of functional compounds from oilseed byproducts

The unsaponifiable fraction only counts for 1 to 2%, and it consists of those ingredients which are soluble in organic solvents but insoluble or barely soluble in water. A few examples of these ingredients are β-sitosterol, phenolic compounds, triterpenes, and other pigments (Bulotta *et al.*, 2014) [22]. Phytosterols are one of the major components of this category. These phytosterols are tetracyclic cyclopenta[α]- phenanthrene form and a side chain with around 10 carbons at C-17. Their saturated form is called phytostanols; however, it is found in lesser concertation. The amount of phytosterol varies from plant to plant, but it is mostly 1000 – 5000 mg/kg (Fernandes and Cabral, 2007) [38]. In addition to phytosterols, other components in the unsaturated fraction are tocopherols which have a chromane ring and hydrophobic side chains. Tocopherols are also present with tocotrienols and perform activities analogs to vitamin E (Munné-Bosch and Alegre, 2002) [56]. The tocopherols and tocotrienols are in demand due to their potential for the oxidation of unsaturated fatty acids. These functional groups are present in high quantities of corn, peanuts, and cottonseed and low quantities of grape seeds and palm seeds. Due to their ability to oxidize the fatty acids, these increase the nutritional value of the oilseeds. It has been found effective in different types of cancers (Sylvester *et al.*, 2014) [86]. Phenolic compounds belong to this category, and these are important for the antioxidant, anti-proliferative, antidiabetic, and antihypertensive properties of the foods. Phenolic compounds have been documented to improve the immune system and reduce the proliferation of body cells (Hollman, 2001) [43]. Many studies have proved the effectiveness of these functional groups of oilseeds. It can be said that this family of compounds has many bioactive and functional groups that are beneficial for the health of humans (Nirmala *et al.*, 2014; Santos-Buelga *et al.*, 2019) [60, 77].

Table 5: Functional ingredients and properties of oilseed byproducts

Functional ingredient	Properties	References
Phytosterols	Block cholesterol absorption	Pritchard *et al.*, 2003 [70]
Tocopherols	Anti-inflammatory, anti-aging	Sanz-Serrano *et al.*, 2021 [78]
Dietary fibers	Lower cholesterol helps in body nourishment and improves the digestive system	Quiros-Sauceda *et al.*, 2014
Phenols	Antioxidants	Quiros-Sauceda *et al.*, 2014
Alcohols	Antioxidants	Liu *et al.*, 2019 [50]
Carotenoids	Boost immune system	Christaki *et al.*, 2013 [25]
Vitamins	Help in skin regeneration and wound healing and improve the immune system	Phan *et al.*, 2021 [69]
Proteins	Balance muscle mass, lower blood pressure, improve the health of kidneys and liver, nourishes the skin	Aider and Barbana, 2011 [4]

7. Conclusion

Currently, functional foods are receiving attention due to their additional therapeutic and health-related benefits. These are obtained from different sources, but their production is low. Due to their high demand, oilseed by-products can be used as the source of these foods. Oilseeds byproducts are rich in nutrients, and after harvesting oil, many beneficial ingredients are left behind in food cakes and mills, which is considered food waste. Food wastage is causing global concerns. The by-products can be used as the source of functional food ingredients, i.e., proteins, vitamins, fatty acids, and minerals. Oilseeds also provide antioxidant, antimicrobial, and anti-inflammatory activities which have health beneficial roles for humans. This way, the agro-food industry waste will be lessened, which will decrease the economic and environmental burden. In addition, the production capacity of functional foods will be enhanced. The oilseeds opened a new avenue for the production of new, innovative byproducts which provides future scope to industries in the processing and production sector of by-products.

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