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EDITED BY
Paulo Cezar Bastianello Campagnol,
Federal University of Santa Maria, Brazil

REVIEWED BY
Bibiana Alves Dos Santis,
Federal University of Santa Maria, Brazil
Yakindra Timilsena,
RMIT University, Australia

*CORRESPONDENCE
Sonia Morya,
sonia.morya8911@gmail.com

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Exploring waste utilization potential: nutritional, functional and medicinal properties of oilseed cakes

Sharvary Arun Vichare and Sonia Morya *

Department of Food Technology and Nutrition, School of Agriculture, Lovely Professional University, Phagwara, India

Nowadays, oilseed cakes are the by-products of oil extraction, have gained significant interest due to their wide range of nutritional, functional, and medicinal properties. The review paper is an overview of the applications of oilseed cakes across due to their nutritional and economic potential. Oilseed cakes present a valuable resource due to rich nutritional profile and potential health advantages. These by-products of oil extraction are not only abundant in proteins, fibres, and essential micronutrients but also possess functional and medicinal properties that can enhance food security and promote overall health. Their utilization in food systems support sustainable agricultural practices, waste reduction, and the development of functional foods, thereby contributing to better health outcomes and a holistic approach to wellbeing aligning with broader sustainable development goals. Overall, this paper underscores the importance of diligent exploration into the multifaceted properties of oilseed cakes, offering valuable insights into their potential applications and avenues for further research and development.

KEYWORDS

bioactives, good health, oilseed cakes, sustainability, wellbeing

Introduction

Oilseed cakes refer to the solid residues remaining from the extraction process of oils in the edible oil industry**.** Cakes derived from oil-bearing seeds in the edible oil industry are termed edible oil cakes when they are utilized to fulfil nutritional needs in animal feed or human consumption (like soybean, groundnut, rapeseed, sunflower, safflower, coconut, linseed, cottonseed). Conversely, those cakes containing toxic compounds and impurities unsuitable for feed are categorized as non-edible are castor, neem, mahua, and karanja (Sunil et al., 2016). India, being the largest producer of oilseeds globally, manufactures more than 25 million metric tons of oilseed cakes every year (Singh et al., 2022). Among the dominant oilcake/meal products in the global market, soybean cake holds the top position, comprising 54% of total production. Following closely behind are rapeseed cake/meal (10%) and cottonseed cake/meal (10%). Other significant contenders include groundnut cake, flaxseed cake, coconut cake, safflower cake, and sunflower cake (Patel et al., 2019). Oilseed cakes, renowned for their pivotal role in various industries, stand as the residue after oil extraction from seeds. These cakes are indispensable components in animal feed, agriculture, and numerous industrial processes. With a wide variety of oilseed cakes like soybean, rapeseed, and cottonseed leading the global market, they are essential in fulfilling

both nutritional and industrial needs worldwide (Hadidi et al., 2023). Oilseed cakes offer a good source of proteins in terms of essential amino acids, and energy, making them invaluable in livestock diets, particularly for poultry, swine, and cattle (Kotecka-Majchrzak et al., 2020). Beyond their significance in animal nutrition, oilseed cakes serve as vital organic fertilizers, contributing to soil health and crop Productivity (Singh et al., 2022). Furthermore, these cakes serve as a sustainable resource in various industrial applications, including biofuel production, pharmaceuticals, and cosmetics. With their versatility and widespread application, oilseed cakes continue to be integral to global agricultural and industrial landscapes. So, there is a multifaceted importance of oilseed cakes, there indispensable role in feeding the world's population, enhancing agricultural productivity, and driving industrial innovation.

This paper aims to, explore oilseed cakes through the lens of diligence and provides a comprehensive understanding of their diverse array of properties. From their nutritional richness to their sensorial qualities, functional attributes, and even medicinal potential, oilseed cakes stand as multifaceted resources deserving of attention and scrutiny. By delving deeper, we can unlock their full potential for various applications, ranging from culinary endeavours to pharmaceutical innovations. This exploration not only enriches our understanding of these often-overlooked by-products but also underscores their significance in fostering sustainable and health-conscious practices within agriculture and beyond.

Nutritional characteristics of oilseedcakes

Oilseeds play a crucial role in human nutrition due to their abundance in fats, proteins, crude fiber, carbohydrates, vitamins, minerals, and a diverse array of phytochemicals (Albuquerque et al., 2020). The composition of an oilcake is contingent upon the processing methods and the manner in which oil is extracted from the oil-bearing source (Table 1; Figure 1). Provides the chemical compositions of prominent solvent-extracted oilcakes worldwide. Among them, soybean cake stands out as the highest in protein content, while olive oil cake registers the lowest. Soybean cake is distinguished as a potent reservoir of energy and proteins, boasting lower fiber content in comparison to other oilseed cakes (Kumar et al., 2024). Soybean cake is renowned for its abundance in protein and energy, featuring a fiber content lower than that of many other oil cakes. Its exceptional digestibility and palatability make it a prevalent choice as a feed ingredient in both animal and human food products. In a study examining chick performance, methionine was found to be the primary amino acid limitation in soybean cake, while lysine, threonine, and valine, were identified as moderately limiting factors (Elahi et al., 2020). Soybean carbohydrates mainly consist of oligosaccharides (15%) like sucrose, raffinose, and stachyose. Only trace amounts of anti-nutrients such as saponins, lectins, and phytates have been detected. Soybean cake, recognized for its high production and market value, is closely trailed by rapeseed cake in terms of production volume and pricing within the oil-cake market. Rapeseed cultivation encompasses two primary species: *Brassica campestris* and *Brassica napus*. Rapeseed (*B. napus*) oilseed cake exhibits an equivalent amino acid balance to soybean cake and is notably enriched in sulphur amino acids such as methionine and cysteine (Singh et al., 2022). Carbohydrate content of rapeseed cake is mostly made up of fucoamyloid, pectins, cellulose, arabinan, and arabinogalactan. The antinutrients (glucosinolates, sinapine, tannins, erucic acid, and phytates) content of rapeseed is quite high thereby limiting use in poultry feed. Canola is a same species of rapeseed (*B. campestris*) with low amounts of erucic acid and glucosinolates that is widely farmed in Canada. Mustard, also part of the Brassica genus, is used both as an oilseed crop and a condiment. In India, *Brassica juncea* is widely cultivated primarily for oil production, while *Brassica nigra* is grown extensively for use as a condiment without oil extraction. The amino acid composition of mustard oilseed cake nearly resembles that of rapeseed cake, although with higher glucosinates (secondary plant metabolites), even though of varying types, compared to rapeseed (Sharma et al., 2022). Cottonseed oil cake constitutes 45% of rich protein content. However the suitability of cottonseed cake as a feed for non-ruminant animals is limited due to the presence of the toxic metabolite gossypol, elevated fiber content, and insufficient essential amino acids (Kumar et al., 2024). Through genetic modification, gossypol-free cottonseed varieties have been cultivated, yielding oil cake with promising

TABLE 1 Nutritional characteristics of oilseed cakes.

Oilseed cakes	DM %	CP %	CHO%	CF%	Ash %	Fat%	References
Soybean oilseed cake	90.3	51.3	23.6	17.8	7.3	0.9	Rani and Badwaik (2021)
Rapeseed oil cake	90.75	42.8	32.2	12.1	7	4.1	Chmielewska et al. (2021)
Cottonseed oil cake	91.53	41.5	27.0	14.67	6.46	5.75	Riaz et al. (2023)
Groundnut oilseed cake	90	45.6	14.1	8.3	5.02	2.47	Fekria et al. (2012)
Sunflower oilseed cake	93	35.6	23.0	28.41	7.36	1.68	Petraru et al. (2021)
Sesame oilseed cake	93.9	48.2	21.0	6.4	12.6	2.3	Melo et al. (2021)
Linseed oil cake	88.9	33.2	36.0	8.1	5.4	2.8	Vajpeyi et al. (2008)
Safflower oilseed cake	93.1	44	20.1	12.1	7.2	5.9	Khalid et al. (2017)
Olive oilseed cake	72.8	4.77	10.1	49.14	2.36	8.72	Uribe et al. (2013)

DM-dry, matter, CP-crude protein, CHO- carbohydrate, CF- crude fibre.

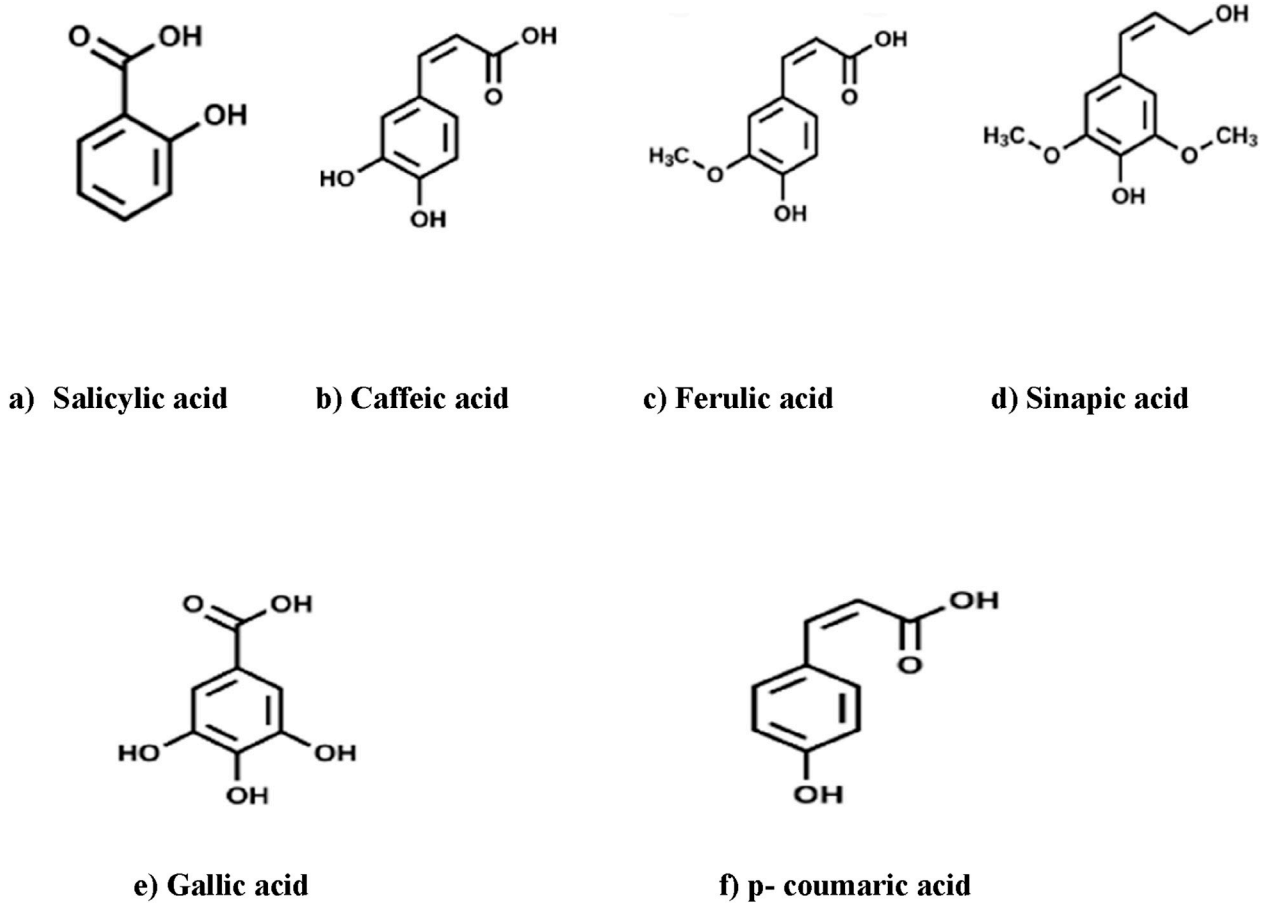

FIGURE 1
Derivatives of benzoic acid and cinnamic acids. The derivatives of Benzoic acid: **(A)** and **(E)**; and Cinnamic acid: **(B)**, **(C)**, **(D)** and **(F)**.

prospects as a protein-rich dietary option. Groundnut oilseed cake with high protein content, contains elevated levels of arginine but is lacking in essential amino acids. These cakes are often contaminated with aflatoxins produced by *Aspergillus flavus* mold (Mansur et al., 2018). The presence of these contaminants significantly influences animal behaviour. Sunflower oilseed cake is plentiful in sulphur amino acids (cysteine) while notably lacking in lysine. It is mostly used for poultry and pigs and contains, a polyphenolic substance, i.e., chlorogenic acid that has been shown to inhibit hydrolytic enzymes, consequently impairing animal behaviour. Sunflower oilseed cake is free of known antinutritional agents such as trypsin inhibitors, and its mineral composition is considered adequate. Sesame oilseed cake has a similar nutritional outline as soybean oilseed cake, with an normal protein level of 40% and 8% fiber. It contains high levels of methionine, cysteine, and tryptophan but lacks lysine (Abedini et al., 2022). Although mineral-rich, the seed hull contains oxalates and phytates, which reduce mineral availability. Although removing the shell enhances mineral accessibility and reduces fiber content, thorough dehulling is generally impracticable due to sesame seeds' tiny size. Linseed cake, made from flaxseed, accounts for 55%–60% of the seed and contains 32% protein. However, its protein value is low due to deficiency of lysine and the, cyanogenic glucoside linamarin, antipyridoxine factor linatin and indigestible mucilage present in it, all of which diminish its nutritional quality as animal feedstuff. The safflower oilseed cakes crude protein content varies between 20% and 60%, depending on the degree of dehulled seed cakes. The seed cakes in which dehulling is done partially usually have 15% crude fiber and 40% crude protein. The cake has a bitter flavour because it contains two phenolic glucosides, matairesinol and 2-hydroxyarctiin (Sivaramakrishnan and Gangadharan, 2009). In its crude state, olive oil cake typically contains 5%–10% protein and 35%–50% crude fiber. With a phenolic content of 4.3%, it has a rather high moisture content, ranging from 35% to 30%. The fiber components include hemicellulose, cellulose, and lignin, i.e. 1.5, 1.72, 2.75 percent respectively (Dermeche et al., 2013).

Functional properties of oilseed cakes

Various oilseed cakes possess distinct functional properties that make each one unique. In addition to their nutritional properties, oilseed cakes also exhibit various functional properties that make them valuable ingredients in food, feed, and industrial applications. Some of these functional properties includes emulsifying properties, water-binding capacity, foaming properties, gelling and thickening, texture modification, nutrient fortification, functional additives in feed, water and oil absorption capacity, foam capacity and foam

stability. The ability to mix two immiscible liquids, such as water and oil, is called emulsion capacity (Wang et al., 2019). Oilseed cakes contain proteins and/or phospholipids that possess emulsifying properties. Emulsifying compounds can stabilize immiscible emulsions by forming a protective layer around dispersed oil droplets, thereby preventing amalgamation and improving the stability of emulsified systems (Ravera et al., 2021). This feature makes oilseed cakes valuable in food applications including salad dressings, mayonnaise, and baking items that require emulsions for texture and mouthfeel. The proteins and polysaccharides present in oilseed cakes have water-binding capacity, allowing them to absorb and retain water (Özbek and Ergönül, 2022). This property is beneficial in food formulations to improve moistness holding, texture, and shelf life. Water absorption capability is crucial for processed food preparation, including bread, sauces, soups, and meat products. Beneficial for quality and yield purposes (Yılmaz et al., 2017). Some oilseed cakes contain proteins that have foaming properties, enabling them to form stable foam structures when whipped or beaten. This property is utilized in various food applications such as meringues, cakes, and whipped toppings where aeration and foam stability are desired. Certain components of oilseed cakes, such as soluble proteins and polysaccharides, can subsidize to the formation of gels and thickening in foods (Zhang et al., 2023). This property is exploited in the production of gelled products like puddings, custards, and gelled desserts, as well as in thickened sauces, gravies, and soups. Oilseed cakes can influence the texture and mouthfeel of food products due to their protein and fiber content. In baked goods, for instance, oilseed cakes can contribute to softness, moisture retention, and crumb structure (Kaur et al., 2022). In meat analogues and vegetarian products, Oilseed cakes can mimic the texture of meat and improve the overall eating experience. Oilseed cakes are often used as nutrient fortificants in food products to enhance their nutritional value. They can be incorporated into fortified flour blends, breakfast cereals, snacks, and beverages to increase protein, fiber, and micronutrient content, thereby addressing malnutrition and improving public health outcomes. In animal feed formulations, oilseed cakes can serve as functional additives to improve feed quality and performance (Rakita et al., 2023). For example, they can act as natural binders, emulsifiers, or texturizers in pelleted feeds, facilitating handling, processing, and digestion by animals. Overall, the functional properties of oilseed cakes contribute to their versatility and usefulness in various food, feed, and industrial applications, making them valuable by-products of oilseed processing.

Medicinal properties of oilseed cakes

Recent advances in the usage of oilseed cakes have centred on improving health and nutrition of the community. These advances are useful in order to meet expanding global demand for protein and bioactive chemicals. More recently, the potential of oilseed cakes as sources of antioxidative peptides has been investigated, most notably in a review by Sarmadi and Ismail (2010). Additionally, Martínez-Maqueda et al. (2013) reviewed various methods for extracting and fractionating proteins and peptides from plant tissues. Despite these investigations, there is currently a paucity of comprehensive reviews on clinical research examining the bioactive qualities of compounds and health benefits obtained from oilseed cakes. Many beneficial components, including polyphenols, proteins, and oligosaccharides, can be specifically isolated from oilseed cakes, as reported by Albuquerque et al. (2020). This is because many seeds, serving as the source for new seedlings, possess innate adaptations to mitigate potential risks encountered during the initial stages of life. Oilseed cakes are the byproduct obtained from seeds after oil extraction. They are rich in proteins, vitamins, fibers, and minerals, making them valuable for various purposes including animal feed, organic fertilizers, and even medicinal applications. Additionally, bioactive compounds derived from oilseed cakes can include carbohydrates, proteins or phenolic compounds as given in (Table 2). Oilseed cakes are rich in proteins, which are crucial for muscle growth, repair, and overall bodily function. They can be used as a protein supplement in the diet, especially for individuals with protein deficiencies. Some oilseed cakes, such as those derived from flaxseed, sunflower seeds, and sesame seeds, contain antioxidants like lignans, phenolic compounds, and vitamin E (Sarkis et al., 2014). (Table 3) shows the antioxidant compounds in the oilseed cakes. These antioxidants aid in neutralizing harmful free radicals in the body, thereby reducing the risk of chronic diseases such as cancer, cardiovascular diseases, and inflammation-related disorders. Polyphenols extracted from oilseed cakes exhibit potent antioxidant properties, which have been linked to various beneficial health effects. These include reducing lipid levels in plasma, protecting the skin from photo damage, promoting vascular health, preserving neurological function, combating aging, preventing cancer, and displaying antimicrobial, antifungal, and antiviral activities (Teh, and Bekhit et al., 2015). Polyphenols comprise a diverse range of compounds, including anthocyanins, catechins, dalbergin, flavonoids, flavanols, isoflavones, phenolic acids, phenolic alcohols, anthocyanidins, proanthocyanidins, polyphenolic amides (such as avenanthramide and capsaicinoid), chalcones, lignans, stilbenes and other non-flavonoids like rosmarinic acid, gingerol, resveratrol, valoneic acid dilactone, metaresinol, secoisolariciresinol curcumin, ellagic acid, and hydrolysable tannins (ellagic acid, and rosmarinic acid, gallic acid) (Sharma, 2014). Oilseed cakes are a good source of dietary fiber, which aids in preventing constipation, digestion and promotes gut health. Fiber also helps in controlling blood sugar levels and cholesterol levels, reducing the risk of diabetes and heart diseases. Oilseed cakes contain essential minerals such as calcium, phosphorus, magnesium, iron, and zinc, which are important for maintaining muscle function, bone health and total metabolism. Certain oilseed cakes, like those from flaxseed, hemp seed, and chia seeds, are rich in essential (alpha-linolenic acid) i.e., omega-3 fatty acids. Omega-3 fatty acids have anti-inflammatory qualities and are useful for heart health, brain function, and to reduce the risk of chronic diseases (Chaliha et al., 2019). Oilseed cakes from seeds like flaxseed and sesame seeds contain the plant compounds phytoestrogens that mimic the hormone estrogen in the body. Phytoestrogens may help in regulating hormonal balance, especially in menopausal women, and alleviate symptoms like hot flashes and mood swings. Some studies suggest that due to the presence of bioactive compounds like flavonoids and polyphenols certain oilseed cakes possess anti-inflammatory properties. These compounds may help in reducing inflammation and associated

TABLE 2 Health benefiting bioactives of oilseed cakes.

Oilseed cakes	Health benefiting bioactives	References
Flaxseed	Proteins, polysaccharides, Oil, lipids, peptides, fiber, lignans, carbs, mucilage, and micronutrients	Teh and Bekhit, 2015
Olive	Polyphenols, (phenolic acids, phenolic alcohols, flavonoids, and secoiridoids) and lipophilic (cresols)	Uribe et al. (2015)
Sunflower	Polyphenols, oleic acid, linoleic acid	Sarkis et al., 2014
Palm kernel cake	Tannase, lauric acid	Mansor et al. (2019)
Mustard	glucosinolates (sinigrin and sinalbin) phenolic compounds, phytic acid and various phytosterols	Teh and Bekhit, 2015
Sesame	sesamin, sesaminol, and gamma-tocopherol, as well as unsaturated fatty acid content (oleic acid, linoleic acid, stearidonic acid, palmitoleic acid, and trace amounts of linolenic acid)	Abbas et al. (2022)
Linseed	ALA, omega-3 fatty acids, protein, fiber, and lignan, especially Secoisolariciresinol Diglucoside (SDG)	Gutte et al. (2015)
Cotton, Copra	Glycerol-1 alkanoates, bikojic acid, limonene, cellulose, hexadecanoic acid, vicilin, and tetradecanoic acid	Tikoria et al. (2023)

TABLE 3 Antioxidants compounds in oilcake.

Oilseed cakes	Antioxidant compounds	References
Rapeseed, Mustard cake	Sinapic, Benzoic and cinnamic acid, esters of phenolic acid and glycosides	Zeb (2021)
Peanut cake	Phenolic acids and esters such as p-coumaric, syringic, caffeic, p-hydroxybenzoic, caffeic and ferulic acid	Shahidi et al. (2019)
Sunflower cake	Syringic, vanillic, gallic, chlorogenic, p-coumaric, caffeic, p-hydroxybenzoic and vanillic acids, epicatechin, catechin	Hussain et al. (2018)
Linseed cake	p-hydroxybenzoic, coumaric, Sinapic, lignans and ferulic acids	Mekky et al. (2022)
Sesame cake	coumaric, Sinapic, lignans, ferulic, vanillic acids	Mekky et al. (2019)
Cottonseed cake	p-hydroxybenzoic, sinapic, ferulic acid, rutin and quercitin	Khasanov et al. (2017)
Olive cake	Flavonoids, secoiridoids, hydroxytyrosol and lignans	Moudache et al. (2021)

symptoms in conditions like arthritis and inflammatory bowel diseases. Compounds found in oilseed cakes, such as silymarin in the case of oilseed cakes derived from milk thistle seeds, have been studied for their hepatoprotective effects (Bedrnicek et al., 2022). They may help in protecting the liver from damage caused by toxins, alcohol, and certain medications. Oilseed cakes have been explored for their antimicrobial properties against various pathogens, including bacteria, fungi, and viruses. This property makes them potentially useful in the treatment and prevention of infections. Some oilseed cakes, when applied topically or incorporated into skincare products, may help in improving skin health by moisturizing, nourishing, and providing antioxidant protection against environmental damage. It's important to note that while oilseed cakes offer various potential medicinal benefits, further research is necessary to thoroughly comprehend their mechanisms of action and identify the most effective therapeutic applications. Additionally, individuals with specific medical conditions or allergies should consult healthcare professionals before incorporating oilseed cakes into their diet or wellness regimen.

Applications of oilseed cakes in different sectors

Oilseed cakes can be characterized as either edible or non-edible oilseed cakes (Jangir et al., 2020). Edible oilseed cakes include mustard, sunflower seeds, soybeans, mahua, and peanuts.

These cakes are abundant in protein and boast a range of antioxidants, fibers, and vitamins, making them desirable as animal supplements and occasionally beneficial for human consumption. Furthermore, sunflower oilseed cakes are utilized in the production of various bakery items (Sunil et al., 2015). Castor, Jatropha, sesame, neem and simarouba are categorized as non-edible oilseed cakes because they contain high levels of hazardous chemicals following oil extraction from the seeds (Dias et al., 2017). The edible and nonedible oilseed cakes have different applications in commercial utilization in different sectors (Figure 2) they are as follows:

Bioelectricity

Certain non-edible oilseeds have antinutritional properties or can be poisonous. These non-edible oils are often utilized for biodiesel production, while the residual oilseed cakes find applications in biopesticides, bioelectricity generation, and various other uses. The generation of bioelectricity using oilseed cakes and the production of biodiesel and biogas from Jatropha biomass involve preparing briquettes for subsequent utilization. The qualities of these briquettes are examined according to American standards, including diameter, length, compressive strength, calorific value, and density. In rural regions lacking access to

electrical infrastructure, biomass-derived bioelectricity could prove immensely beneficial. Research conducted utilizing jatropha oilseed cakes reveals that the electricity-producing device can utilize around 4–5 kg of oilseed bricks per hour, delivering up to 4.5 kW of power (Sarkar et al., 2021).

Antibiotics production

Sarkar et al. (2021) demonstrated the successful production of antibiotics through fermentation processes employing appropriate microorganisms with oilseed cakes as substrates. Solid-state fermentation for antibiotic manufacturing has been demonstrated to be more energy efficient than traditional methods, such as stirred fermenters. The regulation of characteristics such as foaming, air supply and continuous agitation management all contribute to higher energy consumption and expenses. Gupta et al. (2018) demonstrated the use of sesame, soybean, and sunflower oilseed cakes to produce cephamycin and clavulanic acid. When fermented with *Streptomyces peucetius*, sesame oilseed cake provides an effective carbon source for microbial development. The use of a phosphate buffer enhances antibiotic productivity by facilitating the conversion of intermediates into their final products (Imran, 2021). Arumugam et al. (2014) showed the application of sunflower oilseed cake in the production of cephamycin C. In another study, Zarei, (2012) investigated the manufacture of the antibiotic bacitracin via fermentation with *Bacillus licheniformis*, using oilseed cake as a substrate. Soybean oilseed cake exhibited the highest potency, followed by wheat meal and sunflower oilseed cake, with rice hulls showing the lowest productivity.

Biocontrol agent

The effectiveness of neem, castor, mustard, and dhaincha oilseed cakes against plant-parasitic nematodes and soil-inhabiting fungi infesting mungbean and subsequent chickpea crops was examined. The populations of plant-parasitic nematodes, including *Meloidogyne incognita, Rotylenchulus reniformis, Tylenchorhynchus brassicae, and Helicotylenchus indicus*, were significantly reduced by these treatments. Additionally, the frequency of pathogenic fungi such as *Macrophomina phaseolina, Rhizoctonia solani, Phyllosticta phaseolina,* and *Fusarium oxysporum f.* sp. *ciceri* was also notably decreased. However, there was an observed increase in the frequency of saprophytic fungi (Sumbul et al., 2015). Research has explored the efficiency of oil cakes combined with *Bradyrhizobium sp.* and *Paecilomyces lilacinus* for managing root rot in mungbean (Parveen et al., 2019). Nguemezi and Roger (2020) observed enhanced tomato plant growth and reduced nematode populations in soil amended with neem cake. Similarly, Khan et al. (2022) conducted glasshouse experiments testing various nematicides (aldicarb, carbofuran, ethoprop) along with oil cakes (linseed, mustard, neem) against *Pratylenchus thornei* infesting *Mentha citrata, M. piperita, and M. spicata*, demonstrating promising control effects. Mollah et al. (2012) investigated the use of a mixture comprising 35% wheat bran, 20% mustard oil cake (MOC), 25% cow dung, and 20% fine sand for the production of tubificid worms in a culvert system under running water. They witnessed the emergence of new offspring 20 days after the experiment began. The raw ingredients produced 1.0 g of worms from 2.85 g of input material.

Preparation of protein hydrolysate

Oil cakes like soybean oil cake (SOC) and mustard oil cake (MOC) have been explored as alternatives to animal protein hydrolysates for treating protein malnutrition. Growth trials conducted with rats revealed that the resulting product exhibited comparable efficiency to commercial casein (Arrutia et al., 2020). SOC and MOC's amino acid profiles revealed a high concentration of important amino acids such as glycine, arginine, phenylalanine, and leucine. Furthermore, Analysis of the dry matter revealed substantial amounts of crude protein, highlighting their potential as effective protein supplements.

As a growth supplement for nematodes

Sumbul et al. (2015) employed various media, including mustard oil-cake agar, linseed oil-cake agar, neem oil-cake agar, Emerson agar, beef extract agar, and YPSS agar (yeast extract and starch), for cultivating an endoparasite of nematodes. Generally, the maximum radial growth of most isolates occurred on linseed oil-cake agar, while neem oil-cake agar supported the least growth of all *Catenaria anguillulae* isolates. Linseed oil-cake agar also maintained the typical characteristics of the fungus and provided clear visibility of morphological details.

Production of mushroom

Supplementing oilseed cakes (Mustard oilseed cake, Sunflower oilseed cake, Cotton seed cake, and Soyabean oilseed Cake) with rice straw substrate colonized by the mushroom Pleurotus sajor-caju enhanced yields by 50%–100% compared to un-supplemented substrates. Supplementation with oil cake improved the solubility of rice straw, increasing amino acids and free sugars while decreasing cellulose-hemicellulose (Ramachandran et al., 2007). Supplementing discarded rice straw substrate with organic nitrogen (in the form of oil cakes) was studied to increase mushroom production (Pleurotus sajor-caju). The chemistry and *in vitro* digestibility of rice straw were also studied.

Market of oilseed cake industry

India, the world's second most populous country and the third-largest economy in Asia, has seen rapid economic growth since 1990. It has become a major producer and consumer of oilseeds and their derivatives and emerged as one of the largest importers of vegetable oils by the late 1990s. This growth has been driven by factors such as rising incomes, relatively low domestic oilseed productivity, and liberalized edible oil import policies. Despite these relaxed import policies, extensive government intervention still significantly impacts oilseed production, trade, and processing in India.

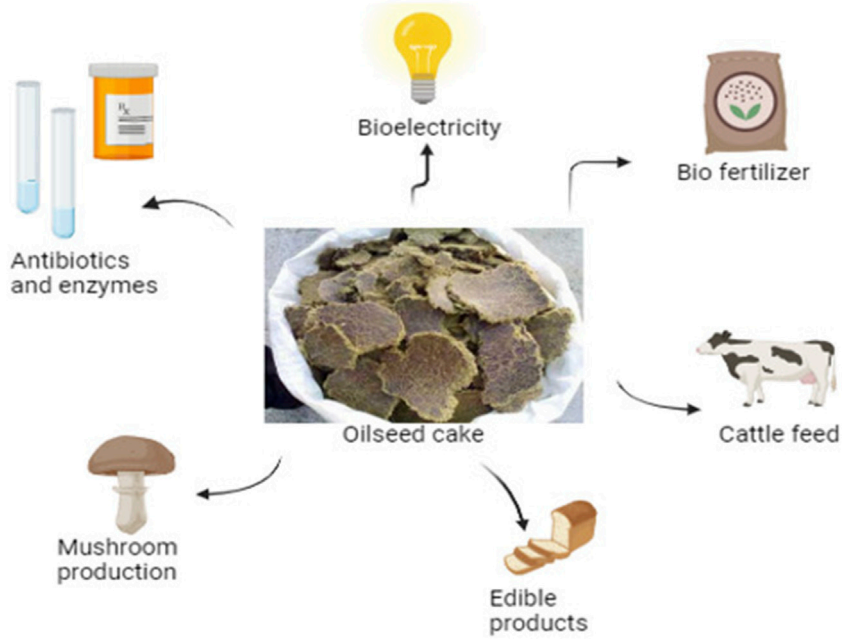

FIGURE 2
Applications of oilseed cakes.

Anticipated policy reforms are expected to significantly influence the future trajectory and composition of India's oilseed and product trade.

Meal demand

India ranks as the world's fifth-largest supplier of oil meals. However, the rapid increase in domestic feed demand has slowed the export of soybean and other meals. (Narayan, 2017). Accelerated income development increases demand for animal goods, resulting in a greater need for oil meal and coarse grain for feed production. India boasts a substantial animal product market, with supply and demand adapting to higher income levels. Despite having significant spare capacity in its domestic oilseed processing sector, oilseed imports remain limited due to a combination of tariff and non-tariff restrictions. The expansion of India's animal products sector, fueled by consumer demand and the growing need for commercial feeds, has substantial consequences for the country's oilseed and products industry. Historically, low domestic demand for oilseed meals for feed has presented issues for both processors and producers. Since meals constitute the bulk of the physical content of most oilseeds, low market returns on meals have generally reduced processing profitability and producer returns (Shenoi, 2003). While meal exports have increased demand and prices for soybeans and soybean meal, most other meal varieties have limited local and export demand, frequently due to low quality, resulting in a large amount being used as fertilizer. The rising local feed market may reduce India's surplus of exportable meal, but it may also increase profits on domestic oilseed production and processing while improving meal quality (Narayan, 2016).

Meal trade

India is the fifth-largest exporter of soybean meal and total oil meals, despite significantly smaller shipments compared to major global exporters such as Argentina, Brazil, and the United States. Indian soybean meal stands out in world markets due to its competitive quality and pricing compared to other domestically produced meals (Voora et al., 2020). Given that soybeans and sunflower seed have been cultivated in India since the 1970s, they are processed in relatively modern, small- and medium-scale solvent extraction facilities. Indian soybean meal finds traction in small, regional markets that prefer India's bagged product over bulk options. The once robust growth in India's soybean meal exports has tapered off due to the expanding domestic demand for feed and slower growth in soybean production (Nuthalapati et al., 2020). The swift rise in demand from domestic poultry meat and egg producers has elevated domestic soybean meal prices relative to global prices, diminishing their competitiveness in international markets and dampening exporters' appeal (Persaud and Landes, 2007).

Future prospects

Oilseed cakes are high in nutrients such as protein, fiber and energy, making them potentially useful as byproducts in the production of organic compounds, bioenergy, and biomolecules. More research is needed to investigate the use, extraction and incorporation of antioxidants and dietary fibers into food products. While edible oilseed cake is a useful feed source, non-edible oilseed cake is largely used for bioenergy generation and pesticide formulations. Oil cake is useful for a variety of tasks and helps to reduce environmental pollution. Its popularity stems from

its widespread availability and inexpensive cost. Biodiesel and biogas production are critical for economic development, and converting waste from oil processing plants into useful products is both efficient and cost-effective. Coupling biodiesel and biogas production with the utilization of seed cakes presents a promising avenue for commercial investment. Research suggests various waste materials, including agricultural waste and wastewater sewage, can be utilized for bioenergy production, but oilseed cake stands out as one of the most appealing options for biogas production. Similarly, in terms of producing cattle feed from oilseed cakes, there is a need for in-depth understanding. With the increasing demand for cattle feed annually due to insufficient farmlands for cultivation, producing cattle feed from oilseed cakes emerges as a feasible and beneficial solution. This approach not only addresses environmental concerns but also promotes eco-friendly practices.

Conclusion

The exploration of oilseed cakes reveals a wealth of potential across various dimensions, including nutritional, functional, and medicinal properties. These versatile by-products, rich in nutrients such as fiber, protein, and energy, offer promising avenues for utilization in diverse industries. From a nutritional standpoint, oilseed cakes contribute valuable dietary components, making them an attractive option for enhancing the nutritional profile of food products. Functionally, oilseed cakes exhibit a range of beneficial properties that can be harnessed in various applications, including their role as organic chemicals, bioenergy sources, and biomolecules. Furthermore, their medicinal properties hold potential for the development of health-promoting products and supplements. The nutritional, functional, and medicinal properties of oilseed cakes make them a valuable asset in promoting Sustainable Development Goal for the Good Health and Wellbeing. By integrating oilseed cakes into diets and food systems, we can improve nutritional intake, support sustainable agricultural practices, and reduce food waste. This not only enhances food security and dietary quality but also fosters better health outcomes, contributing to a more holistic approach to global wellbeing. The continued exploration and utilization of oilseed cakes align with the objectives of sustainable development, emphasizing the importance of leveraging natural resources for improved health and sustainability. As our understanding of oilseed cakes continues to evolve, further research is needed to fully explore their potential and optimize their utilization. By delving deeper into their nutritional, functional, and medicinal properties, we can unlock new opportunities for innovation and development across multiple industries. Overall, oilseed cakes represent a valuable resource with vast untapped potential, warranting continued diligence and exploration in the quest for sustainable and nutritious solutions.

Author contributions

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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