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Valorization of Oilseed Press Cakes for Sustainable Food Production: Nutritional and Technological Perspectives

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Abstract

Oilseed press cakes are major by-products generated during mechanical extraction of vegetable oils from seeds such as soybean, sunflower, rapeseed, sesame, flaxseed, groundnut, and pumpkin. Although traditionally used as animal feed or discarded in some processing systems, press cakes retain substantial amounts of proteins, dietary fibre, minerals, phenolic compounds, peptides, and residual lipids. Their nutritional density makes them promising raw materials for human food applications and supports the development of circular and sustainable food systems. Advances in fractionation, protein extraction, fermentation, enzymatic treatment, drying, and extrusion have enabled the conversion of press cakes into functional flours, protein concentrates, fibre-rich ingredients, bakery products, snacks, beverages, and meat alternatives. However, challenges involving antinutritional factors, allergenicity, oxidation, sensory characteristics, contaminants, and processing costs must be addressed, the nutritional composition, functional properties, processing strategies, food applications, and future opportunities for valorizing oilseed press cakes in sustainable food production.

Keywords: *Oilseed press cakes, food waste valorization, plant proteins, dietary fibre, circular economy, functional foods, sustainable food production.*

1. Introduction

The increasing demand for vegetable oils has resulted in substantial quantities of oilseed processing residues. Mechanical oil extraction produces a solid fraction commonly referred to as press cake or oilseed cake. Major sources include soybean, sunflower, rapeseed, sesame, groundnut, flaxseed, pumpkin seed, and other oil-rich crops [1].

Oilseed press cakes are often considered low-value by-products despite retaining considerable nutritional value. Depending on the original seed and extraction method, they may contain substantial concentrations of proteins, fibre, minerals, residual lipids, phenolic compounds, and other bioactive constituents.

The conversion of these materials into food ingredients represents an important opportunity for sustainable food production. Instead of treating press cakes solely as waste or animal feed, they can be fractionated and transformed into value-added ingredients for human nutrition. Such valorization supports the principles of the circular economy by reducing resource losses and increasing the economic value obtained from agricultural raw materials.

2. Nutritional Potential of Oilseed Press Cakes

The composition of press cakes varies considerably among oilseed species and extraction methods. Mechanical pressing generally leaves a portion of the original oil within the cake, while proteins and dietary fibre remain concentrated in the solid fraction.

Soybean and rapeseed press cakes are particularly valuable as protein sources. Sunflower press cake provides proteins and fibre, while sesame press cake contains proteins, minerals, lignans, and residual oil. Flaxseed and pumpkin seed cakes can provide proteins, fibre, minerals, and phytochemicals.

Phenolic compounds and other bioactive constituents can also remain concentrated in the press cake. Their presence contributes to antioxidant properties and provides opportunities for developing functional ingredients.

Table 1. Selected oilseed press cakes and potential food applications

Press cake	Major nutritional components	Potential food applications
Soybean	Protein, fibre, residual oil	Protein ingredients, meat alternatives
Sunflower	Protein, fibre, phenolic compounds	Bakery products, protein flour
Rapeseed	Protein, fibre, minerals	Protein concentrates and functional foods
Sesame	Protein, lignans, minerals, residual oil	Bakery products, spreads, snacks
Flaxseed	Fibre, protein, residual omega-3-rich oil	Functional bakery and fibre products
Pumpkin seed	Protein, minerals, phytochemicals	Snacks, protein formulations
Groundnut	Protein, fibre, residual oil	Protein-rich foods and bakery products

3. Protein and Fibre Recovery

Protein recovery is one of the most important strategies for press-cake valorization. Protein concentrates and isolates can be produced using processes such as aqueous extraction, pH adjustment, precipitation, membrane filtration, and enzymatic treatment.

Recovered proteins can contribute to emulsification, water binding, gel formation, and texture development. These characteristics make press-cake proteins potentially useful in meat analogues, beverages, bakery products, and protein-enriched foods [2].

Dietary fibre represents another valuable component. Press cakes can contain both insoluble and soluble fibre fractions. These fibres may improve water retention, texture, and nutritional density while contributing to gastrointestinal health.

The simultaneous recovery of protein, fibre, residual oil, and bioactive compounds can increase the economic efficiency of valorization. Integrated fractionation systems are therefore more promising than processes focused on a single component.

4. Bioactive Compounds and Functional Potential

Oilseed press cakes may contain phenolic acids, flavonoids, lignans, tocopherols, phytosterols, and peptides. Sesame press cake, for example, contains lignan-related compounds, while sunflower and other oilseed cakes may retain phenolic constituents.

These compounds have demonstrated antioxidant activity and other biological properties in experimental studies. However, the presence of a bioactive compound does not automatically establish a health benefit in humans. Bioavailability, digestion, metabolism, and effective dietary intake must be considered.

Fermentation can be used to improve the functional characteristics of press cakes. Microbial enzymes may degrade selected antinutritional factors, modify proteins, release bound phenolics, and improve digestibility [3].

5. Processing Technologies for Valorization

Several technologies can convert oilseed press cakes into food-grade ingredients. Milling provides a simple approach for producing press-cake flour. However, excessive residual oil may reduce shelf stability because unsaturated lipids are susceptible to oxidation.

Defatting can improve storage stability and increase the relative concentration of protein and fibre. Protein extraction and membrane separation can then produce concentrated ingredients with tailored functional properties.

Fermentation is another promising strategy. Lactic acid bacteria and other microorganisms can modify the chemical composition of press cakes and improve sensory characteristics. Enzymatic hydrolysis can also release peptides and improve protein functionality.

Extrusion provides opportunities for producing structured foods and meat analogues. Press-cake flours can be blended with cereals, legumes, or other plant ingredients before extrusion to obtain desirable texture and nutritional balance.

6. Applications in Sustainable Food Production

Press-cake ingredients can be incorporated into numerous food products. Bakery applications are among the simplest because press-cake flours can partially replace conventional cereal flour. Depending on the ingredient and inclusion level, this can increase protein, fibre, and phytochemical content.

Protein-rich press-cake fractions can be used in plant-based meat alternatives and high-protein snacks. Their functional properties can contribute to water retention, emulsification, and texture.

Press-cake powders can also be incorporated into beverages, breakfast cereals, crackers, nutrition bars, soups, and extruded products. Combining different press cakes may provide complementary nutritional characteristics.

The valorization of press cakes can additionally reduce dependence on virgin food ingredients. Recovering nutrients from an existing processing stream improves resource efficiency and may reduce the environmental burden associated with food production.

7. Major Challenges

Despite their potential, several factors limit the direct use of oilseed press cakes in foods. Antinutritional compounds such as phytates, tannins, enzyme inhibitors, and glucosinolates may affect nutrient availability or sensory quality in specific oilseed species.

Allergenicity is an important consideration for soybean and groundnut-derived ingredients. Appropriate processing, testing, and labelling are therefore essential.

Oxidative stability is another major concern.

Residual unsaturated oils can undergo oxidation during storage, resulting in rancid flavours and reduced product quality. Controlled drying, defatting, antioxidant protection, oxygen-limiting packaging, and suitable storage conditions can help address this problem.

Sensory properties also require careful consideration. Press-cake ingredients may impart distinctive colours, bitterness, astringency, or earthy flavours. Excessive inclusion may therefore reduce consumer acceptance.

8. Future Perspectives

Future research should move toward integrated biorefinery approaches in which press cakes are separated into multiple high-value fractions. Protein, fibre, residual oils, phenolic compounds, and other components could be recovered sequentially and directed toward different food and non-food applications.

Green extraction technologies may improve the recovery of bioactive compounds while reducing solvent use. Fermentation and enzymatic processing could further improve protein digestibility and functional properties.

There is also significant potential for combining press-cake ingredients with cereals, pulses, millets, fruits, and other plant materials to develop nutritionally balanced foods. Advanced formulation and encapsulation technologies may improve sensory quality and protect sensitive components.

Importantly, future studies should include life-cycle assessment and techno-economic analysis. A valorization process should not only produce a nutritionally valuable ingredient but also demonstrate economic feasibility and genuine environmental advantages.

9. Conclusion

Oilseed press cakes represent valuable secondary resources with considerable potential for sustainable food production. Their retained proteins, dietary fibre, residual lipids, minerals, and bioactive compounds make them promising ingredients for functional and nutrient-enriched foods. Milling, defatting, protein extraction, fermentation, enzymatic treatment, and extrusion can transform these by-products into functional flours, protein ingredients, bakery products, snacks, beverages, and plant-based alternatives. Nevertheless, antinutritional factors, allergenicity, oxidation, sensory characteristics, and processing economics must be carefully addressed. Integrated valorization strategies that recover multiple components offer the greatest potential for maximizing resource efficiency. Future integration of food technology, green extraction, fermentation, life-cycle assessment, and consumer research could establish oilseed press cakes as important ingredients in circular and sustainable food systems.

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