[1.]Mariana IONESCU, [1.]Gigel PARASCHIV, [1.]Mariana FERDEȘ, [1.]Mirela DINCĂ, [1.]Bianca – Ștefania ZĂBAVĂ, [1.]Georgiana MOICEANU, [1.]Nicoleta UNGUREANU, [2.]Andreea MATACHE

INTEGRAL VALORIZATION OF OLEAGINOUS CROPS – A REVIEW

[1)] National University of Science and Technology Politehnica Bucharest/ ROMANIA;
[2)] INMA Bucharest / ROMANIA

Abstract: Worldwide, different oleaginous crops are cultivated, and according to statistics, an increase in the production of these crops is expected in the future. These oleaginous crops are mainly used for oil extraction and this oil can be used for food consumption and for biodiesel production. On the other hand, oilseed industry generates large amounts of by–products and waste. Oilseed cakes are the main residues generated after oil extraction. This article presents the oleaginous crops in biorefinary aspects, especially the biorefinary approach of the oilseed cakes, in order to minimize the agricultural waste and maximize value–added products.
Keywords: oleaginous crop, oilseed cake, biorefinery, agricultural waste

INTRODUCTION

The oleaginous crops are plants whose seeds or fruits have a high lipid content. They are the raw material for the extraction of vegetable oils and are grown mainly for this purpose. The resulted oil can be classified in edible oils (which are used directly for human consumption or as raw material in the production of margarine, mayonnaise, bakery products, pastry, canning etc.) and non–edible oils (which are used in the production of biodiesel, detergents, paints, pharmaceuticals or cosmetics etc.) (*Waseem, S. et al., 2017*).

Worldwide, different oleaginous crops are cultivated, their production reaching 500 million tons between 2018 and 2020. According to statistics, an increase in the production of these crops is expected reaching 600 million tons by 2030 (*OECD–FAO, 2021*). In 2022–2023 growing season, soybeans were the most popular type of oilseed. It was anticipated that worldwide would be produced just over 427.7 million tons of soybeans. In figure 1 it can be observed the worldwide most important oilseed crops and their production in 2022/2023 crop year (*www.statista.com*).

Even if the soybeans represent the most produced oleaginous material, palm oil is the leader on the world's vegetable oil market. As it can be observed in figure 2, in 2021/2022, the worldwide production of palm oil was about 81.38 million tons, while soybean oil production totaled about 65.32 million tons. Figure 2 presents the worldwide evolution of vegetable oils consumption, from 2013/14 to 2022/2023, by oil type (*www.statista.com*).

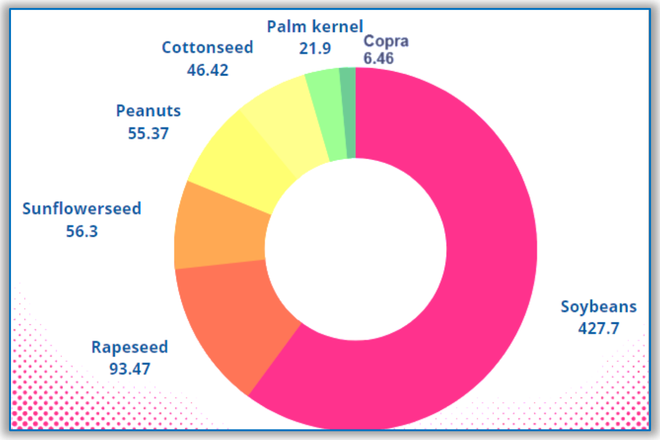

Figure 1 – Worldwide oilseed production in 2022/2023, by type (in million tons) *(plotted with data from www.statista.com)*

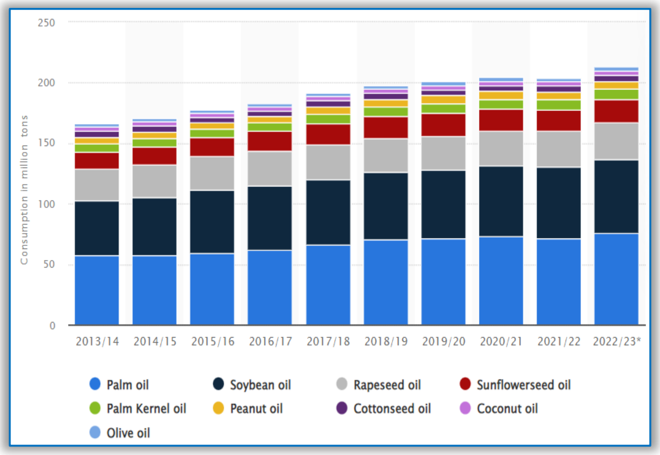

Figure 2 – Consumption of vegetable oils worldwide from 2013/14 to 2022/2023, by oil type *(www.statista.com)*

Large quantities of solid by–products (or agricultural wastes), known as oil cakes, are produced during the oil extraction process, and their production will undoubtedly increase over the next decade due to the high demand for vegetable oil. *(OECD–FAO, 2019; Singh, R. et al., 2022)*.

Through mechanical pressing, approximately 250–350 g of oil are recovered from 1 kg of oilseeds, and as a by–product, 650 g of de–oiled cake (seed cake) are produced. Therefore, around 65% of the oilseeds are left as residue (de–oiled cake), which is a large amount and justifies valorization in the context of the circular economy concept (*Rajpoot, L. et al., 2022*).

"Sustainable management of food considers the food waste problem from the systemic perspective. Think of the many steps when waste can occur in the life cycle of food: agriculture, harvesting, food production, sales, food preparation, consumption, and finally disposal". The sustainable management of food decreases inefficiencies by controlling each of these phases (*www.greenly.earth*). Figure 3 presents the estimation of food waste generated at the processing stage, by categories, in Europe (*Rakita, S. et al., 2023*).

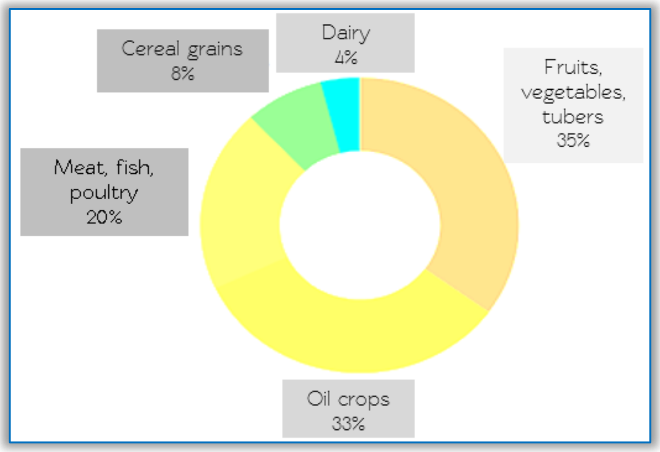

Figure 3 – Estimation of food waste generated at the processing stage, by categories, in Europe *(adapted from Rakita, S. et al., 2023)*

For oil extraction from oleaginous crops are used various methods, from which the most important are mechanical pressing and solvent extraction. The traditional technique for extracting oil is mechanical pressing, but this technique leave an important percent of oil in the oleaginous material. Another technique that is regularly used to recover the remaining oil from oleaginous crops is solvent extraction, which often involves the use of hexane as extraction solvent. The use of hexane in the extraction process in not in accordance with the demands of green chemistry, because hexane is a highly flammable substance, a volatile organic compound obtained from petroleum, and a CMR 2 (carcinogenic, mutagenic and reprotoxic) chemical (*Phan, L. et al., 2009*).

Oilseed cakes can be divided into edible oilseed cakes (such as those obtained from sunflower, soybean, peanut, mustard) and non–edible oilseed cakes (which are made from sesame, castor, jatropha, and neem). Edible oilseed cakes can be used as animal feed or as ingredient in bakery products, because they presents a high content in protein and include a variety of antioxidants, vitamins, and fibers. Whereas, the non–edible oilseed cakes contain a high amount of toxic compounds and can be used in other application such as biopesticides, bioenergy, biopolymer, and bioelectricity (*Jangir, M. et al., 2020; Sunil, L. et al., 2015; Dias, A.L.B. et al., 2017; Naik K.S. et al., 2018*). The integrated biorefinery concept is a process that convert biomass into energy and value–added products (https://www.sciencedirect.com).

This article presents the oleaginous crops in biorefinary aspects, especially the biorefinary approach of the oilseed cakes. The main advantages of biorefineries in an integrated perspective are minimizing agricultural waste and maximize value–added products, in the context of circular economy concept.

APPLICATIONS OF OILSEED CAKES AS EDIBLE PRODUCTS

Oilseed cakes are agriculture waste obtained from the oil processing industry. In other words, oilseed cakes represents the residues remaining after the partially oil removal from the oilseeds. Therefore, the oilseed cakes that are produced present a higher protein content. In accordance to a waste management system, it is necessary to use oilseed cakes as a functional ingredients that may be included into different foods (*Kotecka–Majchrzak, K. et al., 2020*). Due to variations in oilseed quality, oil extraction techniques, and storage conditions, the oilseed cakes have different compositions and nutritional contents (*Kapoor, M. et al., 2016*).

Nearly all food categories, such as dairy, bakery, beverage, confectionery, and baby food industries, have functional foods on the market. Therefore, underused oilseed cakes receive growing attention from researchers as functional ingredients in food items (*Siró, I., et al., 2008*).

In the beverage industry, the researchers analyzed the flaxseed cake–based fermented beverages in comparison with kefir as substrate. Three different experiments that contained flaxseed cake at variable concentrations of 5%, 10%, and 15% w/w were successfully used to inoculate kefir grains (*Łopusiewicz, Ł. et al., 2019*).

Edible oilseed cakes that are rich in protein and fiber can be added to various bakery products, such as cakes, cookies, and bread (*Bochkarev,* *M.S. et al., 2016)*. Another study utilized poppy, sesame, chia, and flaxseeds cakes to replace the wheat flour in the recipe of cookies.

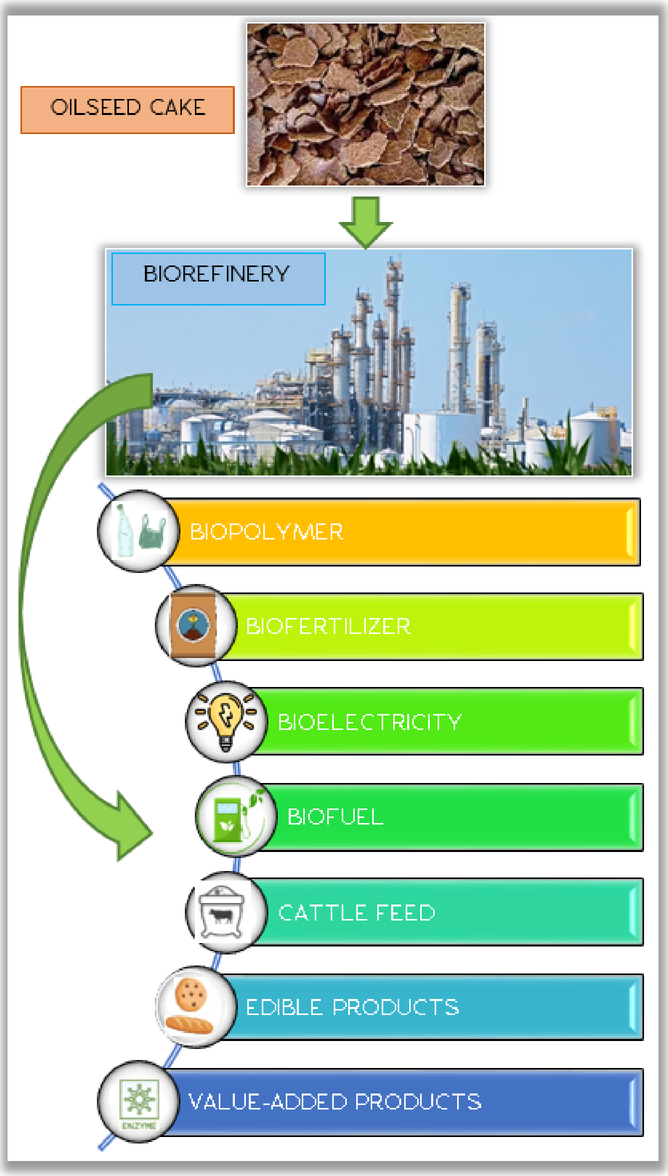

Figure 4 – Biorefinary approach of the oilseed cakes
(*adapted from Sarkar N. et al., 2021*)

The nutritional profile of the cookies was increased with this innovation *(Martinez, E. et al., 2021)*. Also, hemp seed meals were used in different amount, along with the rice flour, to produce energy bars (*Norajit, K. et al., 2011*).

Due to the therapeutic potentials of oilseeds and by–products (antidiabetic, cardio protective, antimicrobial, anticarcinogenic, neuroprotective), researchers realized compressed tablets from sunflower, coconut, pumpkin, and flax cakes, that were utilized as supplements *(Sobczak, P. et al., 2020)*.

The proteins and fibers from oilseed cakes were used to replace the meat in different food products. For example, researchers tried to partially replace the porcine and beef meat mixture from hamburgers with soy and chia meals. The results showed that this innovation conducted to a higher quality product *(Souza, A.H.P. et al., 2015)*.

An important percent of crude protein is found in oilseed cakes. For example, the oilseed cakes obtained from copra, sesame, and palm kernel contain 14–20% crude protein, while the groundnut cake has 40–5–% crude protein. Thus, these cakes are used to make value–added products in the field of fermentation and enzyme technology *(Sunil, L. et al., 2015)*. Used as a substrate or as a supplement for production medium in the solid–state fermentation, the oilseed cakes from sesame, soybean, coconut, olive, and palm, improved the enzymes production, such as protease, lipase (*Gupta, A. et al., 2018 –1; Gupta, A. et al., 2018 –2; Treichel, H. et al., 2010*). For the proteases and cellulases production, as value–added products, mahua and jatropha oilseed cakes were utilized (*Nagegowda, D.A. et al., 2020*). The utilization of sal oilseed cake increased the yield of protease obtained by *Aeromonas* sp. S1 (*Saini, G.A. et al., 2020*). Coconut oilseed cake was utilized to produce neutral metalloprotease and amylase, using *A. oryzae* (*Sumantha, A. et al., 2005; Joo, C.S. et al., 2002*), while palm and palm kernel cakes were used to produce different enzymes, using *A. niger* (*Ramachandran, A. et al., 2004*).

Other study showed that in solid–state fermentation, an increase in the yield of mushrooms was obtained when cotton cake was used; also, a higher content of protein and fat was observed in the mushrooms (*Jatuwong, K. et al., 2020*).

Another utilization of the oilseed cakes refers to the antibiotics and antimicrobials production. Sesame cake was involved in the antibiotic production; soybean, sesame and sunflower cakes were utilized for clavulanic acid and cephamycin C production; for obtaining Bacitracin was used sunflower cake, while *Bacillus licheniformis* and *Bacillus thuringiensis* were produced with sesame cake (*Usman, I. et al., 2023*).

OTHER APPLICATIONS OF OILSEED CAKES

The use of organic fertilizer, a good substitute for artificial fertilizer, is demonstrated in numerous studies and researches. The most important advantage of organic fertilizer over chemical fertilizer is that it transforms nitrogen into a less soluble form *(Aziz, S. et al., 2018)*. Due to the phosphorous, nitrogen, and potassium content, many of the non–edible oilseed cakes (cottonseed, mahua, karanja, neem, and castor) are utilized as organic fertilizers (*Ramachandran, S. et al., 2007*). The utilization of cottonseed cake as organic fertilizer was demonstrated in a study where the cottonseed cake composition was investigated by Atomic Absorption Spectroscopy *(Aziz, S. et al., 2018).*

Recent research focused in producing biogas with the aim of oilseed cakes. The studies also investigated the factors involved in the biogas production, such as pre–treatment methods, type of inoculums and operation parameters (*Sriti, J. et al., 2013*). In order to produce biogas from oilseed cakes the method of anaerobic digestion is used *(Ben–Youssef, S. et al., 2017).* The productivity of bioconversion depends on the biomass's lignin content. It has been possible to enhance the availability of biodegradable material in lignocellulosic biomass via several functional and physicochemical features. One of the by–products that is suitable for biogas production is represented by jatropha seed cake *(Deepanraj, B. et al., 2021).*

Another application of the oilseed cakes is as biomass–producing electricity. This application is very important for areas where electric facilities does not exist. In a study, briquettes obtained from jatropha oilseed cake were successfully used in an electricity–generating machine *(Gutiérrez, C. et al., 2010).*

Due to the high concentration of polysaccharides and proteins, oilseed cakes are a unique polymeric substance that is used to create a variety of biopolymer film–based packaging materials *(Ancuța, P. et al., 2020).* The biopolymer films obtained from oilseed cakes present a favorable gas barrier properties under low moisture circumstances, and various characteristics of the biopolymer films can be improved through several optimization procedures *(Popović, S. et al., 2020).* The oilseed cakes represent a natural composite, which can be successfully used at the polymer fiberboards production. This process involves the thermo–pressing of the oilseed cake. The oilseed cake protein improves the fiber's consistency and entanglement *(Saini, G.A. et al., 2013).* The biopolymer obtained is renewable, biodegradable and environmental friendly, thus the production of agro–materials by oilseed cakes thermo–pressing represents an innovative solution for valorization *(Sarkar N. et al., 2021).*

The proteins, vitamins, electrolytes content of the oilseed cakes improve the performance of the animals when is used as a supplement in animals diet. Also, the animal metabolism is improved due to the linoleic acid content of the oilseed cakes *(Sarkar N. et al., 2021).* In addition, the oilseed cakes can be utilized as an aquaculture feed for fish. An improvement in the fish fillet texture and a growth rate of the fish was observed when the fish diet contained hempseed cake (*Lunger, C.S. et al., 2007; Callaway, J.C., 2004*).

CONCLUSIONS

After cereals, oilseeds are considered to be the second most significant factor affecting agricultural economies. Large quantities of solid by–products (or agricultural wastes), known as oilseed cakes, are produced during the oil extraction process, and their production will undoubtedly increase over the next decade due to the high demand for vegetable oil.

It is known that around 65% of the oilseeds are left as residue (de–oiled cake), which represents a large amount of agricultural waste. Thus, in accordance to a waste management system, it is necessary to use these oilseed meals in a sustainable way, contributing to the development of low–cost, and novel products while reducing food waste disposal.

The available studies from the literature, presented the importance of these oilseeds' by–products in the context of the circular economy concept. Taking into account that oilseed cakes have an important content of proteins, fibers, and bioactive compounds, they are recommended as functional ingredients in food items (such as meat, bakery, and beverage industry products), as substrate for enzymes and mushroom production, or in the antibiotics and antimicrobials production.

Beyond the nutritional value, the oilseed cakes valorisation will help in accomplishing the zero–waste challenge. In this purpose, other applications of the oilseed cakes are developed, such as: the oilseed cake use as organic fertilizer, the biogas production by anaerobic digestion of substrate enhanced with oilseed cakes, the oilseed cake use as biomass–producing electricity, the use of oilseed cake at the biopolymer production or the oilseed cake use as a supplement in the cattle feed.

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