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RECOVERY OF BIOACTIVE COMPOUNDS FROM OILCAKES - A REVIEW

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Abstract: *Worldwide, food waste and by-product are concernig topics, due to the fact that annually large amount of these are generated from the food industry. Their management should include first waste prevention, recycling, recovery and lastly disposal. The concerning awareness of consumers regarding healthy diets has led to an increase demand for foods containing bioactive compounds, namely proteins, dietary fibers and antioxidants with numerous health benefits. In other words, the food industry is heading towards innovations by using wastes as raw materials for the development of new products or applications. This paper provides a critical review of the possible ways to recovery the nutritive compounds from oilcakes obtained after the oilseed processing.*

Keywords*: circular economy, bioactive compounds, oilcake, protein, dietary fiber.*

1. Introduction

The current global issues (over-exploitation and mismanagement of resources, unsustainable consumption behaviour, climate change and degradation of the environment) caused by the impact of human activities, calls for a transition towards a circular economy. In this system the idea of waste is not contemplated because it is recycled and re-circulated within the production [1,2] .
Food wastes and by-products are the leftover edible materials (lost, discarded degraded or consumed by pests) generated from the food industry, in all phases, from agricultural production up to direct consumption into households [3]. The management of these poses a challenge due to the cost related to their handling. However, the increasing consciousness about environment issues and the legislative pressure require new methods for food waste recovery, rather than its disposal [4]. The most common practices of valorisation are animal feed, composting and biofuel conversion, but unfortunately they only provide a partial use of food industry waste [5].
Lately the food waste was acknowledged as a rich source of various nutraceuticals and valuable compounds [6,7]. These compounds (pigments, fibers, minerals, proteins and antioxidants) can be reintegrated in the food, agricultural, cosmetic and pharmaceutical industries [8]. The extraction includes three stages: in the first the materials are subjected to a pretreatment to remove microbes without affecting biological activities, the second step is extraction trough classical (solvents, maceration, stream distillation) or novel/greed methods (pulsed electric field, supercritical fluid, microwave, ultrasound, high voltage electric discharge extractions, the final stage involve purification of the final product [9].
In order to ensure the protection of human health, the legal permissibility of the high valuable components as input substance is fundamental. They must undergo a safety assessment before their placement on the

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market. The bioactive compounds are separated from the food matrix trough operations without creating hazards and in the final must comply with the existing food regulations [4,10].
Oilcakes are the principal by-products of the oil industry with many bioactive compounds, such as dietary fibers and proteins, that can be isolated and after consumption, provides positive health benefits and unique properties in the food industry [11,12].
This paper provides a critical review of the possible ways to valorisate the oilcake resulted from the oil industry and the methods used for the recovery of bioactive compounds.

2. Extraction and identification of bioactive compounds from food waste and by-products

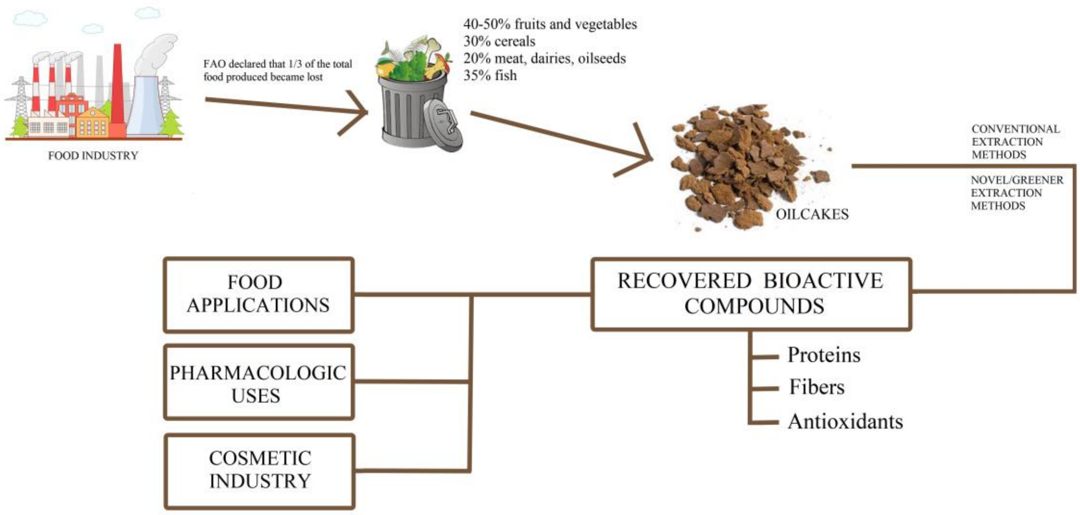

Fig. 1. The main applications of bioactive compounds extracted from oilcakes

2.1. Proteins

During the last decade the rising world population and limited resources poses a challenge for protein supply, encouraging their searching in alternative sustainable and renewable sources [13]. The Food Agriculture Organization has stated that proteins will be limited in the future so that a sufficient quantity and quality of proteins will become a fundamental right of every citizen. A balancing protein intake from both animal and vegetables sources is recommended [14].
The most widespread protein extraction methodology involves two steps process: an alkaline solubilization with a removal of insoluble material by centrifugation and an isoelectric precipitation (pH 4-5), followed by centrifugation and neutralization. Alternative and improved version for this method have been developed. Three methodology were developed: aqueous extraction, dry techniques and combined approaches [15].
Aqueous extraction is a process in which water alone or in combination with acid, basic or saline agents is used as extraction medium. This extraction is followed by an isoelectric precipitation and then a membrane filtration technique for purification [16].
Extraction with alkaline solution offers high protein yield, but at the same time has

some disadvantages such as low oil extraction yield, the presence of chemical contaminants in the end products and the loss of protein functionality [17,18]. At pH>12 the proteins suffer an irreversible denaturation and a decline in nutritive value [19]. Alkaline extraction also can provoke Maillard reaction, which causes the darkening of the final products color and negatively affects smell and taste [20]. Acid extraction in comparison with basic extraction are less efficient regarding the protein content obtained in the final product [21]. Taking into account all the previous observations an extraction with NaCl at a moderate basic pH value could be a good alternative to obtain proteins with high yields without compromising their functionality and nutritional value. Another drawback is the necessity to dry the final product, which increase the costs [15].

The dry methodologies includes always a milling or deagglomeration pre-treatment [22]. The procent of protein obtained (40%) by dry methods is less than those obtained by aqueous extraction (80%) [16]. The advantages of these methods are: low physical impact on the particles, preservation of the native structure, the involvement of less expenses. However, the expensive equipment is the major drawbacks [15].

Enzyme treatments are an interesting approach due to the enzymes superior mode of action that allows the targeting towards specific components of the protein bonds. The cost of enzymes plus the difficulty to recycle the treatment stream works against this option [23].

The method used for protein extraction should achieve the following: obtaining of high yield, reduction of the number of purification steps, preservation of the nutritional and functional values, elimination of antinutrients and reduction of the environmental impact [15]. Taking all these factors the aqueous extraction is the most preferable.

2.2. Antioxidants, phenolic compounds and polyphenols

Antioxidants are compounds that at relatively low concentrations can inhibit or delay the oxidation process [24]. Antioxidant functionality can be explained with the following mechanisms: scavenging free radicals that generate and distribute peroxidation, chelating metal ions that hasten the oxidation process, prevention of hydroxyl radical and interruption of the auto-oxidation reaction [25].

Phenolic compounds are the largest group present in phytochemicals. The compounds include phenols with one aromatic ring, polyphenols with more than one aromatic ring and hydroxyl group and their derivates such as glycosides and esters. Phenolic acids and their derivates (lignans, tannins, flavonoids) are the most important class of polyphenols [26].

There is no universal method for the extraction of antioxidants, but for a method to be suitable several requirements must be fulfilled such as selectivity, high extraction yield, possibility to recover solvent, the use of green solvent, mantaining the functionality of the recovered molecules [27]. The classical methods include maceration (solid-liquid extraction) and the use of solvents. The solvent used depends on the type of material and compounds that need to be recovered [10]. For flavonoids and proanthocyanidins, the extraction yield was improved when organic acids in combination with water were used [28,29]. These conventional methods present some limitations regarding the high amount of solvent and development time. To overcame these limitation green/innovative/alternative/sustainable processes (microwave, ultrasound, pressurized liquid, enzyme extractions) can be used [10] . The identification and quantification of the recovered antioxidants is realized through high pressure liquid chromatography and spectrophotometric methods (UV-VIS). The antioxidant capacity of the recovered compounds with 2,2-diphenyl-1-picrylhydrazyl (DPPH), ferric reducing antioxidant power (FRAP), 2,2'-azino-bis 3-ethylbenzothiazoline-6-sulphonic acid (ABTS), cupric reducing antioxidant capacity (CUPRAC), oxygen radical absorbance capacity (ORAC) and peroxide value [27].

The application and effectiveness of polyphenols in the functional foods, nutraceutical, and pharmaceutical industries depends on their stability, bioactivity and bioavailability [30]. Moreover, many phenolic compounds have low water solubility and an unpleasant taste, that must be masked before their incorporation in foods or medicines [31]. The shelf life and stability of phenolics can be improved with microencapsulation (a process in which particles are coated with a homogeneous or heterogeneous matrix that act as a physical permeability barrier) [32].

2.3. Dietary fibers

Dietary fiber (DF) includes a mixture of plant carbohydrate nonstarch polysaccharides, that enters in the cell wall composition [33]. Fiber is an essential nutrient resistant to the human digestive enzymes in the small intestine [34]. Depending on the water solubility, dietary fiber can be classified as soluble or insoluble [35]. Soluble DF include pectin (sugars from whole grain, legumes, fruits, etc.), inulin (agave, garlic, onion, artichoke, etc.), gums (sugar from beans, legumes, oatmeal, etc) and mucilage (from aquatic plants, cactus, aloe vera, food additives, etc.), whereas insoluble DF include cellulose (from fruits, root vegetables, etc.), hemicellulose (sugars from cereal bran and grains), lignin (aromatic alcohols from vegetables) and resistant starch (uncooked potato, banana, legumes, oats) [36]. The soluble and insoluble forms vary in physicochemical and physiological properties [37]. Soluble forms presents water solubility, viscosity and the ability to reduce blood lipids and glucose intestinal absorption [4]. The insoluble form is characterized by its porosity and density, and promotes the proper functioning of the intestinal tract (increase fecal bulk, decease intestinal transit time, enchance intestinal peristalsis) [38].

Fibers are fractioned in individual constituents in order to eliminate unwanted compounds [39]. All these affects also the behavior of the fiber in the human body and in the food applications [33,40]. Moreover the cost, time, yield, technological characteristics and lost functionalities occurring change considerably depending on the fractionation process applied [41].

DF can be extracted through traditional (dry, wet, chemical, gravimetric, enzymatic, physical, microbial process or a combination of the latters) [42] or green/innovative methods (ethanol, water, steam, ultrasonic, hydrostatic pressure, and pulsed electric field extractions) [43].

The dry methods involve the disintegration by milling and air classification to separate the fiber fraction. Wet milling methods (includes conventional, alkali and enzymatic) use water for fiber extraction and differs by the addition of reagents and conditions. Physical methods were performed to preserve the structure of fibers. Through microbial methods, a fermentation of the fibers is carried out with the help of microorganisms and enzymes [33].

An ideal extraction method should be environmentally friendly, safe, easy to perform and cost-effective. The chemicals, enzymes and equipments used to perform the majority of the previous presented methods tend to be very costly. The methods have different advantages and limitation presented in Table 1. From all these methods wet-milling presents better extractibility, produce high quality fibers (purity 50-90%), it is cost effective and use small amounts of reagents and water [33,36,39].

Table 1.

Advantages and limitations of fiber extractions methods

EXTRACTION METHODS	ADVANTAGES	LIMITATIONS	REFERENCES
DRY PROCESSING	-reduced water and energy consumption -it does not imply the use of chemicals -compared to wet milling the process is cost-effective, environment friendly and high yield	- require repeated classification to purify fractions/reduces product recovery -suitable for plants that presents starch as their main storage material	[44,45]
WET MILLING	-allows the obtaining of an appreciable amount of fibers -usage of water and minimal chemicals	-time-consuming (36 hours) -very costly -usage of a large amounts of sulfur dioxide (SO_2), that is environmentally unfriendly and can produce severe respiratory disorders	[42,46]
ALKALI WET MILLING	-produces a relatively environmentally acceptable stream of waste water	-time-consuming -tedious -the method can damage the molecular structure of dietary fiber	[36,46]
MODIFIED WET MILLING	-high purity products -it does not imply the use of reagents -it used less water -it is cost-effective	-produce waste water	[33]
CHEMICAL	-removal of starch and protein can be more complete	-poor selectivity -difficulty in controlling extraction conditions -decrease in overall fibers physiological activity -creation of significant waste of strong acids and alkalis, unfriendly with the environment	[39,47]
ENZYMATIC WET MILLING	-alternative method to reduce SO_2 (at minimal levels that impart only antimicrobial properties) produced with the conventional wet milling -reduction of the processing time	-possible SO_2 residues in final product	[42]

ENZYMATIC-GRAVIMETRIC	-higher yield of fiber compared to enzymatic-chemical methods -quick and easy to carry out	-some insoluble polysaccharides, lignin and soluble polysaccharides are lost -resistance starch is not quantified in totality -the residues contain some nitrogenous material	[48]
ENZYMATIC-CHEMICAL	-quick and easy to perform compared to enzymatic-gravimetric methods	-chemical residues in the obtained products -time-consuming -decrease in the dietary fiber yield (loss of polysaccharides during hydrolysis and chemical pre-treatment)	[49,50]
NONENZYMATIC-GRAVIMETRIC	-provides fibers with high purity	-poor selectivity -difficulty to control the extraction conditions	[48]
PHYSICAL	-the structure of the obtained fibers is mantained	-unreliable	[33,39]
MICROBIAL	-high selectivity -the structure of the obtained fibers is mantained -reaction conditions are easy to control	-production of toxic substances	[33,39]

Recently green extractions are widely used for extraction purposes. The innovative methods present advantages such as easy reproductibility, high quality extraction and low environmental impact [51,52]. However, there are some drawbacks for these modern extraction methods as follows: high temperature consumption (microwave extraction), separation issues (ultrasonic extraction) and lack of user friendliness (electric field extraction) [36].

3. Oilcake: potential source of bioactive compounds

Worldwide oilseed crops are the major grown agricultural commodities. Oilseeds are crops grown all over the world mainly for the oil extraction. They are rich in proteins, fibers, fatty acids (mono and polyunsaturated), minerals, antioxidants and vitamins [53]. More than 61% of the total production in 2020/2021, was dominated by soybean, followed by rapeseed, peanut, sunflower, cottonseed and groundnut [54].

From oilseed processing (performed by either solvent extraction or mechanical pressing) results significant amounts of peels, oilcakes and oil sludge. Oilcakes are the by-products resulted after the oil extraction from the oilseeds [55], either by mechanical (oil content around 6-7%) or solvent (<1% oil) extraction [56].

The chemical composition of seed oil cake depends on different factors, mainly extraction method, plant variety and growing conditions [40]. Sesame, walnut, pumpkin and almond oil cake, despite the seed defatting process contain high amount of oil (5.10-48%) [4,57–65]. Instead, olive, hemp and sunflower oil-cake are rich in fibers and carbohydrates [66–75]. The protein content is high in all oil-cakes, varying between a maximum of 60% in groundnut and a minimum of 24.79% in cottonseed [40,64,70,74].

The most conventional practices of valorisation include animal feed, landfilling, and biofuel conversion [4]. They can be used as animal feed due to the rich content in protein and fibers. Unfortunately, the presence of toxic/antinutritional compounds can affect both animals and humans [56]. Landfilling through the decomposition leads to methane production and thus to water pollution. The conversion in energy is realized through incineration, this sparked concerns about the negative impact of the emissions [5]. New valorisation methods include the recapturing of valuable components for the development of new products and production of biopolymer films [76].

From oil press-cakes can be extracted proteins, antioxidants, phytochemicals, and dietary fiber.

3.1. Proteins

Plant proteins from oilseeds and their by-products gained increasing attention due to their relative low cost [77]. Moreover, the proteins are gluten-free and represent an alternative for those of animal origin since they are easily digestible, non-toxic and high nutritive [78]. In the case of oilcakes when the material is defatted the aqueous extraction facilitates the recovery of proteins at high concentrations (80%). The use of full fat material led to a low protein content (40-50%). The use of solvents as ethanol, methanol or acetone also achieved low protein content in the concentrate (45-60%) [15]. However, Helling et al. [79] observed that with an aggressive alkaline solution with pH higher than 10 the fat can be dissolved. Aqueous method facilitates the removal of antinutrients present in the samples, while in the dry methodologies the absence of an antinutritional removal step is a major drawbacks [80,81].

Proteins from rapeseed contain a well-balanced amino acid composition with large amounts of sulfur amino acids that exceed the requirement for adults and children. The dominating protein groups are napin and cruciferin, together represents 85-90%. In terms of nutritional value the protein ca be compared with those from soy [82]. Rapeseed protein extracted with ultrasonic and ultrafiltration methods presented good functional properties (solubility, emulsifying capacity and stability) compared to soybean protein, indicating these proteins as a potential replacement of other proteins [83].

Protein extracted from soybean and groundnut oilcakes can be absorb and digest easily and nutritionally are equivalent to animal protein. In the amino acidic profile can be observed the absence of methionine in soybean and the rich content in arginine found in groundnut.

Linseed oilcake proteins are rich in arginine, glutamic acid and aspartic acid. Moreover, the proteins presents antifungal and emulsifying properties [84].

Sunflower oilcakes proteins have high nutritional value and are easily digestible [85]. The essential amino acids present are cysteine, methionine, leucine, valine, isoleucine, tryptophan, alanine and phenylalanine [86].

From oilcake can be prepared protein hydrolysates, isolates (>90%) and concentrates (30-80%) [23]. The isolates are obtained by solubilization with alkali at high pH, isoelectric precipitation with acid and then washing and drying. Isolates presented high water holding capacity, emulsion activity and stability. For this reasons they find application as emulsifier and functional ingredients [87]. Protein isolates from canola cannot be used as food ingredients due to their poor technological and solubility abilities [88]. Good water, fat, emulsifying and foaming properties were found in flaxseed and sesame isolates [65].

Hydrolysates are obtained after the hydrolysis of protein isolates. Through this process the protein structure is modified (improvement of functionality, solubility, hydratation and gelling abilities) and a fragment of protein, known as bioactive peptone, is created. Bioactive peptone presents biological, antioxidant, antithrombotic, hypercholesterolemic, immunomodulatory activities [56]. Peptides from sesame and rapeseed presented antihypertensive, antioxidant and bile acid binding activities, while those obtained from peanut have antithrombotic activity [89–92].

3.2. Antioxidants

Oilcakes contains natural antioxidants (free, esterified, condensed phenolic acids, flavonoids and lignans) that play the role in reducing oxidative stress and thus preventing various types of cancers [56]. These compounds can be extracted with different methods (with organic or non-toxic solvents, high pressure, microwave and supercritical fluid) and used in the preparation of a variety of foods (bakery, beverages and extruded products) [10].
The principal antioxidants present in sunflower, rapeseed, coconut, mustard, cotton and sesame oilcakes are the phenolic compounds [56]. The major antioxidants in oilcakes are presented in Table 2.

Table 2.

Major antioxidants in oilcakes

OILCAKES	ANTIOXIDANTS	REFERENCES
Rapeseed/Canola oilcake	Gallic acid, p-coumaric, Catechin, Caffeic acid, Epicatechin, Ferulic acid, Quercetin, Luteolin, Sinapic acid	[40,69,90,93,94]
Linseed/Flaxseed oilcake	Tannic acid, p-coumaric, Ferulic acid, Lignans, p-hydroxybenzoic acid	[40,56,93,94]
Peanut oilcake	p-coumaric, Caffeic acid	[40,56,93]
Sunflower oilcake	p-coumaric, Catechin, Caffeic acid, Epicatechin, Chlorogenic acid	[40,69,93,95]
Sesame oilcake	p-coumaric, Ferulic acid, Lignans	[40,93,96,97]
Mustard oilcake	p-coumaric, Caffeic acid, Ferulic acid, Sinapic acid	[40,56,93]
Palm oilcake	p-coumaric, Caffeic acid, Ferulic acid, p-hydroxybenzoic acid	[40,56,93,94]
Cottonseed oilcake	Ferulic acid, Quercetin	[40,93,97]
Hempseed oilcake	Caffeic acid, Quercetin, Luteolin	[40,56,93]
Olive oilcake	p-coumaric, Quercetin, Lignans, p-hydroxybenzoic acid	[40,56,93,94]
Walnut oilcake	Gallic acid, Ferulic acid, p-hydroxybenzoic acid	[40,93,98]

Sesame oilcake contains phytochemicals (phenolic compounds, flavonoids, tocopherols, vitamins, carotenoids, lignans, pigments and steroids) with numerous benefits for health such as antioxidant, anticarcinogenic, antiproliferative, antimicrobial, anti-inflammatory, neuroprotective, and hypocholesterolemic activities [99].

3.3. Dietary Fibers

The increasing consumers awareness for the nutritional benefits of dietary fiber explained the demand for high fiber foods [100–102]. In order to meet this demand new alternative source of dietary fiber need to be studied, such low-cost source can be the oilcakes resulted from oilseed processing. DF from oilcakes can be used as functional ingredient, supplements or additive in the food and pharmaceutical industry.

Sun et. al. [103] used a combined extraction method (ultrasonic and alkali) for the extraction of insoluble DF. The results indicated that comparative to the classic methods the temperature can be reduced to 30˚C, the time to 10 min and the consumption of alkali can be reduced up to 95%. Moreover, the physicochemical properties of dietary fibers are better than those obtained with the conventional methods because the ultrasound treatment changed the structure of DF, increasing the amount of short-chain and surface area.

Zheng et al. [104] studied the physicochemical and functional properties of defatted coconut DF that was subjected to acidic treatment, enzymatic hydrolysis and particle size distribution. The hydrolysis and particle size reduction caused structural modification, an increment in water holding capacity, water swelling capacity, soluble DF content and a decrease in oil holding capacity, emulsion capacity and color. The opposite observations were obtained with acidic treatment.

4. Bioactive compounds from oilcakes in foods

The recovered compounds extracted from oilcakes can be re-utilized as food additives, functional foods, pharmaceuticals, cosmeceuticals and bio-packaging. Nowadays, consumers are concerned about a healthy diet, since nutrition is associated with many lifestyle diseases like obesity, cancers and diabetes [100].

Plant proteins are used in foods due to their good fat/water absorbing, emulsifying, texture-modifying properties [105]. Fibers are used in various food products to alter their consistency, rheological behavior, texture and sensory properties. Moreover, fibers can be employed to improve shelf life due to their gel forming, water holding, fat mimetic and thickening abilities [33]. The addition of antioxidants to lipid-rich foods can reduce lipid-oxidative reactions. In foods are widely added synthetic antioxidants, such as butylated hydroxytoluene (BHT), due to their efficacy and low cost. However, natural antioxidants are more accepted by consumers [106].

New food products can be developed with two categories of ingredients, the first includes new and alternative food ingredients and in the second enters the ingredients obtained by the valorisation of by-products. For a successful implementation, the marketing strategy applied need to include new regulations, customer education and clear transparency (better communication, adequate labelling) [107]. When ingredients with important benefits for consumers (functional ingredients) are introduced, the final products bears the name functional [56]. Residues from the oil industry could be used as co-products for high value-added products, food additive or supplements [108].

4.1. Flaxseed oilcake (FOC)

FOC is rich in omega 3 fatty acids, proteins, insoluble and soluble DF, lignans, vitamins (A, C, D, E) and minerals with role in colon cancer prevention and reduction of cardiovascular diseases [109].

Increasing interest for new vegetarian/vegan products for consumers with intolerance to dairies led to the production of kefir-like fermented beverages with different amounts of flaxseed cake. Products with high percentages presented high viscosity (presence of mucilage and protein) and antioxidant activity (production of phenolic compounds and bioactive peptide [110].

4.2. **Peanut oilcake (PNOC)**

PNOC is an excellent source of proteins with emulsion and foam properties. The high nutritional value makes it suitable for the improvement of the physicochemical properties of pasta and cookies extraction and evaluation of functional properties [111,112].

Protein isolates from PNOC can form alone brittle films. For this reason it is necessary the introduction of glycerol or a crosslinking process to improve mechanical properties without influencing the barrier properties [113,114]

4.3. **Rapeseed oilcake (ROC)**

Sausages with canola protein concentrates in place of casein presented improved sensory properties (taste, texture and aroma) [90].

Proteins from ROC cannot be used alone in the formation of biopolymers films because they present bad mechanical and antimicrobial activities, therefore it is necessary to use emulsifiers and plasticizers. Taking this into account proteins hydrolysate from ROC with chitosan presented antimicrobial activity against *Staphylococcus aureus, Bacillus subtilis, and Escherichia coli* [76,92].

4.4. **Sunflower oilcake (SFOC)**

SFOC is a good source of antioxidants, proteins and fibers that can be used for emulsion applications.

Kreps et al. [115] compared the antioxidant potential of SFOC with a synthetic antioxidant and observed that the oilcake showed more stability during 56 day storage. The antioxidant potential is due to p-coumaric, catechin, epicatechin and chlorogenic acid.

Protein concentrates extracted from SFOC present the following properties: dissolvation appropriately in water, forming foam, emulsion at different pH and gel production. However, their enrichment with phenolic compounds limited their application in food because the phenolic acids react with the proteins decreasing solubility, digestibility, affect color and shelf-life of products [116]. When introduced this in biopolymer films, Salgado et al. [117,118] obtained films with antioxidant properties, good properties (high water solubility) and the percentage of phenolic compound to aqueous phase was high.

Protein isolated from SFOC can be used to form films with good characteristics: good mechanical, barrier and adhesive characteristics, resistance to fats and organic solvents. Further, the films are more elastic and resistance than those obtained with protein isolated from soybean oilcake [119–121].

4.5. **Sesame oilcake (SOC)**

SOC as great potential in increasing nutritional values, sensory and physicochemical properties [12].

The lignans extracted from SOC at lower amount (150 ppm) can be used as food additive for the improvement of oil stability [96]. The lipid oxidation time was reduced in butter when SOC was used in comparison to when BHT was used without changing sensory properties [122].

Sesame meal introduced (5-20 ppm) in sunflower and soybean oil inhibited thermal deterioration and loss of polyunsaturated fatty acids due to the redox properties of the phenolic compounds [60] .

Flavonoids and phenolics acids extracted from SOC and COC and BHT were introduced in vanilla cake compositions to compare their potential to improve their chemical, microbial and oxidative stability. The natural oilcakes mantained the stability up to 13 days compared to the 11 days mantained by the synthetic

antioxidant. The natural antioxidants are stable thermally and mantained the sensory quality up to 12 days [123]. The introduction of SOC flour in biscuits increase the resistance to microbial contamination, thus improving their shelf-life [108].
The introduction of 10% sesame protein concentrate in extruded snacks improved organoleptic properties, color and protein content, while lowering the carbohydrate content [124].
Sharma et al. [125] developed films with different sesame protein isolate (SPI) and gum rosin (GR) ratios. The highest tensile strength and lowest WVP, moisture and solubility were found for the 80:20 ratio. The increase in GR percentage improved the optical properties (increase and decrease in films transparency and color). The addition of GR also improved the structure (porosity decreased and compactiness increased). Considering all, the addition of GS to SPI composite films improved their mechanical, optical, morphological and physical properties.

4.6. **Walnut oilcake (WOC)**

Food can act as a vector for bioactive ingredients. The incorporation WOC as a replacement for wheat flour. Increasing the level of oilcake enrichment led to a bread with a high antioxidant potential compared to the control [126].
The addition of walnut oilcake in macaroons improved their quality (decrease in carbohydrates, omega-6/omega-3 ratio and energy). The same was observed for cakes. However, the addition of more than 10% for macaroons and 15% for cakes was not appreciated, due to the increase in phenolic and volatile compounds that affect the taste [127,128].
Grosso et al. [106] evaluated the performance of polyphenols extracted from WOC on the preservation of walnut oil obtaining good antioxidant properties against oxidation.

4.7. **Soybean oilcake (SBOC)**

SBOC is a source of high quality of proteins, essential amino acids, antioxidants (isoflavones, phenolic compounds), dietary fibers, minerals and fat that can be used in a food and other sectors [12]. Biscuits and cookies with SBOC have better antioxidant capacity, due to isoflavones content. The other nutritional compounds enchance the physicochemical, functional, nutritional and sensory properties [129,130].
For the production of films, protein extracted from SBOC are superior in comparison to other plant proteins. The films are clean, smooth, flexible and presented adhesive ability. Unfortunately, during long term storage, they suffer an aging that can be improved by crosslinking [15,76].
The direct incorporation of fiber from SBOC produced films with poor film-forming properties, for this reason a dynamic pressure micro-fluidization treatment was performed. The final product presented excellent barrier and mechanical properties that can be used as packaging material for instant noodle, beverages, biscuits, sausages and candies [131].

4.8. **Pumpkin oilcake (POC)**

POC is a source of natural macromolecules with film-forming ability. Protein isolates obtained from POC were used as substrate for the development of biopolymer films. The resulted films had gas barrier properties 150-250 times better than the commercially polyethylene and polypropylene films [132].

4.9. **Hempseed oilcake (HOC)**

Worldwide hempseed, grown primarily for the production of fabrics and papers, are gaining increasing interest for oil production. Industrial hemp although contains trace amount (<0.3%) of δ-9-tetrahydrocannabinol (THC) is suitable for agricultural production [6].
The incorporation of oilcakes rich in antioxidants, essential fatty acids (desirable omega-6/omega-3 ratio), fiber, and minerals led to the development of healthy, non-caloric, and high nutritional snacks. The highest appreciation was achieved with the highest addition level [133].
The supplementation with 20% in bread formulation with hemp flour resulted in products with higher nutritional value (elevate intake of important nutrients such as proteins and macro- and microelements, especially iron) [134].

5. Conclusion

The food industry generates enormous amounts of wastes, which opens a research area with the role to manage and minimizate them efficiently to support the circular economy concept. The wastes remain currently underutilized. The main solutions for reducing wastes are conversion in energy, introduction in livestock and fish feedstuff, production of fertilizer and compost. Another solution is the extraction of the maximum value (phenols, fibers, antioxidants, proteins, etc.) and they reintroduction in foods, pharmaceutics, cosmetics, and textiles. This represents a challenge, but at the same time could add more value to food, reducing disposal costs and risks caused by residues.
Bioactive compounds, extracted from oilcakes have beneficial health effects. The extraction processes depend on several factors: technique used, type of raw material and organic solvent used. Conventional technique presents some drawbacks: use of large amounts of solvents, is time and energy consuming. For these reasons, there is an increasing interest for greener technologies, that are more friendly with the environment.
Moreover, the production of ingredients or additives from food wastes and by-products may contribute to lower some nutritional problems.

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