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Review

Defatting and Defatted Peanuts: A Critical Review on Methods of Oil Extraction and Consideration of Solid Matrix as a By-Product or Intended Target

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Abstract: Peanuts, being crucial crops of global importance, have gained widespread recognition for their versatility and nutritional value. In addition to direct consumption, either with or without treatment, peanuts can be the subject of diverse applications focusing mainly on two distinct objectives: oil extraction and defatting processes. As a result of the first process, a solid matrix is generated as a by-product, necessitating the exploration of strategies for its valorization, while the second process is centered on obtaining protein-rich, low-fat peanuts, for which the oil recovered becomes the by-product. As consumers increasingly seek out plant-based foods for their potential health benefits, this trend is expected to persist, encompassing peanut-based foods as well. This review elucidates the methods used for extracting peanut oil, including mechanical and chemical processes that have been combined with biological or physical pre-treatment techniques. Their primary goals are to maximize oil extraction and unlock the untapped potential of defatted whole peanuts. Additionally, the review addresses the challenges and opportunities in both oil extraction and defatting processes, emphasizing the importance of sustainable practices and efficient resource utilization. The advantages and disadvantages of each method were also evaluated and critically analyzed. Developing novel methods for potential industrial applications and limiting the drawbacks associated with traditional methods became necessary. A comparison in terms of productivity, efficacy, specificity, quality of the extracts, and operating conditions was conducted, which favored the novel methods as being mostly environmentally friendly and cost-efficient.

Keywords: defatting peanuts; defatted peanuts; oil extraction; peanut protein; nutritional characteristics

Citation: Mahfoud, F.; Assaf, J.C.; Elias, R.; Debs, E.; Louka, N. Defatting and Defatted Peanuts: A Critical Review on Methods of Oil Extraction and Consideration of Solid Matrix as a By-Product or Intended Target. *Processes* **2023**, *11*, 2512. https://doi.org/10.3390/pr11082512

Academic Editor: Yonghui Li

Received: 1 August 2023
Revised: 16 August 2023
Accepted: 17 August 2023
Published: 21 August 2023

1. Introduction

Peanut, or *Arachis hypogeae* L., is currently a vital oilseed crop widely utilized in the confectionery, snack, and fat/oil manufacturing industries [1]. This plant belongs to the Fabaceae family and originates from South America. It is grown in areas with tropical, subtropical, and temperate climates [2] and has become well-known for being a high-protein source, containing between 22% and 30% protein. Additionally, it is a source of nutrients like niacin, which helps promote healthy blood flow and brain function, folate, antioxidants, vitamin E, magnesium, phosphorus, and dietary fibers [3]. Peanuts are commonly eaten as a snack or processed into peanut butter, while more than 70% of the harvest is used for oil extraction [4]. Indeed, peanuts contain between 45.9% and 55.4% of lipids that are specifically high in essential polyunsaturated fatty acids [5–7].

Among the unsaturated fatty acids, oleic acid and linoleic acid account for 33.3–61.3% and 18.5–47.5%, respectively. Despite being high in calories, many studies have highlighted the health-promoting properties of peanuts [8]. In fact, high consumption of nuts is associated with a beneficial impact on the cardiovascular system [9], due to their antioxidant and anti-inflammatory properties [10,11]. Research has also found that consuming peanuts and peanut butter five times per week can reduce the likelihood of developing type 2 diabetes [11,12] and chronic diseases such as cancer [11,13]. Peanuts and their by-products could potentially serve as natural chemo-preventive agents [14].

Removing lipids from food products is sought by health-conscious individuals who require diets that are low in fat and high in protein. While several methods are available for extracting oil from oilseeds, some of them might negatively affect the extracted oil and/or the remaining solid matrices. The mechanical methods are the most commonly used ones, including hydraulic pressing [1–4,8], extrusion [15,16], screw pressing [16–18], and cold pressing [6,19–21]. Hydraulic pressing has been significantly enhanced in certain instances to preserve the physical form of whole peanuts following defatting. This was achieved through a technique known as "Mechanical Expression Preserving Shape Integrity" (MEPSI) [8,22], combined with a reconstitution process called "Intensification of Vaporization by Decompression to the Vacuum" (IVDV) [1,8,23–25]. This method relies on the use of a separating agent during defatting to prevent irreversible physical damage and distortion of peanuts. In other scenarios, the reconstitution happened via soaking in water for a sufficient time and then drying to a water content of 7–10% dry basis (d.b.) before roasting [2,3]. Chemical methods are also frequently cited in the literature. They include organic solvent extraction, such as hexane [15–17], trichloroethylene [26], or utilizing supercritical CO_2 (SC-CO_2) adjusted through the addition of a co-solvent containing ethanol [19–21], as well as aqueous extraction processing (AEP) employing water [6,17]. Another technique is Soxhlet extraction, which uses various solvents such as ethanol [23]. Advanced, environmentally friendly technologies have been implemented, involving a synergistic combination of multiple treatments and extraction methods. This strategic approach aims to enhance oil yield while reducing expenses and energy consumption. Several methods of AEP are discussed, including enzyme-assisted aqueous extraction (EAAE) [27–29], aqueous and mechanical extraction by treatment with NaCl [30], and aqueous extraction combined with membrane separation by applying two-stage microfiltration and ultrafiltration (MF/UF) [31]. Additionally, aqueous enzymatic extraction was coupled to an ultrasonic pre-treatment [32,33], infrared radiation (IR) [34], or microwave radiation by treatment with $CaCl_2$ [35], which usually relies on heat transfer and varies depending on the type of product and the oven's chamber design and operation [36].

The growing interest in the bio-functional properties of peanut oil and defatted peanuts has established them as significant subjects of study. This review stands as a pioneering effort in the field, meticulously compiling and analyzing a comprehensive range of methods employed over the past 45 years for oil extraction from peanuts and the production of partially defatted peanuts. The main objective is to assess and compare various oil extraction methods for peanuts based on factors such as the percentage of oil recovery, the nutritional value of the peanut-based by-products, and efficiency in valorizing the defatted peanuts by physical reconstitution. The pre-treatments, post-treatments, and optimal parameters adopted in each process are highlighted. The advantages and disadvantages of each method are also discussed.

To gather relevant information, scientific databases, including Google Scholar [37], ScienceDirect [38], Web of Science [39], Wiley online library [40], and Research Gate [41], were searched for published research studies and Espacenet [42] and Google Patent [43] for patents. The combined terms used in this work include: "peanut", "oil extraction", "peanut oil", "by-product", "valorization", "partially defatted", "peanut meal", "peanuts flour", "reconstituted peanuts", "IVDV", "mechanical pressing", "hydraulic pressing", "extrusion", "cold pressing", "organic solvent", "Soxhlet", "aqueous extraction", "enzyme assisted", "microwave", "infrared", "ultraviolet", "protein-rich by-products", "peanut butter", "peanut protein isolate", "peanut protein concentrate".

To ensure the relevance and quality of the retrieved articles, the title and abstract of each article were carefully examined by the first and second authors of this review. In cases of disagreement, the opinions of the co-authors were sought. Additionally, the references cited in the retrieved articles were assessed to identify further sources that could provide useful information for this review. The selected papers were then organized and managed using Mendeley reference manager software (version 1.19.8) to avoid duplication and facilitate analysis.

2. Mechanical Methods of Oil Extraction from Peanuts

Mechanical techniques for oil extraction from peanuts are grouped into three main sections: extrusion and screw pressing, cold pressing, and hydraulic pressing. Table 1 showcases all these mechanical methods employed, along with their experimental conditions, including pre-and post-treatments, evaluation of the nutritional value of the final products, and oil yield.

Table 1. Mechanical methods of oil extraction from peanuts.

Methods/Year/ Reference	Target Product(s)	Product(s) Description	Nutritional Value	Oil Recovery (%)	Pre-Treatment	Post-Treatment	Parameters
MEPSI (2014) [1]	Partially defatted peanuts and Peanut oil.	Expansion, preserving structural integrity, and organoleptic properties	High protein content in the defatted peanut	50 (Optimal conditions) up to 80%	- Air roasting: 140 °C, 15 min. - Rehydration: different water content (W).	IVDV texturization: P = 0.9 MPa, 10 s	Pressing optimal conditions: - 5% d.b. water content. - Homogenization: 2 days, 4 °C. - P = 9.7 MPa. - T = 20 °C. - t = 4 min. - compression speed: 8 mm/s.
MEPSI optimized by RSM (2016) [3]	Partially defatted peanuts and Peanut oil.	Expansion, recovering original shape, and organoleptic properties	High-protein, crunchy snacks with reduced fat	70–80%	- Air roasting: 140 °C, 15 min. - Rehydration: 5, 7, 10, 13, 15% d.b. water content.	Reconstitution and roasting: - Soaking: 30 min. - Drying: 50 °C. - Roasting with salt: 170–180 °C, 210 s. - Rapid cooling.	Pressing optimal conditions: - W = 13.17% d.b. - P = 12 MPa. - t = 19.19 min. - Response optimum: Expansion Ratio = 1.2, Grain Appearance = 6.2, Grain Hardness = 4.5 N, Work Done = 15.7 mJ, Quantity of Fractures = 17, Consumer Textural Evaluation = 8.5.
MEPSI optimized by RSM (2016) [2]	Partially defatted peanuts and Peanut oil.	Expansion, recovering original shape, and organoleptic properties	High protein, low fat, and high fiber content in the defatted peanut	70.6%	- Air roasting: 140 °C, 15 min. - Rehydration: W < 8% d.b.	Reconstitution and roasting: - Soaking: 30 min. - Drying: 50 °C. - Roasting with salt: 170–180 °C, 210 s. - Rapid cooling.	Pressing optimal conditions: - W = 5% d.b. - P = 9.7 MPa. - t = 4 min.

Table 1. *Cont.*

Methods/Year/Reference	Target Product(s)	Product(s) Description	Nutritional Value	Oil Recovery (%)	Pre-Treatment	Post-Treatment	Parameters
MEPSI optimized by RSM (2017) [8]	Partially defatted peanuts and Peanut oil.	Full shape recovery of peanuts, assuring better morphological, organoleptic, and rheological properties	High protein, low fat, and high fiber content in the defatted peanut	56.26%	- Air roasting: 140 °C, 15 min. - Rehydration: W = 5% d.b.	- Rehydration: 7.1, 11.5, 18, 24.5, 29% d.b. of water content. - IVDV texturization. - Dehydration: 50 °C. - Roasting with salt: 180 °C, 210 s.	IVDV optimal conditions: - W = 17.3% d.b. - $P = 12 \times 10^5$ Pa. - t = 18.6 s. - RSM: Expansion Ratio = 1.54, Grain Appearance = 7.11, Defatting Ratio = 56.26%, Overall Appreciation (/10) = 7.71
MEPSI optimized by RSM (2018) [4]	Partially defatted peanuts and Peanut oil.	Full shape recovery of peanuts, assuring better morphological, organoleptic, and rheological properties	High protein, low fat, and high fiber content in the defatted peanut	45.02 ± 0.4%	- Air roasting: 140 °C, 15 min. - Rehydration: W = 5% d.b.	- Rehydration: 7.1, 11.5, 18, 24.5, 29% d.b. of water content. - IVDV texturization. - Dehydration: 50 °C. - Roasting with salt: 180 °C, 210 s.	IVDV optimal conditions: - W = 19.9% d.b. - $P = 9.1 \times 10^5$ Pa. - t = 17.1 s. - RSM: Grain Hardness = 5.94 N, Work Done = 5.76 mJ, Texture Sensory Analysis (/10) = 8.14, Consumer Colour Evaluation (/10) = 7.66.
MEPSI optimized by RSM (2021) [22]	Partially defatted peanuts and Peanut oil.	Full shape recovery of peanuts, assuring better morphological, organoleptic, and rheological properties	High protein, low fat, and high fiber content in the defatted peanut	70.62%	- Air roasting: 140 °C, 15 min. - Rehydration: 5, 7, 10, 13, 15% d.b.	- Dehydration: 50 °C. - Roasting with salt: 180 °C, 210 s → 2% d.b. - Coating and rapid cooling.	IVDV optimal conditions: - W = 12.2 ± 0.6% d.b. - P = 6 ± 0.3 MPa. - t = 18.2 ± 0.6 min. - RSM: Free Fatty Acid = 0.13%, Total Oxidation = 19.68 $meqO_2/Kg$, Taste (/10) = 9, Aroma (/10) = 7.57.

Table 1. *Cont.*

Methods/Year/ Reference	Target Product(s)	Product(s) Description	Nutritional Value	Oil Recovery (%)	Pre-Treatment	Post-Treatment	Parameters
Hot and cold press (2020) [6]	Peanut Oil	Formation of PDPM	Low fat, High protein, and high fiber content in the PDPM	N/A	Roasting: 180 °C, 20 min (With or without removing the red skin).	N/A	Pressing optimal conditions: - P = 100–110 MPa. - T = 180 °C. - t = 20 min.
Hydraulic press (pre-treated with IR irradiation) (2020) [44]	Partially defatted peanuts and Peanut oil.	Full shape recovery of peanuts, assuring better morphological, organoleptic, and rheological properties	Rich in fiber and more than 30 essential nutrients. High concentrations of polyphenols and antioxidants in the defatted peanut	45%	- Placing the peanuts in a round bottom flask: distance = 1 cm from the ceramic IR emitter. - Irradiation: Different exposure times and temperatures.	IVDV texturization.	Process optimal conditions: - IR irradiation: 88.5 °C, 56 min. - Hydraulic pressing: 80 bar, 1 min.
Extrusion optimized by RSM (2009) [15]	PDPF and Peanut oil.	PDPF was used to develop peanut-based Textured Meat Analogue	High protein content and cholesterol-free in the peanut-based TMA	N/A	N/A	N/A	Extrusion Optimal conditions: - 60–65% protein. - 160–165 °C. - 80–90 rpm screw speed.
Screw pressing (2019) [17]	Peanut oil	The peanuts exhibit compromised integrity characteristics of oil were investigated.	Peanut oil is a rich source of bioactive components	-Roasted peanuts: 41.18–46.28%. -Non-roasted peanuts: 41.17%	- Dry air roasting: 140, 160, and 180 °C, 5 and 10 min. - Cooling: Room temperature.	Centrifugation of peanut oil: 12,000 rpm, 10 min.	- Pressing optimal conditions: T < 50 °C. - Roasting optimal conditions: 180 °C, 10 min.

Table 1. *Cont.*

Methods/Year/ Reference	Target Product(s)	Product(s) Description	Nutritional Value	Oil Recovery (%)	Pre-Treatment	Post-Treatment	Parameters
MEPSI optimized by RSM (2016) [45]	Partially defatted peanuts and Peanut oil.	Full shape recovery of peanuts, assuring better morphological, organoleptic, and rheological properties	High protein, low fat, and high fiber content in the defatted peanut	70%	- Air roasting: 140 °C, 15 min. - Rehydration: 5, 7, 10, 13, and 15% d.b. water content.	- Soaking. - Drying: 50 °C. - Roasting with salt: 180 °C, 210 s.	Pressing optimal conditions: - W = 5% d.b. - P = 9.7 MPa. - t = 4 min. - RSM: Colour consumer evaluation = 8.03/10, Total colour change = 74.9, Facturability = 7.12 N; First fracture percentage of deformation = 8.2%; Rupture force = 22.93 N; Percentage of deformation at rupture = 4.8%.
Dry, wet extrusion and Screw Pressing (2009) [16]	PDPF and Peanut oil.	Formation of PDPM	High protein, low fat, and high fiber content in the PDPM	65.6% extruder only vs. 90.6% extrusion and screw pressing	Dehulling and separating of skins.	N/A	Extrusion optimal conditions: 136–138 °C, 30 s, feed rate = 142 kg/h. Pressing optimal conditions: T = 90 °C, 1 min discharge opening in the screw press: 4.49 mm.
Cold pressing (2018) [19]	PDPM and Peanut oil.	Formation of PDPM	High-quality oils are obtained suitable for direct consumption	65%	- Peeling. - Drying.	N/A	Pressing experimental conditions: - T = 50, 100, 150, and 200 °C. - Cold Rotation speeds = 17, 49, 96 rpm - T(oil) $\leq$ 84 °C.

Table 1. *Cont.*

Methods/Year/ Reference	Target Product(s)	Product(s) Description	Nutritional Value	Oil Recovery (%)	Pre-Treatment	Post-Treatment	Parameters
Cold pressing (2020) [21]	PDPM and Peanut oil.	Formation of PDPM	Low fat, High protein (>25%), and high fiber content in the PDPM	30%	- Mechanical shelling. - Dehydration: W = 4–8% d.b. - Skin coat removed.	N/A	Pressing experimental conditions: - Twinscrew press: T < 60 °C. - Frame filter (press and filter three times): T < 30 °C.
Cold pressing (2017) [20]	PDPM and Peanut oil.	Formation of PDPM	High protein, with reduced fat in the PDPM. Oil is in line with national standards.	39.8%	- Shelling. - Crushing. - Regulation of moisture content. - Frying.	Filtering: Peanut oil.	Pressing optimal conditions: - T(oil) < 65 °C. - W (peanuts) = 7% d.b.
Screw Pressing (2020) [46]	PDPM and Peanut oil.	Formation of PDPM	Peanut oil contains oleic and linoleic acids (38–56%) and (16–38%), respectively, and is low in free fatty acids	75.89%	- Nude peanuts hot air exposure: 105 °C. - Rehydration: 8, 11, and 14% w.b.	N/A	Pressing optimal conditions: - Screw speed: 20 rpm. - T = 66.5 °C. - W = 8% d.b.
Hydraulic Pressing (2007) [47]	Peanut oil	Formation of PDPM	High protein, with reduced fat in the PDPM.	33.36%	N/A	N/A	Pressing optimal conditions: - P = 25 MPa. - t = 7 min. - W = 1.76% d.b.
Hydraulic Pressing (2014) [48]	Peanut oil	Formation of PDPM	High protein, with reduced fat in the PDPM.	32.36%	Drying: 130 °C, 6 h	N/A	Pressing optimal conditions: - P = 15.77 MPa. - t = 6.69 min. - W = 8.13% d.b.

2.1. Extrusion and Screw Pressing

The process of food extrusion involves a series of thermal and mechanical steps that can result in various physicochemical changes in the raw materials. These changes include but are not limited to binding, cleavage, loss of native characteristics, fragmenting, and recombination. Extrusion processing is a more favorable option over conventional methods since it typically operates continuously at high temperatures for a short amount of time, resulting in greater nutrient retention [49]. In most cases, extrusion involves screw pressing, which makes oil extraction possible through the application of axial pressure generated through volumetric compression. The rotating worm shaft also contributes to the process by applying force, resulting in the squeezing of the oil from the kernels [50]. A screw press is made up of a horizontal screw that is secured in a perforated barrel, which is used to extract oil [46].

In 2009, Rehrah et al. studied the use of PDPF, a protein-rich ingredient [51], to create a plant-based alternative to meat that would be attractive to health-conscious consumers. The flour is first processed into a PPC, which is then mixed under specific conditions (at 160–165 °C, screw speed of 80–90 rpm, and moisture content of 50–55%) through a process of extrusion to yield a final product with 60–65% protein. Riaz et al. studied the creation of PDPF, a new product with less than 10% oil that had reduced fat content, improved protein content, good flavor, and a long shelf life [16]. This was achieved by removing enough oil from raw peanuts through a combination of dry extrusion and screw pressing. An extruder was developed to aid in oil extraction, and the single-screw machine operated at a low moisture level of 6.13 $\pm$ 0.14%. Importantly, this process did not involve any chemical agents or produce waste streams. Using only extrusion, it was possible to remove 65.6% of the oil from raw peanuts, while extrusion combined with screw pressing removed 90.6% of the original oil. Optimal conditions for the process included a feeding rate of 142 kg/h, dry extrusion at 136–138 °C for 30 s, and coupling the extrusion to screw pressing at a temperature of 90 °C for 1 min [16]. These two studies provided complementary information on the process of producing PDPF from peanuts. They demonstrated a clear pathway from oil extraction, which has potential applications in various industries, notably the development of a meat alternative for vegans. Overall, these findings represent an exciting development in the utilization of peanuts that deviates from the concept of maintaining the peanut's original structure.

A study carried out in 2019 by Suri et al. examined how peanut oil quality characteristics were affected by a combination of dry air roasting and mechanical extraction using screw pressing [17]. The researchers found that optimal conditions for air roasting were 180 °C for 10 min, followed by cooling at room temperature. Oil extraction using screw pressing at a temperature below 50 °C resulted in a yield of 41.18–46.28%, followed by centrifugation of the oil at 12,000 rpm for 10 min to remove impurities. The study demonstrated that this method led to a lower PV and a higher oxidative stability index (OSI) [17]. Mridula et al. conducted a study in 2020 that involved subjecting peanuts to hot air treatment at 105 °C and then mixing them with distilled water to increase moisture levels [46]. They achieved an extraction of 75.89% of the oil in peanuts by using a screw speed of 20 rpm and pressing the samples at a temperature of 70 $\pm$ 2 °C with a sample moisture content of 8%. RSM response parameters showed a desirability of 81.8%. It was observed that maintaining a lower pre-treatment temperature of 105 °C and a moisture content of 8% w.b. yielded a higher quantity and quality of oil, thus ensuring a relatively high level of desirability for consumers. However, it is important to note that the experimental conditions and methods employed in the two studies may have varied, leading to differences in the results. For instance, the optimal air roasting temperature and duration were different. In addition, factors such as the type of peanuts used, processing equipment, and the duration of storage after extraction could influence the quality of the oil obtained. Therefore, further research is required to determine the optimal pre-treatment conditions for extracting high-quality peanut oil.

2.2. Cold Pressing

The cold press extraction method has gained popularity in recent years, primarily due to its ability to obtain premium-quality oils without subjecting them to high temperatures or the use of solvents, thus aligning with environmentally friendly practices. This method can be classified into three types: expellers, expanders, and twin-cold systems [19]. The procedure generally involves the shelling, crushing, moisture content adjustment, and frying of peanuts before they are cold-pressed, with the resulting peanut oil then being filtered [20].

In 2017, Chen et al. examined the effects of pressing temperature and moisture content, which are associated with the cold-pressing technique, on the yield, acid value, moisture content, and volatile matter content of peanut oil [20]. When prioritizing acid value as a factor, the pressing temperature had the most significant impact, followed by moisture content. After experimentation, it was determined that the optimal cold-pressing conditions to ensure the production of high-quality peanut oil are an oil temperature of 65 °C and a moisture content of 7%. Under these conditions, the acid value of the oil was 0.133, the moisture and volatile matter content were 0.015%, and the oil yield was as high as 39.8% [20]. In 2020, Shin et al. extracted oil from peanuts using the cold pressing method and aimed to valorize the partially defatted peanut meal (PDPM) obtained [21]. In the process of producing cold-pressed peanut oil, mechanical shelling is commonly used, and the peanut kernels with red skin are then dehydrated to a moisture content of 4–8% to make them easier to peel. The peanuts are then placed in a conditioning tank, where the pressing temperature and moisture are adjusted to maximize the oil yield. To commercially extract cold-pressed peanut oil, a twin-screw press is used, and the pressing is performed at specific temperatures that do not exceed 60 °C. The oil yield was not evaluated in this study, but the researchers were very interested in utilizing the by-product of this extraction (i.e., the meal), knowing that 70 kg of PDPM was recovered out of 100 kg of peanuts [21]. In 2019, Konuskan et al. investigated the physicochemical properties of cold-pressed nuts, specifically peanuts in the Eastern Mediterranean region, with a focus on their fatty acid composition [52]. An oil screw expeller was used to extract the oil, which was then subjected to malaxation and centrifugation processes at 25 °C for 30 min and at 5000 rpm, respectively. Peanuts were found to have the highest free fatty acid content at 1.36%, which can result in poor-quality oils with significant losses during the refining process. Additionally, peanut oil had a high initial PV of 8.39 meq O_2/kg, indicating a short shelf life and limited suitability for human consumption [52]. On another note, a study performed by Ji et al. in 2020 aimed to investigate the presence of cancer-causing compounds in extracted peanut oil [6]. The amount of AF in oil extracted through hot pressing was much higher than that in oil extracted through cold pressing. This increase in concentration at high temperatures could be due to the breakdown of other food components and the release of bound AF. It is crucial to implement preventative measures against AF contamination from the outset because of its adverse health impacts [53]. This includes sound agricultural practices and effective chemical and bio-control strategies targeting AF-producing *Aspergillus* spp. [54]. It is worth noting that the cold press extraction method has a relatively low oil yield (<40%), which is considered mediocre. These findings suggest that appropriate pre-treatment/extraction methods can improve the quality and yield of cold-pressed peanut oil, making it more suitable for human consumption. Additional research may be needed to optimize the cold-pressing process to produce high-quality peanut oil with desirable physicochemical properties and minimal contaminants.

2.3. Hydraulic Pressing

Five identified factors can affect hydraulic pressing. They include the moisture content of the peanuts before pressing, the level of pressure applied, the speed at which the piston moves, the thickness of the cake after the number of seeds per unit area, and how long the pressing duration lasts [2].

In 2007, Olajide et al. assessed the predictive precision of a recently devised neural network concerning oil yield. The extraction process involved hydraulic pressing, and the researchers identified the optimal operating conditions as follows: pressure of 25 MPa, pressing time of 7 min, and moisture content of 1.76% d.b. Under these specified conditions, the maximum oil yield was 33.36% [47]. Another related study explored the influence of operating parameters on the mechanical extraction of oil from groundnut kernels through the utilization of a hydraulic press [48]. The oil yield recorded was 32.36% under a pressure of 15.77 MPa for 6.69 min, and with a moisture content set at 8.13% d.b. The low oil yield raises concerns about the efficiency of the extraction process, knowing that higher oil yields are often desired in industrial applications to maximize the utilization of raw materials and increase overall production efficiency. Additionally, the obtained results can be compared with alternative extraction methods to ascertain the competitiveness and practicality of the hydraulic press approach.

A recent improvement has led to a more efficient and economical defatting process for whole peanuts, resulting in less waste of misshapen seeds, a reduced risk of grain breakage under high pressure, and streamlined oil extraction for diverse applications. The unique aspect of this defatting method is the use of a special separation material placed between the grains within the press chamber [3,46], which helps to retain the structural and sensory qualities of the final product [2]. Consequently, the objective of this technique is to maximize oil extraction while generating defatted whole peanuts with high levels of protein and fiber and reduced oil content. The details are clearly explained in the patents LB-10,492 [55] and LB-10,493 [56], in which MEPSI involved air-roasting peanuts as a pre-treatment. The purpose of this step was to improve the taste and appearance of the nuts, enhance the oil extraction, reduce the deformation of the kernels, and decrease the moisture content to 2–3% d.b. The peanuts were then rehydrated and pressed at room temperature to achieve different water content levels ranging from 5% to 15%. This was necessary to improve the compressibility of the grains and their resistance to disintegration, which in turn reduced the occurrence of permanent deformation during the pressing process [1,4,8,46,57]. A supplementary post-treatment using IVDV was applied to improve the properties of the final product. It involved subjecting the distorted seeds to a steam pressure of up to 1.5 MPa, reached within one second, and treating them under such high pressure and temperature for a certain period of time. The pressure is then suddenly released into the vacuum, causing some of the water content to auto-vaporize, thus leading to an expanded structure. The resulting products were subsequently dried in a ventilated oven at 50 °C until the relative humidity reached 7–10% w.b. This thermo-mechanical process was aimed at texturizing the product by regaining its original shape and size, as well as enhancing its textural, physiochemical, and sensorial properties [1].

A coupling between MEPSI and IVDV was achieved by Nader et al., reaching around 56% of the oil extraction rate from whole peanuts when the optimal conditions were applied [1,8]. When lower pressure and processing times were used, a slight decrease in the oil yield was noted [4]. The physical characteristics of peanuts were examined after oil extraction. The consumer color evaluation and the textural sensory analysis demonstrated a significant advantage over previously produced partially defatted whole peanuts [2,3]. Further enhancements were introduced by the same team, and a significantly higher defatting ratio of 70.62% was reached upon applying greater pressure [22]. An evaluation of the response factors was performed, providing insights into the impact of the treatment on the textural qualities of the peanuts. The treated whole peanuts exhibited reduced malleability, lighter coloration, and enhanced crunchiness, indicating desirable textural characteristics [45]. Following an RSM optimization, the desirability of the defatted peanuts increased by up to 80%. The physical constraint induced by pressing caused a greater exposure of the remaining oil to oxygen during defatting and final roasting, resulting in a reduction in the oxidative stability of peanuts. Furthermore, the optimal conditions obtained through multiple optimizations using RSM resulted in a significant reduction of lipid oxidation. The texture of partially defatted whole peanuts appears to be preserved better when MEPSI is combined with IVDV, owing to the lower risk of damaging the product. With that being stated, the integration of MEPSI-IVDV enables manufacturers to provide a variety of product lines to cater to diverse consumer demands with varying levels of fat and protein content. Processing conditions can therefore be optimized to maximize oil extraction while keeping desirable partially defatted whole peanuts. It is also pertinent to note that in a product that underwent expansion, an increase in porosity leads to heightened product aeration, decreased hardness, an elevated occurrence of mechanical fractures, and a greater number of acoustical events [58].

3. Chemical Methods of Oil Extraction from Peanuts

Chemical methods of oil extraction from peanuts, as detailed in Table 2, are grouped under three major flags: organic solvent extraction, aqueous extraction processing (AEP), and supercritical fluid extraction (SFE) based on the use of CO_2 as solvent (SC-CO_2). Details about the corresponding experimental parameters, pre- and post-treatment methodologies, nutritional value, and oil yield are given. Subsequently, a detailed discussion delves into each reference, initiates a chronological comparison, and provides a critique that can offer additional insights into each study.

Table 2. Chemical methods of oil extraction from peanuts.

Methods/Year/ Reference	Target Product(s)	Product(s) Description	Nutritional Value	Oil Recovery (%)	Pre-Treatment	Post-Treatment	Parameters
Organic solvent extraction (2020) [6]	PDPM and Peanut oil	Formation of PDPM	High protein, low fat, and high fiber content with a medium amount of carbs, vitamins, and minerals in the PDPM	N/A	Deskinning of peanuts.	Removal of Hexane using a rotary vacuum evaporator	Optimal conditions for oil extraction with Hexane by thermal cycles: - T = 55 °C - t = 6 h.
SC-CO_2 Extraction (1996) [59]	PDPM and Peanut oil	Formation of PDPM	N/A	95%	- Roasting: 160 °C, 35 min. - Cooling, and deskinning.	N/A	Intermittently depressurized process optimal conditions: - P = 8000 psi - T = 80 °C
Soxhlet extraction (2017) [60]	Peanut Oil	Peanuts are completely defatted but not fit for consumption	N/A	- 95% with Hexane - 100% with petroleum ether	N/A	- Distillation of solvents - Oil drying: 105 °C, 1 h. - Cooling: Room temperature.	Soxhlet optimal conditions: - W = 6.68% d.b. - T = 100 °C. - t = 8 h. - 4 to 5 drops of solvents.

Table 2. *Cont.*

Methods/Year/Reference	Target Product(s)	Product(s) Description	Nutritional Value	Oil Recovery (%)	Pre-Treatment	Post-Treatment	Parameters
SC-CO_2 Extraction and Soxhlet Extraction (2018) [57]	Peanut skin oil	Peanut skin powder	Peanut skins are rich in antioxidants such as procyanidin, catechin, and epicatechin.	SC-CO_2: 15.47% oil extract from the total product Soxhlet: 36.282% → (SC-CO_2: ~42.63% Soxhlet: 100%)	- Drying: 60 °C, 4 h. - Blending into powder. - Frozen for future use.	N/A	Soxhlet Extraction optimal conditions: - Boiling points: n-hexane: 68 °C, ethanol: 78 °C, water: 100 °C. - t = 6 h. Vacuum drying: - P = 80 mbar. - T = 40 °C. SFE optimal conditions: - t = 180 min. - T = 70 °C. - P = 30 MPa. - CO_2 flow rate: 3 mL/min.
SC-CO_2 Extraction (2022) [61]	Peanut Oil	Integrity of peanuts is compromised	N/A	Increasing temperature of extraction: 50 °C→60 °C, oil recovery increase on a mass basis by 12.2%	N/A	CO_2 compression and recycling	SFE optimal conditions: - Optimal T = 40–80 °C. - Critical P = 74 bar. - Addition of cosolvents such as petroleum ether, chloroform, and acetone.
SC-CO_2 Extraction with co-solvent ethanol (2018) [62]	Peanut skin oil	Peanut skin powder	Peanut skins are rich in antioxidants such as procyanidin, catechin, and epicatechin.	14.95% Total product mass oil extract	Pulverize thoroughly	N/A	SFE optimal conditions: - P = 29.95 MPa. - T = 40 °C. - 6.49% (Vethanol/VCO_2). - CO_2 flow rate of 3 mL/min.

Table 2. *Cont.*

Methods/Year/ Reference	Target Product(s)	Product(s) Description	Nutritional Value	Oil Recovery (%)	Pre-Treatment	Post-Treatment	Parameters
SC-CO_2 Extraction and Soxhlet extraction (2018) [63]	Peanut skin oil	Peanut skin powder	Peanut skins are rich in antioxidants such as procyanidin, catechin, and epicatechin.	SC-CO_2:15.53% Total product mass oil extract Soxhlet: 36.28% → (SC-CO_2: ~42.8% Soxhlet: 100%)	- Drying: 60 °C, 4 h. - Pulverize thoroughly. - Frozen for future use.	N/A	SFE optimal conditions: - P = 30 MPa. - T = 70 °C. - flow rate of CO_2 3 mL/min, and rate of cosolvent 5%. Soxhlet optimal conditions: - P = 80 mbar. - T = 40 °C.
Organic solvent Extraction (2019) [17]	Peanut oil	Partially defatted peanuts (not fit for consumption) and Peanut oil	Peanuts are a rich source of bioactive components	Roasted peanuts: 47.77–55.35% Non-roasted peanuts: 47.75%	- Roasted: 140, 160 and 180 °C, 5 and 10 min. - Cooling: T = 20 °C	N/A	Experimental conditions for oil extraction with Hexane: - Agitation: 200 rpm, 2 h. - Filtration: 40 °C. Optimal conditions for pretreatment: 180 °C, 10 min.
SC-CO_2 Extraction (2019) [64]	Peanut oil	The integrity of peanuts is compromised	Peanut oil is an important source of edible oils, aroma compounds, and fatty acids, particularly oleic (18:1) and linoleic (18:2) acid	15.50% Total product mass oil extract	Drying: 80 °C, 24 h	N/A	SFE experimental conditions: - P = 25–30 MPa. - T = 40–60 °C. - Flow rate of 15 kg/h. - t = 60 min (stabilize the pressure before extraction).

Table 2. *Cont.*

Methods/Year/ Reference	Target Product(s)	Product(s) Description	Nutritional Value	Oil Recovery (%)	Pre-Treatment	Post-Treatment	Parameters
Organic solvent extraction (2008) [65]	Peanut Oil	Partially defatted peanuts (not fit for consumption) and Peanut oil	N/A	85%	N/A	N/A	Oil industrial extractor with the following characteristics: - Bed Length = 14.5 m. - Bed Height = 1.8 m. - Bed Width = 2.4 m. - Number of trays in the extractor = 8. - Drainage length = 2.3 m. - Velocity of transporter = 0.003 m/s. - Vertical bulk phase velocity in the bed = 0.0125 m/s. - Tray Volume = 2.31 m^3.
AEP (2016) [66]	Peanut oil	Peanut Paste extracts: peanut oil, fiber precipitate, residual cream, and skim	N/A	92.20% of free oil	- Roasting: 150 °C, 20 min. - Cooling and grounding into flours (<2 mm). - Crushing peanuts into a paste.	N/A	AEP experimental conditions: - 1:5 solidsliquid ratio. - pH = 9 with 2 M NaOH. - Incubation: 60 °C, 2 h. - Centrifugation: 4180× g, 15 min. - Deemulsification: pH = 4.5. - Incubating: 50 °C, 2 h. - Centrifugation: 4180× g, 10 min. - Average particle size: 15.2 µm.

Table 2. *Cont.*

Methods/Year/ Reference	Target Product(s)	Product(s) Description	Nutritional Value	Oil Recovery (%)	Pre-Treatment	Post-Treatment	Parameters
SC-CO_2 Extraction vs. Soxhlet extraction (2022) [67]	Peanut oil	The integrity of peanuts is compromised	- Peanuts have a high concentration of proteins and lipids, and they are a good source of minerals like phosphorus, calcium, magnesium, and potassium. - Peanut oil is rich in fatty acids.	- SC-CO_2: 30% in 80 min - Ethanol: 26% in 480 min	- Drying: 60 °C, 72 h. - Crushing.	N/A	SFE of peanut oil: - P = 240–280 bar. - T = 40 °C and 60 °C. - flow rate of 2.0 mL/min, 80 min.
SC-CO_2 Extraction (2018) [68]	Peanut skin oil	Peanut skin powder	Peanut skin is rich in antioxidants and bioactive compounds	0.83 g extract of 5 g peanuts skin (16.6% Total product mass oil extract)	- Drying: 60 °C, 4 h. - Pulverization. - Sieving and freezing at −7 °C.	N/A	SFE optimal conditions: - P = 279 bar. - T = 70 °C. - Rate of the modifier of 7.5%. - CO_2 mixture and modifier flow rate of 3 mL/min.
AEP (1996) [69]	Peanut oil	Formation of either PPC or PPI in addition to peanut oil	N/A	89% when pH = 4 86% when pH = 7	Dry grinding of peanuts.	N/A	AEP experimental conditions: - pH = 4.0, 7.0, or 10.0. - T = 60–65 °C - Solid:Water ratios recommended range: 1:5 to 1:12.

Table 2. *Cont.*

Methods/Year/ Reference	Target Product(s)	Product(s) Description	Nutritional Value	Oil Recovery (%)	Pre-Treatment	Post-Treatment	Parameters
Organic solvent extraction (Alternative solvents to hexane) (1983) [26]	PDPM and Peanut oil	Formation of PDPM	N/A	N/A	- Cracking, heating, and flaking. - *OR* - Conditioned, ground, and flaked.	N/A	N/A
SC-CO_2 Extraction with co-solvent ethanol (2021) [70]	Peanut skin oil	Peanut skin powder	Peanut skins are rich in antioxidants such as procyanidin, catechin, and epicatechin.	14–15%	- Drying: 60 °C, 4 h. - Pulverize thoroughly. - Sieving and freezing: −20 °C	N/A	SFE experimental conditions: - P = 10–30 MPa - T = 40–70 °C - Rate of modifier 0.075–0.225 mL/min, 180 min. - Flow rate = 3 mL/min of CO_2 and ethanol.

3.1. Organic Solvent Extraction

When extracting oil from oilseeds, the organic solvent is used to separate crude vegetable oil from the meal, which contains both proteins and carbohydrates too. The most frequently utilized organic solvent for this process is hexane [18,71]. Oilseeds that have been pre-treated and are in the form of a porous solid matrix are exposed to either pure solvent or a mixture of solvent and oil (known as miscella). This allows the oil to be transferred from the solid matrix to the fluid medium. The majority of corresponding industrial extractors are designed to operate in multiple stages, in a counter-current manner [65].

A mathematical model for vegetable oil-solvent extraction in a De Smet-type extractor was developed [65]. The model was two-dimensional and unsteady-state, and it could be utilized to estimate oil concentration in pellets and miscella throughout the extractor and its outlets. By choosing specific characteristics of the extractor, such as a bed length of 14.5 m, a bed height of 1.8 m, a bed width of 2.4 m, a pump number of 8, a drainage length of 2.3 m, a transporter velocity of 0.003 m/s, a vertical bulk phase velocity of 0.0125 m/s, and a recipient volume of 2.31 m^3, an oil extraction rate higher than 85% could be achieved during the last three extraction stages [65]. Later research investigated how dry air roasting and solvent extraction methods affected the characteristics of peanut oil quality [17]. The residual oil was recovered using n-hexane solvent extraction after continuous pressing. Peanuts that had been roasted at 180 °C for 10 min were ground into powder, treated with n-hexane, and agitated at 200 rpm for 2 h. The process of extraction was repeated twice using n-hexane. The mixture was then filtered using a Buchner funnel under vacuum, and the solvent was removed using a rotary evaporator at 40 °C. This allowed the recovery of 55.35 $\pm$ 0.40% oil with an acid value of 0.79 $\pm$ 0.09 mg KOH/g, a PV of 2.57 $\pm$ 0.01 meq O_2/kg, an OSI of 8.10 $\pm$ 0.05 h, and an RSA of 69.66 $\pm$ 0.56%. Oxidation products start degrading at a higher roasting temperature, which may increase the oxidative stability of peanut oil, reflected in a lower PV and a higher OSI value. This is also backed up by the high RSA of peanut oil obtained at a higher temperature. The increased antioxidant activity can be attributed to the release of phenolics or Maillard reaction products that are known to have strong antioxidant properties [17]. These two studies demonstrate that the use of n-hexane in extraction leads to a high oil yield with favorable qualities, although evaluating an extraction method solely based on oil yield has its limitations.

Fornasari et al. used the Soxhlet extraction method to extract peanut oil for use as biofuel [60]. Two different solvents, n-hexane, and petroleum ether, were used. The moisture level of the peanuts used in the experiment was 6.68% d.b. The extraction process was carried out for 8 h at 100 °C with a solvent feeding rate of 4–5 drops per second. After the extraction, the peanut oil was distilled and held in an oven at 105 °C for 1 h. Although the obtained oil was not suitable for human consumption, impressive yields of 95% and 100% were obtained using n-hexane and petroleum ether, respectively [60]. This study presents an interesting avenue for the utilization of peanut oil as biofuel. It could, however, be complemented by highlighting the properties of the extracted oil and the potential environmental concerns before its large-scale application.

Ji et al. compared the oil extraction outcomes of red-skinned peanuts that were either untreated or deskinned using thermal cycles at 55 °C for 6 h [6]. An additional post-treatment was applied to the peanuts that retained their red skin in order to remove the solvent using a rotary vacuum evaporator, resulting in what was referred to as leached peanut oil. The study found that deskinned peanut kernels contained only 20–30% of the AF content of the original peanut kernel, indicating that AFs were primarily concentrated on the peanut seed coats. Removing the skin from the peanuts can reduce the risk of contamination from AF and phthalate esters in peanut oil, but it was observed that the amount of polycyclic aromatic hydrocarbons in the oil increased after deskinning [6]. While the study findings suggest the potential benefits of deskinning in reducing contamination risk, the observed increase in polycyclic aromatic hydrocarbon levels raises concerns. Future research should therefore focus on identifying ways to minimize polycyclic aromatic hydrocarbon contamination during deskinning processes while still maintaining the benefits of reducing AF and phthalate esters in peanut oil.

In the end, it is urgent to mention that if humans inhale large amounts of n-hexane, they may experience mildly damaging CNS effects [66]. This led to the US's classification of n-hexane as a hazardous volatile organic compound (VOC), and its release must therefore be carefully monitored and reported [30]. VOCs themselves are considered "greenhouse gases," some of which are toxic and have carcinogenic properties. Their production during the conventional process is alarming, as they can react with other pollutants in the atmosphere to form ozone and other photochemical oxidants that can be harmful to human health and crops [69]. As a result, scientists have shifted their focus toward alternative techniques that address these significant concerns.

3.2. Aqueous Extraction

Aqueous extraction processing (AEP) is a method that utilizes water as the solvent for oil extraction [66]. It was developed as a greener and healthier alternative to organic solvents for extracting oil from various sources. AEP has gained popularity due to growing concern for the environment. This method allows for the simultaneous recovery of high-quality oil and proteins from most oilseeds [69]. During AEP, the oil is extracted due to its inability to dissolve in water; it floats to the surface of the hot water. On the other hand, the proteins dissolve in water and can be recovered through acid precipitation or membrane separation processes. The same researchers explored the efficacy of utilizing a three-cylinder roll crusher to enhance oil and protein yields [66]. By crushing the peanuts into a paste, an optimal average particle size of 15.2 µm was determined, followed by roasting in an oven at 150 °C for 20 min to improve the oil extraction yield. However, it was observed that the protein yield showed a slight decline from 84.33% to 78% upon roasting, and this decline was further exacerbated as the roasting temperature increased. The study results also revealed that the highest free oil yield of 92.2% was achieved by roasting the peanuts at 150 °C for 20 min, using a solid-to-liquid ratio of 1:5 (twice ground peanut pastes/water), a pH of 9, a temperature of 60 °C for 2 h, followed by demulsification at pH 4.5, and incubation at 50 °C for 2 h [66]. This study presents a promising approach to optimizing the extraction process for higher oil yields. Further investigations may be necessary since a significant portion of the oil remained entrapped within the cream residue, precipitated, and was subsequently skimmed off.

The feasibility of the aqueous extraction of peanut oil instead of hexane was investigated [69]. To facilitate aqueous extraction, efficient dry grinding that breaks down the cellular structures containing oil is crucial. Smaller particles provoked the disintegration of the original structure and easier oil diffusion. Optimal conditions for extraction were achieved for a solid:water ratio of 1:5, at 60–65 °C and pH 4, resulting in oil and protein yields of 89% and 92%, respectively. Centrifugation was used for phase separation after demulsification, but an alkaline medium was necessary for the complete separation of oil from proteins. Therefore, when optimizing the process, consider not only the highest possible oil yield but also the ease of breaking the resultant emulsion [69]. While the study provides encouraging results for the utilization of aqueous extraction of peanut oil, complementary investigations could focus on suggesting comprehensive details about the process and its optimization to assess the feasibility of its implementation in large-scale production.

The aqueous process' main limitation resides in its low oil yield due to the oil getting clogged within the by-product, thus making it hard to implement industrially. For that reason, the utilization of enzymes to facilitate oil release and improve extraction yields in aqueous processes has garnered significant attention in recent years, as has the utilization of combined physical techniques that rely on microwave and ultrasonic treatments. Further on in this review, the efficacy of such enzymes and physical techniques for oil extraction from peanuts is debated.

3.3. Supercritical Fluid CO_2

In recent years, there has been a growing interest in SFE as an alternative to conventional solvent extraction in food processing. Food technologists have recognized the potential of SFE as a technique for differential extraction, leading to extensive investigation of its applications in this field [59]. Numerous researchers have employed SC-CO_2 extractions to efficiently extract bioactive compounds from plants [62]. It is a beneficial technique due to its ability to maintain high levels of solute purity and avoid the use of organic solvents [57]. By adjusting temperature and pressure, the solubility of SC-CO_2 can be manipulated to obtain the highest possible yield of a desired compound during extraction [63]. Knowing that SC-CO_2 is only able to extract nonpolar compounds, the method is sometimes enhanced by the use of ethanol to extract polar and nonpolar compounds from the solute [19,23,69].

A semi-continuous process was applied by Chiou et al. to extract oil from peanuts using SC-CO_2, with the aim of producing PDPM [59]. The peanuts were roasted at 160 °C for 35 min, cooled, and deskinned. The optimal conditions for the extraction process were found to be a pressure of 8000 psi and a temperature of 80 °C. Lower temperatures resulted in decreased extraction rates. Furthermore, a 3-min holding time was the most effective for dissolving peanut oil up to the saturation level in the SC-CO_2 fluid. The extraction medium was released under a constant pressure of 4 mL/min, and the process was repeated six times, yielding a 95% oil recovery [59]. While the findings of this study demonstrate the feasibility of extracting oil from peanuts using SC-CO_2, several limitations should be noted. Firstly, the use of a semi-continuous process may have introduced variability in the extraction process, potentially affecting the reproducibility of results. Furthermore, while the study achieved a high oil recovery rate, the feasibility and sustainability of the process must take into consideration the necessity for machines that are expressly engineered to withstand exceedingly high pressures (reaching as high as 800 bars [61]).

In 2018, Putra et al. explored the optimization of the operational conditions for SC-CO_2 extraction of peanut skin oil [62]. The authors sought to maximize the oil yield and diffusivity coefficient while preventing the degradation of bioactive compounds present in the extract. By applying optimal conditions, which included a pressure of 29.95 MPa, a temperature of 40 °C, 6.49% co-solvent ethanol ($V_{ethanol}/V_{CO2}$), and a CO_2 flow rate of 3 mL/min, a 3 h extraction process yielded a 14.95% oil extract from the total mass of the product and a diffusivity coefficient of 8.47×10^{-12} m^2/s. The authors noted that the optimized conditions effectively prevented the degradation of the extracted bioactive compounds, thereby highlighting the potential of this method for yielding high-quality peanut skin oil extracts [62]. In the same study, Putra et al. expanded their research to create a practical model to optimize the extraction of oil from peanut skin using SC-CO_2. By applying the optimal conditions of P = 279 bar, T = 70 °C, a 7.5% modifier rate, and a CO_2 mixture and modifier flow rate of 3 mL/min, they were able to achieve a maximum yield of 0.83 g of oil from a 5 g sample of peanut skin. The study found that increasing the pressure, temperature, and modifier rate led to a higher yield of peanut skin oil and a faster extraction rate during the modified SC-CO_2 extraction process [68]. The study did not include an investigation of the potential consequences of using higher pressures and temperatures on the quality of the extracted oil.

In the same year, Putra et al. performed a comparative study on the extraction of peanut skin using SC-CO_2 and Soxhlet [57]. The study aimed to evaluate and optimize the oil yield and catechin content of the extracted peanut skin. Regarding the Soxhlet extraction method, the optimal conditions involved using 100 mL of either denatured ethanol (95%) or distilled water as the solvent, a duration of 6 h at a boiling point temperature of 78 °C, and vacuum drying at 40 °C and 80 mbar. The results obtained under these conditions showed a maximum oil yield of 100% and a low catechin yield of 42.2473 μg/g sample. In contrast, the optimal conditions for the SC-CO_2 included a temperature of 70 °C for 180 min, a pressure of 30 MPa, ethanol as a co-solvent with a concentration of 5%, and a CO_2 flow rate of 3 mL/min. Under these conditions, a low oil yield of 42.63% was obtained, but the catechin yield was remarkably high at 208.73 μg/g sample. The study concluded that SC-CO_2 was preferable over the Soxhlet method due to its ability to extract higher amounts of catechin within a shorter time with lower solvent usage [57]. The authors did not investigate the maturity of the peanuts, which could have an impact on the quality of the extract from peanut skin. The same authors extended their previous study with the aim of investigating how particle size affects the oil yield and antioxidant activity in extracts from peanut skins, utilizing modified SC-CO_2 and the Soxhlet method [63]. It was identified that the maximum yield of peanut skin extract was obtained using a mean particle size of 425 μm when optimal conditions were applied, including a pressure of 30 MPa, a temperature of 70 °C, a flow rate of 3 mL/min of CO_2, and 5% ethanol as a co-solvent. Soxhlet extraction yielded a maximum extract percentage of 100%, much higher than modified SC-CO_2 extraction's 42.8% oil yield. However, the antioxidant activity in the extract was lower for Soxhlet extraction (62.11%) than for SC-CO_2 extraction (93.43%). Further research would help to fully understand the effects of co-solvents and other extraction parameters, such as the maturity of peanuts, on the composition and activity of the extracted compounds.

Additional correlated research aimed to investigate the possible conditions for a feasible SC-CO_2 extraction of oil from roasted peanuts [64]. After applying optimal conditions of P = 25–30 MPa, T = 40–60 °C, and a solvent flow rate of 15 kg/h, the researchers found that a stabilization time of 60 min was necessary before extraction. They concluded that increasing the solvent flow rate would be advisable to shorten the time taken to achieve maximum extraction yield. For a full experiment, three hours would be the ideal duration to obtain sufficient results [64]. In 2021, Putra et al. extended further research on the extraction of oil from peanut skins [70]. This study aimed to determine the mass transfer involved in the extraction process using SC-CO_2 -ethanol. The optimal extraction conditions were achieved when a pressure range of 10 MPa to 30 MPa and a temperature range of 40 °C to 70 °C were applied. Additionally, a modifier rate of 0.075 mL/min to 0.225 mL/min for 180 min and a flow rate of 3 mL/min for liquid CO_2 and ethanol were used, resulting in an oil recovery rate of 14–15%. The study provides valuable insights into the potential use of SC-CO_2-ethanol as an oil extraction method from peanut skins. A limitation has to be mentioned, though, which is the absence of a definitive optimum for pressure and temperature as well as a specific percentage of extracted oil [70].

In a review published on SFE [61], the authors highlighted the potential advantages of SFE as a technique for achieving reactions that are difficult or impossible to achieve using conventional solvents with a short processing time of 10 to 60 min. An important advantage of SFE is that the supercritical fluid can be easily separated from the analyte, leaving almost no trace of the solvent and yielding a pure residue. However, the review also emphasizes the need to carefully evaluate the experimental conditions to optimize the efficiency of SFE. Anand et al. found that the optimal temperature range for SFE was between 40 °C and 80 °C, with a critical pressure of 74 bar. Furthermore, the addition of a modifier or co-solvent to CO_2 can improve the efficiency of extraction by increasing the solubility of the solutes. Notably, the review suggests that increasing the temperature from 50 °C to 60 °C can lead to an increase in oil recovery of up to 12.2% [61]. SFE may, however, not be suitable for extracting certain types of compounds, and the cost of implementing this technique may be higher and still needs to be evaluated.

Last but not least, oil was extracted from peanuts using SC-CO_2 in order to be used as biofuel rather than edible oil [67]. The study evaluated the kinetic behavior of the extraction method and found that optimal conditions were achieved at a pressure range of 200 to 280 bar and a temperature range of 40 °C to 60 °C, with a flow rate of 2.0 mL/min over 80 min. After the experiments were completed, a yield of 30% was obtained using the supercritical method (80 min), while a yield of 26% was obtained using Soxhlet extraction with ethanol as a solvent for 480 min. The results suggest that SC-CO_2 is a more efficient method for extracting oil from peanuts than traditional Soxhlet extraction using ethanol as a solvent [67]. This study provides valuable insights into the potential of using SFE methods for oil extraction from peanuts. One questionable outcome could potentially be attributable to the utilization of ethanol instead of more efficient choices like hexane or petroleum ether. Additionally, the suitability of the extracted oil as a biofuel needs to be thoroughly evaluated before consideration.

4. Combined Methods of Oil Extraction from Peanuts

This section will elucidate the merits of supplementing traditional oil extraction methods with either a biological, chemical, or physical approach, to intensify the process and elevate its efficacy. Subsequently (Table 3), several innovative techniques are examined, detailing the nutritional value of the products, pre-treatments, post-treatments, experimental parameters, and outcomes, while also identifying areas of uncertainty that may warrant further improvement.

Table 3. Combined methods of oil extraction from peanuts.

Methods/Year/ Reference	Target Product(s)	Product(s) Description	Nutritional Value	Oil Recovery (%)	Pre-Treatment	Post-Treatment	Parameters
Aqueous and mechanical extraction (2020) [30]	Peanut oil and PDPM.	Formation of PDPM and clarified-free oils	High protein content and low residual oil in the PDPM	96.1 ± 0.2%	- Baking - Cooling - Peeling - Grinding. - Agitation: 64 °C.	- Centrifugation - Drying: 105 °C	Combined experimental conditions: - 1.5:10 liquid:peanut seed kernel slurry ratio with 1 g NaCl/100 g of slurry. - Cold and low-pressure pressing. - Centrifugation: 4000 r/min, 64 °C, 10 min.

Table 3. *Cont.*

Methods/Year/ Reference	Target Product(s)	Product(s) Description	Nutritional Value	Oil Recovery (%)	Pre-Treatment	Post-Treatment	Parameters
AEP combined with membrane separation (2020) [31]	Peanut oil, proteins, and insoluble fiber-rich solid residual fraction	The peanuts exhibit compromised integrity	N/A	AEP: 96.51 ± 1.14%. UF processing: 95.30 ± 0.78%	- Cracking. - pH adjustment of the slurry. - Incubation. - Stirring.	- Centrifugation - Freeze-drying of permeate of MF and UF	AEP experimental conditions: - pH(slurry) = 9. - Incubation: 60 °C. - Stirring: 100 rpm - 2 h extraction. - Centrifugation: 3000× *g*, 15 min. MF/UF experimental conditions: - Tangential flow filtration system area: 0.11 m^2. - Crossflow filtration system area: 0.4 m^2. - Concentration: V(permeate) > 4 V(aqueous phase) - MF permeation concentration to 10% of original volume by UF.

Table 3. *Cont.*

Methods/Year/Reference	Target Product(s)	Product(s) Description	Nutritional Value	Oil Recovery (%)	Pre-Treatment	Post-Treatment	Parameters
EAAE (2002) [27]	Peanut oil	The peanuts exhibit compromised integrity	Peanut seeds contain 27–29% protein and 40–50% oil	86–92%	- Water soaking: 2 h - Grinding. - Dispersing. - Stirring with a magnetic stirrer. - Adjusting of pH. - Incubation. - Centrifugation.	N/A	Extraction optimal conditions: - Enzyme concentration: 2.5% in 10 g of peanuts. - pH = 4.0. - T = 40 °C. - Incubation: 18 h, stirring at 80 rpm. - Centrifugation: 18,000× *g*, 20 min.
Diesel-based reverse-micellar microemulsion extraction (2010) [72]	Peanut oil/diesel blend (biodiesel fuel)	The peanuts exhibit compromised integrity	N/A	91.6 ± 2.5%	N/A	- Centrifugation. - Evaporation of hexane.	Extraction optimal conditions: - Room temperature. - Solid:solvent ratio 1:5 - Shaking speed: 200 rpm. - Centrifugation: 4000 rpm, 30 min - 10 min extraction.

Table 3. *Cont.*

Methods/Year/Reference	Target Product(s)	Product(s) Description	Nutritional Value	Oil Recovery (%)	Pre-Treatment	Post-Treatment	Parameters
Ultrasound-assisted Enzymatic Extraction (2018) [32]	Peanut oil and PDPM.	Formation of PDPM	Peanuts are a source of protein and oil. Peanut oil is rich in mono- and poly-unsaturated fatty acids.	An increase in oil yield by 30.61%, and 173.77% compared to n-hexane solvent extraction and AEP	- Airdrying → constant moisture content - Passing: 80mesh sieve. - Ultrasound pretreatment using n-hexane as solvent.	- Removal of hexane (rotary vacuum evaporator): 50 °C, 20 min. - Heating: 45–50 °C, 2 h. - Centrifugation: 13,000× g, 20 min.	Extraction optimal conditions: - 1:4 Peanut/Hexane ratio. - pH = 4.61. - Ultrasound frequency 250 Hz, 45 ± 5 °C, 33.23 min - Cellulase enzyme concentration: 1.47% - Incubation: 56 °C, shaking: 120 rpm, 120 min
EAAE (2011) [73]	Peanut oil and PDPM.	Formation of PDPM	Peanut seeds contain 25–29% protein and 40–50% oil	86–90%	- Roasting: 130, 160, 190, and 220 °C 20 min. - Cooling and milling. - Dispersion in distilled water. - pH = 9.5 adjustment. - Incubation: 55 °C, 1 h, shaking 120 rpm.	Demulsification: - Freezing the emulsion: −18 °C, 20 h. - Water bath: 35 °C, 2 h. - Centrifugation: 8694× g, 15 min.	Extraction optimal conditions: - Roasting: 190 °C, 20 min. - Solid:water ratio 1:5. - Alcalase 2.4 L enzyme concentration: 2%. - Incubation: 1 h, shaking: 80 rpm - Heating of suspension: 90 °C, 10 min - Centrifugation: 3000 rpm, 15 min

Table 3. *Cont.*

Methods/Year/ Reference	Target Product(s)	Product(s) Description	Nutritional Value	Oil Recovery (%)	Pre-Treatment	Post-Treatment	Parameters
EAAE (2010) [28]	Peanut oil and PDPM.	Formation of PDPM	-Peanuts: high-quality oil (45–55%) and protein (24–36%). -Peanut oil: glyceride mixture of about 80% unsaturated fatty acids and 20% saturated fatty acids.	91.98%	- Drymilled → uniform meal - Heating.	N/A	Extraction optimal conditions: - Hydrolysis temperature: 60 °C - pH = 9.5 - Ratio of material to water 1:5 - Alkaline extraction t = 90 min - Enzyme amount 1.5% and hydrolysis time 5 h.
Ultrasonic-assisted aqueous enzymatic extraction (2011) [33]	Peanut oil	Peanut Paste extracts: peanut oil, residual cream, and skim	Peanut oil mix: 40–50% oil and 27–29% protein, with high monounsaturated content.	88%	- Drying. - Peeling. - Grounding. - Adjusting pH and temperature. - Ultrasound pretreatment.	N/A	Extraction optimal conditions: - Enzyme amount 1.7% - Hydrolysis time 3.8 h - Hydrolysis temperature 56 °C - Materials to water rate 1:4 - pH = 9.3 - Ultrasonic time 20 min. - Ultrasonic temp 45 °C.

Table 3. *Cont.*

Methods/Year/Reference	Target Product(s)	Product(s) Description	Nutritional Value	Oil Recovery (%)	Pre-Treatment	Post-Treatment	Parameters
EAAE (2008) [29]	Peanut oil	Peanut Paste extracts: peanut oil, residual meal	Peanut seeds: 24–28% protein and 45–52% oil	91.7 ± 1.3%	- pH adjustment by adding 1 M NaOH - Incubation: 60 °C, 30 min - Stirring: 200 rpm	- Solid phases were dispersed water. - Incubation. - Centrifugation.	Extraction optimal conditions : - pH = 8.5. - T = 60 °C. - Alcalase 2.4 L enzyme level: 1.5%. - Incubation: 8 h, alcalase 2.4 L. - Centrifugation: 3000 rpm, 20 min.
Microwave-integrated Soxhlet (MIS) (2008) [74]	Peanut oil	The peanuts exhibit compromised integrity	The nine compounds: Palmitic (C16:0), palmitoleic (C16:1), margaroleic (C17:1), stearic (C18:0), oleic (C18:1), linoleic (C18:2), linolenic (C18:3), arachidic (C20:0), and gadoleic (C20:1) acids (98% of the total composition of identified fatty acids in the extracted oils).	46.1% in 32 min.	- Drying. - Grinding: t < 0.5 h - Heating: 80 °C. - Cooling.	N/A	MIS experimental conditions: - m = 30 g ± 10 mg. - Solvent: nhexane 300 mL. - Cooling: T = 25 °C. - W = 3.6% d.b.

Table 3. *Cont.*

Methods/Year/ Reference	Target Product(s)	Product(s) Description	Nutritional Value	Oil Recovery (%)	Pre-Treatment	Post-Treatment	Parameters
EAAE (2022) [75]	POB	Peanut Paste extracts: peanut oil, residual meal	Peanuts: rich in protein (24.16%) and oil (51.43%). Fatty acids in crude Oil bodies are oleic acid (40.70%) and linoleic acid (35.01%).	N/A	- Mixing with deionized water at a ratio of 1:4. - Grounding for 2 min.	N/A	Extraction experimental conditions: - Viscozyme® L (1.25%) - Enzymolysis: 2 h, 50 °C. - Water bath: 100 °C, 5 min. - Centrifugation: 5000× g, 20 min. - Incubation: 50 °C, 30 min.
Ultrasound-assisted Soxhlet extraction (2020) [76]	Peanut oil	The peanuts exhibit compromised integrity	Peanut oils: rich in protein, monounsaturated, and polyunsaturated fatty acids	51.50%, 10 min	N/A	N/A	Extraction experimental conditions: - Ultrasound frequency 35 kHz for 10, 20, and 30 min - Soxhlet for 5 h at 50 using petroleum benzine solvent.

Table 3. *Cont.*

Methods/Year/ Reference	Target Product(s)	Product(s) Description	Nutritional Value	Oil Recovery (%)	Pre-Treatment	Post-Treatment	Parameters
Short-wave IR radiation aqueous enzymatic extraction (2013) [34]	Peanut oil	The peanuts exhibit compromised integrity	Peanuts: 44–56% lipids, 22–30% protein, 16–25% carbohydrates, and a low percentage of minerals and vitamins. Oleic acid and linoleic acid: 80% of the total fatty acids in peanut oil.	83.75 ± 2.90%	- Heating: 70 °C, 20 min. - Thermal program: 40 °C → 80 °C, 1.0 °C/s, 80 °C → 250 °C, 2 °C/s.	N/A	Extraction experimental conditions: - Pastewater at a ratio: 1:5. - Alkali extraction: 60 °C, 10 min - pH = 8.5. - Alcalase 2.4 L enzyme concentration: 1.5% - Incubation: 60 °C, 3 h. - Reaction terminated by heating: 90 °C, 10 min - Centrifugation: 4500 rpm, 15 min.
EAAE (2020) [77]	Peanut oil	The peanuts exhibit compromised integrity	Peanuts lipid molecules integrate with the protein molecules and are surrounded by a cell wall containing cellulose, hemicelluloses, lignin, and pectin	91.98%	N/A	N/A	Extraction experimental conditions: - Enzyme: alcalase 2.4 L - T = 40–45 °C. - Incubation time: 9 h.

Table 3. *Cont.*

Methods/Year/ Reference	Target Product(s)	Product(s) Description	Nutritional Value	Oil Recovery (%)	Pre-Treatment	Post-Treatment	Parameters
EAAE (1996) [69]	Peanut oil	The peanuts exhibit compromised integrity	N/A	74–78%	Dry grinding.	N/A	Extraction experimental conditions: - pH = 4, 7, or 10 (Optimal: pH = 4). - T = 60–65 °C. - solid: water ratios recommendation range: 1:5 to 1:12.
Salt-Assisted ($CaCl_2$) Microwave Aqueous Enzymatic Extraction (2020) [35]	Peanut oil	Peanut Paste extracts: peanut oil, residual cream, and skim	N/A	92.3%, 2 min	Grinding to paste	Demulsification using microwave radiation or by freezing-thawing and heating treatment	Extraction optimal conditions: - pH = 9.5. - Alcalase 2.4 L enzyme concentration: 0.05%. - Incubation: 60 °C, magnetic stir: 300 rpm, 2 h - Centrifugation: 4000 rpm, 15 min Microwave demulsification optimal conditions: - $CaCl_2$ concentration: 10 mmol/L, - Microwave power: 390 W, 2 min - Centrifugation: 4000 rpm, 15 min

Table 3. *Cont.*

Methods/Year/ Reference	Target Product(s)	Product(s) Description	Nutritional Value	Oil Recovery (%)	Pre-Treatment	Post-Treatment	Parameters
EAAE (2021) [78]	POB	The peanuts exhibit compromised integrity	POBs are rich in essential amino acids, unsaturated fatty acids, vitamin E, and phytosterols. The oil bodies contained three inherent proteins (oleosin, caleosin, and steroleosin) along with two adsorbed foreign proteins (arachin and lipoxygenase).	90.7%	- Peeling. - Crushing. - Dispersion in distilled water.	N/A	Extraction optimal conditions: - cellulase and pectinase at a 1:1 ratio. - Incubation: 80 min. - Boiling: 5 min. - Cooling: room temperature. - Centrifugation: 5000× *g*, 20 min.
EAAE (2016) [71]	Peanut oil	The peanuts exhibit compromised integrity	N/A	1st case: 92.2% 2nd case: 79.32%	Grinding + Enzyme exposure (alcalase 2.4 L).	N/A	Extraction optimal conditions: - 1st case: Enzyme: alcalase 2.4 L, pH = 8.5, T = 60 °C, t = 8 h. - 2nd case: Enzyme: alcalase 2.4 L, T = 60 °C, pH = 9.5, the ratio of material to water 1:5, enzyme concentration 1.5%, hydrolysis time 5 h.

Table 3. *Cont.*

Methods/Year/ Reference	Target Product(s)	Product(s) Description	Nutritional Value	Oil Recovery (%)	Pre-Treatment	Post-Treatment	Parameters
EAAE (2020) [79]	POB	The peanuts exhibit compromised integrity	Peanuts: 46.84% oil, 24.44% protein, 4.65% crude fiber, 4.63% water, 2.35% ash	48.44%	- Grinding. - Stirring. - Enzyme exposure after the mechanical shock.	N/A	Extraction optimal conditions: - Enzyme: Viscozyme® L concentration: 1.35% - Hydrolysis: T = 52 °C, Solid:liquid ratio of 1:4, 90 min

4.1. Enzyme-Assisted Aqueous Extraction

The advent of novel methodologies has facilitated the improvement of traditional techniques, including the chemical-based "aqueous extraction" approach. These modern approaches incorporate the use of enzymatic agents to augment the efficiency of oil extraction [76] by dismantling the cell wall. This results in the disruption of its structural integrity, which in turn facilitates the transfer of intercellular contents, ultimately leading to a more effective oil recovery process [77].

An earlier study was intended to validate the efficacy of aqueous and enzyme-based processes for extracting oil from peanuts with low water content [69]. The objective was to address concerns related to these methods and their associated parameters. The researchers implemented optimal conditions, which included a pH of 4, a temperature range of 60–65 °C, and solid-to-water ratios ranging from 1:5 to 1:12. The addition of protease, cellulase, and a-1,4-galacturonide glycanohydrolase during the extraction process resulted in an oil yield ranging from 74% to 78% [69]. Another study was conducted by Sharma et al. to extract peanut oil using aqueous extraction with the assistance of an enzyme called Protizyme [27]. The process involved soaking the peanuts for 2 h, grinding them into a thick paste, and stirring. The optimal conditions for extraction included a 2.5% (w/w) concentration of enzyme in 10 g of peanuts, a pH of 4.0, a temperature of 40 °C, an 18 h incubation period with constant shaking at 80 rpm, and centrifugation at 18,000 × g for 20 min. This method resulted in an oil yield of 86–92% [27]. More extensive research would be helpful in comparing the yield achieved in the studies and the potential of this extraction approach, as well as in evaluating the nutritional and sensory characteristics of the extracted oil.

Edible peanut protein hydrolysates were produced upon oil extraction from peanuts using an aqueous extraction process assisted by the enzyme alcalase 2.4 L [29]. The study employed optimal conditions, including a pH of 8.5, a temperature of 60 °C, an enzyme content of 1.5%, and an 8 h incubation period, which resulted in an oil yield of 91.7 ± 1.3% and a protein yield of 82.5% [29]. Similarly, oil and protein hydrolysates were simultaneously extracted from peanuts using aqueous extraction assisted by alcalase 2.4 L. The peanuts were initially ground into a uniform meal using a grinder and then heated. The researchers applied optimal conditions, including a hydrolysis temperature of 60 °C, a pH of 9.5, a material-to-water ratio of 1:5, an alkaline extraction time of 90 min, an enzyme amount of 1.5%, and a hydrolysis time of 5 h. As a result, the oil yield increased significantly from 79.32% to 91.98%, and the protein yield increased from 71.38% to 88.21% [28]. These findings demonstrate the potential of utilizing alcalase 2.4 L for the simultaneous extraction of oil and edible proteins from peanuts, which has significant implications for the food industry. However, it is necessary to conduct further studies to evaluate the economic feasibility and scalability of this approach in large-scale production processes.

The effects of the roasting process on the extraction yield and oil quality of peanut seeds were investigated [73]. The researchers employed an aqueous extraction method assisted by alcalase 2.4 L following the roasting of peanut seeds at various temperatures for a duration of 20 min. Optimal conditions for the experiment were determined to include a roasting at 190 °C for 20 min seed-to-water ratio of 1:5, an enzyme concentration of 2%, and an incubation time of 3 h. Notably, the study found that roasting the seeds at 190 °C for 20 min resulted in a relatively high yield of 78.6% for free oil and 80.1% for protein hydrolysates [73]. Furthermore, the authors demulsified the residual emulsion using a freezing and thawing method, which significantly increased the total free oil yield to 86–90%. Future studies could explore alternative methods of demulsification and investigate the correlation between the effects of variations in roasting temperature and duration on oil yield and quality.

Various modern extraction methods, their impact on yield and quality, and their industrial applications were the subject of a study in 2020 [77]. One technique discussed was EAAE. In their experiment, the authors used alcalase 2.4 L an enzyme-to-substrate ratio of 1%, and an incubation time of 9 h at 45 °C. Using these conditions, an oil yield of 91.98% was attained [77]. Another study investigated the impact of various enzymes on the molecular weight distribution of peanut protein as well as the yield of peanut protein and oil bodies during an aqueous enzymatic extraction process [79]. Oil bodies, which are small spherical structures composed of neutral lipids, phospholipids, and proteins embedded in the phospholipid layer, are found in the cytoplasm of cells. The authors identified an optimal enzyme, Viscozyme® L, among the selected ones. The other conditions used were as follows: enzyme hydrolysis at 52 °C, a solid-liquid ratio of 1:4, an enzyme concentration of 1.35%, and an enzyme hydrolysis time of 90 min. These conditions resulted in a protein yield of 78.60% and an oil body yield of 48.44% [79]. However, it is important to note that the efficacy of EAAE can be influenced by various parameters such as enzyme type, hydrolysis time, temperature, solid-liquid ratio, and enzyme concentration. Hence, the conditions utilized in the study may not be applicable to all scenarios, as shown in the differences between the two cases above.

The enzymatic aqueous extraction, composition, and rheological properties of peanut oil bodies were assessed to provide a theoretical foundation for the large-scale utilization of peanut oil bodies in the food and cosmetic industries [78]. The study demonstrated that a combination of cellulase and pectinase at a 1:1 ratio produced the maximum oil body yield of 90.7%. An analysis of the oil body's microstructure revealed that triacylglycerols were enveloped in an interfacial membrane formed by proteins and phospholipids. The endogenous proteins of peanut oil bodies (POB) consisted mainly of oleosin, caleosin, and steroleosin, while two foreign proteins, arachin, and lipoxygenase, were adsorbed on the POB surface. The primary phospholipid in the POBs is combined with proteins, providing stabilization. The measured rheological properties demonstrated that the POBs represented a stable system governed by elasticity [78]. In a connected study, Liu et al. aimed at expanding our understanding of the composition and structure of POBs and their theoretical basis for demulsification [75]. The study involved the use of Viscozyme® L (1.25%) for enzymolysis, which was performed at 50 °C for 2 h, followed by centrifugation at 5000× g for 20 min and incubation at 50 °C for 30 min. The results revealed that the oil droplets had a spherical shape and were evenly dispersed in the aqueous phase, while proteins and phospholipids were uniformly distributed on the surface of the POBs. However, during the extraction process of the POBs, weak interactions such as electrostatic, hydrophobic, and hydrogen bonding caused several peanut proteins, including lipoxygenase, arachin, conarachin, allergen, and ferritin, to be adsorbed on the POBs surface, which led to some degree of instability in the POBs [75]. The findings of these two studies provide useful insights into the enzymatic aqueous extraction, composition, structure, and rheological properties of POBs. From this perspective, a wider range of enzymes and experimental conditions can be assessed. The sensory properties of the POBs can be tested for their potential use in specific food and cosmetic products.

4.2. The Applications of Microwave-, Infrared-, and Ultrasound-Assisted Oil Extraction

Ultrasonic-assisted extraction is an emerging approach involving the generation of complex mechanical effects such as cavitation bubbles [33], vibration, mixing, and pulverization. These effects collectively disrupt the cell wall, increase its permeability, and promote the rate of mass transfer [77]. As a pre-treatment method, ultrasonic-assisted extraction enables the attainment of high oil yields with lower solvent consumption and reduced processing time while preserving the quality of the extracted oil [76]. Furthermore, the use of organic solvents or enzymatic treatments is not necessary to achieve higher extraction yields [80]. The response surface analysis method was employed to determine the optimal conditions for oil and protein extraction based on the ultrasonic temperature and time [33]. The optimal conditions were identified as follows: enzyme amount at 1.7%, hydrolysis time at 3.8 h and 56 °C, materials to water rate at 1:4, pH at 9.3, ultrasonic time at 20 min, and a temperature of 45 °C. This allowed for an oil extraction rate of 88–92% and a protein extraction rate of 95.50 ± 0.44% [33]. The authors did not provide an explanation for why they used a single-factor experimental design. The feasibility of combining ultrasound pre-treatment with enzymatic treatment using cellulase enzyme to extract oil from peanuts in n-hexane solvent was scrutinized [32]. The peanuts were air-dried to a constant moisture content in the shade before processing. The optimal conditions for ultrasound-assisted enzymatic extraction were identified as a frequency of 250 Hz, a temperature of 45 ± 5 °C for 33.23 min of ultrasound pre-treatment, a cellulase concentration of 1.47%, and an adjustment to a pH of 4.61 before incubation at 56 °C for 120 min. Post-treatment involved removing n-hexane solvent from the extracted oil using a rotary vacuum evaporator at 50 °C for 20 min, followed by heating in an oven at 45–50 °C for 2 h. The residual oil was then centrifuged at 13,000× *g* for 20 min to separate free oils and wax. The oil yield increased by 30.61% and 173.77% in comparison with organic solvent extraction and AEP, which are considered more traditional techniques. These findings suggest that the combination of ultrasound and cellulase enzymatic extraction methods using n-hexane solvent could serve as a more efficient industrial alternative to conventional extraction methods for obtaining high-quality and healthy edible oil from peanuts [32]. In a review published in 2020, Mushtaq et al. evaluated the use of ultrasound technology in conjunction with Soxhlet extraction as a means of enhancing oil extraction yields [76]. The authors identified an optimal ultrasonic wave frequency of 35 kHz and duration of 10 min, combined with a 5 h Soxhlet extraction at 50 °C using petroleum benzine solvent, as the most effective conditions for achieving a significant increase in oil yield, which was measured at 51.5% [76]. Further investigation is necessary to assess the scalability and cost-effectiveness of these promising techniques for commercial applications.

Microwave technology is frequently employed in conjunction with other extraction methods to promote the transfer of mass and improve the recovery of components. Microwave-assisted enzymatic extraction (MAEE) represents a method that leverages the use of enzymes to elevate the efficacy of the extraction process. Conventional enzymatic reactions often exhibit sluggish kinetics, necessitating prolonged reaction times. A prevalent strategy to expedite these reactions involves the utilization of microwave energy, which imparts synergistic effects that stimulate the rate of enzymatic reactions. Furthermore, the radiation emitted by microwaves serves to delay the denaturation of enzymes, thereby conferring heightened stability and endurance to the enzymes [77]. However, a validation of this concept is essential, as the mechanism has not been described to ascertain all the speculative beneficial effects that advocate for the utilization of microwave heating over conventional heating methods. Additionally, it is not advisable to use microwave heating to roast peanuts, as it can lead to the formation of oxygenated compounds [81]. Compounds with negative health effects, such as 5-hydroxymethylfurfural, furan, and acrylamide, may also be formed [82]. A study evaluated the effectiveness of microwave integrated Soxhlet (MIS) as an alternative method for extracting oils and fats from peanuts [74]. The authors used a sample of peanuts weighing 30 g ± 10 mg that was subjected to a drying and grinding process before being heated in an oven at 80 °C and then cooled to reach a water content of 3.6% d.b. The MIS method involved using n-hexane as a solvent and performing Soxhlet extraction. The solvent was heated to a boiling point using a microwave and continuously stirred. The solvent vapors penetrated the sample, and the condensation took place on the condenser. The authors noted that repeated washing with a clean, warm solvent followed the extraction. After extraction, the solvent was lowered to concentrate the extracts. The authors found that this method yielded an impressive 46.1% of extracted oil in just 32 min, which is significantly shorter than traditional Soxhlet methods [74]. No comparison between the MIS and other modern extraction methods was realized. The efficacy of salt-assisted microwave radiation demulsification of an oil-rich emulsion prepared with EAAE from peanuts was assessed [35]. Alcalase 2.4 L enzyme was employed in the initial stages of the experiment, followed by incubation at 60 °C for 2 h and magnetic stirring at 300 rpm. The resulting suspension was then centrifuged at 4000 rpm for 15 min, and the free oil, cream, and skim fractions were separated. The researchers observed that under optimal conditions, which included a $CaCl_2$ concentration of 10 mmol/L and a microwave power of 390 W, a higher yield of free oil was extracted in just 2 min as compared to the conventional heating and freezing–thawing methods. The addition of salts resulted in a notable improvement in free oil yields, which reached 92.30% [35]. A comparative analysis of this technique in terms of efficiency, cost-effectiveness, and environmental impact would help increase its adoption in industries.

IR is a relatively novel energy source utilizing electromagnetic waves with a wavelength range of 0.78 to 1000 μm. It has been reported that IR-roasted peanuts demonstrate superior quality and increased oxidative stability compared to peanuts roasted using traditional methods [34]. The impact of short-wave IR on the EAAE of peanut oil was examined. The study assessed the yield and quality of the extracted peanut oil using the OSI as an indicator of lipid oxidation. The thermal program utilized started at 40 °C and increased to 80 °C at 1.0 °C/s, then went directly to 250 °C at 2.0 °C/s and held for 100 s. The experimental conditions included using alcalase 2.4 L enzyme and incubating the mixture at 60 °C for 3 h with continuous stirring. The reaction was stopped by holding the temperature at 90 °C for 10 min, and then the mixture was centrifuged at 4500 rpm for 15 min. The results showed that SIR significantly increased the oil yield by 8.74% to reach 83.75 ± 2.90% [34].

4.3. Other Combined Methods for Oil Extraction

The possibility of creating a biodiesel fuel (a blend of peanut oil and diesel) by extracting the oil using a diesel-based reverse-micellar microemulsion as a solvent was researched [72]. The extraction process consists of three stages: grinding the seeds, dispersing the solid/solvent mixture in a water-oil microemulsion, and separating the solid and liquid by centrifugation for 30 min at 4000 rpm. The resulting peanut oil/diesel blend is then examined. The remaining solid is extracted using 20 mL of hexane, and the hexane is evaporated to concentrate the remaining peanut oil. This process takes place at room temperature during a short extraction time of only 10 min and achieves an extraction efficiency of 91.6 ± 2.5% in a single step. A multistage extraction could yield an efficiency of almost 99%. The blend is tested for peanut oil fraction, viscosity, cloud point, and pour point and meets the requirements for use as a biodiesel fuel [72]. Additional information about the energy and resource inputs required to produce and dispose of the diesel-based microemulsion solvent would be beneficial. In 2020, Tu et al. looked into separating peanut oil using a combination of AEP and cold pressing [30]. The authors used a mixture of liquid-to-peanut seed kernel slurry in a ratio of 1.5:10, to which 1 g NaCl was added for every 100 g of slurry. The mixture was agitated until free oils and an aggregated particle were observed, and the free oils were recovered by cold and low-pressure pressing using a cold screw press. This process was repeated three times and followed by one round of centrifugation at 4000 r/min at 64 °C for 10 min. The PDPM from both the press and centrifugation was subsequently dried in an oven at 105 °C. An impressive oil yield of 96.1 ± 0.2% without any additional demulsification steps is reported [30]. In parallel, Liu et al. in 2020 utilized an AEP technique to extract oil from peanuts, coupled with a two-stage MF/UF process for peanut protein recovery and water recycling. The slurry was prepared by mixing peanuts with deionized water, and the pH was adjusted to 9.0, followed by incubation at 60 °C with constant stirring at 100 rpm. While the yield of oil declined slightly from 96.51 ± 1.14% to 95.30 ± 0.78%, the protein yield also decreased. Nevertheless, the use of the third recycling permeates obtained from the UF processing in AEP was deemed acceptable by the researchers as the losses of oil and protein were minimal. The researchers suggest that membrane processing in AEP provided a cost-effective means of recycling water that met the necessary quality standards. Additionally, it eliminated the requirement for alkali-acid isolation and desalinization processing, providing technological advantages for protein recovery at the industrial scale [31].

5. Advantages and Disadvantages of the Oil Extraction Methods from Peanuts

The defatting and oil extraction techniques employed in the processing of peanuts exhibit shared and distinct advantages and disadvantages. In the subsequent table (Table 4), clarification of these variations will be presented, and a critical analysis of each method will follow.

Table 4. Advantages and disadvantages of defatting peanuts and methods of oil extraction from peanuts.

Methods		Advantages	Disadvantages
Mechanical	Traditional Hydraulic Pressing	- No chemical agents (peanut cake residue remains healthy) [1] - Lower operating costs (compared to solvent extraction) [1] - Oil extraction efficiency (up to 70%) [2,24,82] - High-quality oil [27,32]	- The need for pre-treatments: Flaking, grinding, and heating [1] - Energy-consuming process [1] - Less efficient process [27,32] - Low oil recovery (40–60%) due to clogging [27,32] - Severe protein denaturation [15,29]
	MEPSI	- Prepare low-calorie peanuts [8] - Preserve the sensory properties of the finished roasted product [8] - Eco-friendly defatting process [22] - Low energy consumption [22] - No need for high pressures and long pressing durations [45] - Need for a specific separation material (avoid irreversible deformation and damage) [3] - High oil extraction yields (attained 70 to 80%) [3] - No conventional polluting agents such as chemicals [3] - Low cost due to relatively low applied pressure and pressing duration [2]	- High risk of lipid oxidation and flavor deterioration [22]
	Screw Pressing	- Remarkable stability and improved flavor [15] - Low energy consumption [15] - Superior quality of oil and meal [15] - Roasting improved oil yield [17] - Higher OSI [17] - Absence of solvents or chemicals [16] - No generation of waste streams [16] - Low residual moisture content (6%), which is desirable for storage [16] - Mechanically extracted oils had lower PV and higher [17]	- Loss of peanut structure [50,83]

Table 4. *Cont.*

Methods		Advantages	Disadvantages
Mechanical	Cold Pressing	- Superior preservation of proteins and bioactive ingredients [6] - Simple use [19] - Short duration of the process [19] - Low cost [19] - Byproduct protein, rich press cake [19] - High amounts of essential fatty acids and bioactive lipid components within the oil [21] - High-quality peanut oil *(clear appearance, higher linoleic acid content, lower low acid value, and PV)* [20] - Meal possesses higher nutritional value [20] - Better morphological, organoleptic, and rheological properties [4,8]	- Difficulty obtaining a consistent quality product [84] - Low productivity [19] - Low oil extraction yield [19] - Low oxidative stability [21] - High residual oil rate [20] - No selectivity in extracting the oil from peanuts [64] - Require another process step after fractionation called degumming [64] - Loss of peanut structure [53,62]
	MEPSI combined with IVDV as a Post-treatment	- Adequate texturing of the matrix by enabling a greater expansion [4] - preserving the peanuts' shape [4,8] - Higher efficiency, faster kinetics [4] - Lower costs, lower environmental impact [4] - Higher quality finished product [4]	
Chemical Chemical	AEP	- Water is a safe and healthy solvent [1] - Little impact on the environment [66] - Production of edible oil and protein isolate (without antinutritional factors) [69] - Improved process safety due to the lower risk of fire and explosion [69] - Costeffective [69]	- Low oil extraction yield [1] - Long processing durations [1] - Demulsification requirements to recover oil from emulsions [69] - Treatment of the resulting aqueous effluent [69]

Table 4. *Cont.*

Methods		Advantages	Disadvantages
Chemical Chemical	SC-CO_2 extraction	- Better oil quality (compared to solvent extraction) [1] - Lower protein denaturation [1] - Easy removal without contamination [2] - Environmentally and nutritionally nontoxic [2] - High oxidative stability and low protein denaturation [2] - Selective extraction to produce superior quality products [64] - CO_2 is inexpensive [59] - Easy separation of the extract allows for the recycling of the solvent [57] - High purity on solute content [62] - CO_2 is easily found [62] - No residual organic chemicals in the final product [64] - High selectivity for a particular compound in the solute [67] - Low consumption of solvents [68] - Ethanol as a modifier is safer in terms of toxicity compared with other solvents such as methanol and ethylene glycol [70] - Gentle treatment of heat-sensitive substances [77] - Enhanced transport properties due to the relatively high diffusivity and low viscosity of $SCCO_2$ offer selective extraction [77]	- High capital investment for an SCE extraction plant is much higher than that of a conventional plant [1] - Compression of solvent requires elaborate recycling measures to reduce energy costs [61] - Technical knowledge of supercritical fluid properties is required [61] - Lower extraction yield of nonpolar solutes [61] - Need cosolvent ethanol to maximize the extraction process [62] - Long extraction time (Three hours) [64] - Elevated pressure is required: 240 and 280 bar pressures [67] - $SCCO_2$ can only extract nonpolar bioactive compounds from plant and herb matrices [68] - The modification of $SCCO_2$ is needed to extract polar compounds with the addition of ethanol [70] - Phase equilibrium of the solvent/solute system is complex [77] - Highly polar substances are insoluble [77]
	Soxhlet Extraction	- High yield for peanut skin oil, up to 37% [61] - Ethanol and water as solvents [61] - When ethanol is used as a solvent toxicity is ruled out [63]	- Toxicity risks with nhexane as a solvent [61] - Low-quality extract [63] - High extraction temperature (risk of degradation) [63] - Cause damage to the environment [67] - Process that consumes a significant amount of energy [67] - Long operation time [74] - A large amount of solvent use, and the need for evaporation [74]

Table 4. *Cont.*

Methods		Advantages	Disadvantages
Chemical Chemical	Organic Solvent extraction	- High extraction yield (80–90%) [2] - Oil recovery is in the 90–98% [27,32] - Low costs [19] - Simple equipment use [19] - No need to filtrate the oil obtained [19] - High efficiency [19] - NHexane: high stability, low evaporation loss, low corrosion, low greasy residue, and better odor and flavor of products [26] - Trichloroethylene: nonflammable solvent [26]	- Hexane is the most used solvent [2] - Excessive damage to the environment [19] - Persistent solvent remaining in the product [64] - Acute inhalation exposure of humans to large amounts of hexane causes mild CNS effects, including dizziness, giddiness, slight nausea, and headache [15–17] - Hexane is highly flammable, and its explosive nature may jeopardize the safety of plants and humans [15–17] - Contribute to the industrial emissions of VOCs [69] - React in the atmosphere with other pollutants to produce ozone and other photochemical oxidants, which can be hazardous to human health and cause damage to crops [69] - +Trichloroethylene: [26] - High cost compared to hydrocarbon naphtha. - Less selective. - High investment and energy requirements [27,32] - Poor quality of protein in the residual meal [29]

Table 4. *Cont.*

Methods		Advantages	Disadvantages
Combined Combined	EAAE	- Lower rates of peroxides and phospholipids that were removed from the solid phase [60] - No need for a degumming process, which reduces the overall cost [60] - It is safer to utilize enzymes because, in solvents, it is more difficult to remove the residues after use [60] - High (in some cases, over 90%) extraction yield (vs. original aqueous process) [69] - Lower investment costs [69] - High-quality oil complying with Codex Alimentarius Commission specifications [69] - Possibility to avoid solvents [27] - High meal quality [32] - Beneficial to people's health [32] - Valuable extracted components can be preserved [32] - Water is used as the extraction solvent (no use of organic solvent) [75] - Low energy consumption [75] - Environmentally friendly process [75] - Lower protein damage and improved food safety [34] - Enzymes have high selectivity [77] - High specificity to boost extraction efficiency [77] - Mild reaction temperature [71] - Requires a low degree of refining and fewer antioxidant treatments [79] - Protein can be recycled at the same time [79]	- Enzymes require critical storage conditions and cause the degradation of grains [1,2] - Uses large quantities of water (liquid: solid ratio being >2:1) [30] - Low final yield of peanut oil recovered because of serious emulsion [30] - High cost of drying defatted meals and treating large quantities of wastewater produced [30] - Loss of valuable compounds with the wastewater [30] - High cost of the enzyme [27] - Long extraction time [32] - Demulsification requirement [32] - High greenhouse gas emissions, especially CO_2 emissions [32] - Acute toxicity of the NaOH used for pH adjustment [32] - High effluent generation [32] - Long incubation time if pretreatment is not applied [77] - The unavailability of the enzymes [77] - High disbursement for the drying process after the enzyme treatment [71] - The need for downstream steps such as centrifugation for separation, emulsification, and drying for proteins and residues [71]
	Infrared pre-treatment	- Solvent free [44] - Eco-friendly [44] - Inexpensive [44] - Energy-saving pretreatment that enhanced the recovery of oil [44] - Uniform heating [34] - Efficient heat transfer [34] - Reduced quality loss and substantial energy saving [34] - High oxidative stability of the oil [34]	

Table 4. *Cont.*

	Methods	Advantages	Disadvantages
Combined	Diesel-based micellar emulsions	- Reduced emulsion formation [72] - Fewer refining steps (vs edible oil extraction) [72] - 95% of extraction efficiency by a single extraction step [72]	- Not edible oil, but instead was a blend of vegetable oil and diesel that can be used as biodiesel fuel [72]
Combined	Ultrasound-assisted enzymatic extraction	- nhexane as a solvent instead of water: [32] - High oil yields. - High solvent recovery. - Low greenhouse gas emissions. - Ultrasonic benefits: - Preserving the bioactive compounds of the extracts. - Aqueous: [33] - Low operational temperatures. - Environmentally friendly. - Low treatment time by ultrasound (20 min). - High oil extraction yield [76] - High-quality oil [76] - Low required solvent amount [76] - Reduction of extraction time by five times, a solvent saving of 70%, and a lower temperature (50 vs. 68 °C). (compared to Soxhlet) [76] - Low thermal damage to the final product [77] - Greater solvent penetration [77]	- High power requirements [77]
	MIS	- Microwave energy: [74] - Enhanced thermal efficacy. - Selective heating. - Reduced equipment size. - Faster response to process heating control. - Increased production.	- Microwave energy can pose serious hazards in inexperienced hands [74] - A high level of safety and attention to detail when planning and performing experiments [74]
	MAEE	- Synergistic effects that decrease the extraction time [77] - Radiations delay the denaturation of the enzymes [77] - Boost the stability profile of enzymes over time [77]	- Care should be exercised as very high temperatures affect the nutritional and sensory characteristics of the final product [77]
	Rapid Salt-Assisted Microwave Demulsification	- High-quality oil (acid value, PV, phosphatide content, and oxidative stability) compared to conventionally heated demulsified peanut oil [35] - High oil extraction yield (up to 92.3%) [35]	-

5.1. Mechanical Methods

While traditional mechanical techniques may offer some advantages, they may not be the most efficient or desirable approach to adopt because of their limitations and challenges. This is why an innovation in hydraulic pressing was implemented, with the promising advantages of MEPSI (MEPPI) coupled with IVDV over traditional techniques. Complementary research may be recommended in order to establish the nutritional value and health benefits of the defatted peanuts produced using this method. Additionally, the specific separation material may require further enhancement to increase its absorption capacity. It is imperative to emphasize that, ultimately, this represents the only effective method capable of removing a significant quantity of oil from peanuts without completely altering the shape of the whole kernels.

5.2. Chemical Methods

The use of organic solvents for oil extraction has long been a conventional approach, despite its potential negative impacts on both human health and the environment. To ensure sustainability and safety, it is necessary to evaluate the organic solvents used and explore alternative ones that are more environmentally friendly. Although the AEP method, which utilizes water as a solvent, presents numerous advantages, the low oil yield is a major concern. Achieving a commercially viable oil yield is essential to ensuring profitability and cost-effectiveness. SFE, particularly using CO_2, has been proposed as an innovative approach for oil extraction that offers several advantages. However, it also requires a high level of capital investment and technical expertise, which may limit its practicality for certain applications.

5.3. Combined Methods

The methods previously discussed have been found to have specific limitations, prompting the exploration of alternative approaches aimed at enhancing the process and the overall characteristics of the extracted oil and the defatted by-product. One such approach is EAAE, which employs enzymes to enhance extraction efficiency. Although EAAE has several benefits over conventional AEP, it also exhibits notable drawbacks that can make it less attractive than other extraction methods. To address these limitations, researchers have endeavored to supplement the technique with various physicochemical approaches that employ diverse wave types, such as ultrasound, microwave, and IR. The application of ultrasound to enhance the efficiency of the extraction of bioactive compounds from natural sources has gained considerable attention among researchers, presenting a promising improvement to the conventional method of EAAE. However, while ultrasound-assisted EAAE may improve extraction efficiency, it may also result in changes to the chemical composition and functionality of the extracted compounds. The use of microwaves to facilitate the extraction process of enzymes for EAAE has also been discussed. Similarly, the utilization of IR as a pre-treatment strategy to enhance the efficacy of EAAE has been explored. The integration of microwaves with Soxhlet extraction has also been considered a potential technique for improving the efficiency of the extraction process. Additionally, the feasibility of integrating microwave-assisted rapid salt extraction into industrial-scale extraction processes must be carefully assessed, including the costs and technical challenges associated with scaling up this technique.

6. Other Technologies

The preceding sections have examined a selection of studies that summarize the achievements made over the past 45 years. However, it is important to note that these studies alone do not fully capture the entirety of the advancements and enhancements made towards the attainment of a superior product, notably partially defatted peanuts. Therefore, the following section will delve into the various patented treatment processes (Table 5), highlighting the target product, improvements, and innovations. Regrettably, the absence of comprehensive information about the parameters employed prevented their integration into the previous tables.

Table 5. Defatting and oil extraction methods from peanuts based on patents, treatment process, target products, and improvements/innovations introduced.

Title/Year/Reference	Treatment Process	Target Products	Improvements/Innovations
Partially defatted nut coating and reconstituting process (1968) [85]	- Hydraulic Pressing for oil extraction. - Aqueous reconstitution with a coating solution. - Drying and roasting (with or without oil).	Partially Defatted nuts	Reconstitution of the nuts to their original shape and even 25% greater than their original shape.
Process for treating partially defatted nuts (1977) [86]	Heating the nuts with an aqueous solution containing V > 2% glycerol, 2 min, T > 65.55 °C	Partially defatted nuts	- Reconstitution of the nuts to their original shape. - Improved flavor, texture, and storage stability
Low-Fat nuts with improved natural flavor (1982) [87]	- Roasting: 4 < W < 8% d.b. - Defatting: 20 → 55%. - Hydration → restore shape. - Final Roasting.	Partially defatted nuts	- Reconstitution of the nuts to their original shape. - Enhanced natural flavor, texture, and mouthfeel.
Method of producing flavor-infused partially defatted nuts and products (1989) [88]	- Defatting the nuts by mechanical pressing to 40 → 52%. - Hydration → restore shape. - Roasting: W < 3% d.b. - Infusion with edible oil containing a flavoring agent and a sweetener. - Coating with a powder flavoring agent.	Partially defatted nuts	- Reconstitution of the nuts to their original shape. - Improved flavor. - Low caloric content.
Process for preparing low-calorie nuts (1990) [89]	- Pretreatment by ionizing microwave radiation. - Humidification: 8 < W < 11% d.b. at 50 °C < T < 70 °C. - Remicrowaving.	Partially defatted peanuts	- Virtually unbroken peanut kernels. - Optimization of conditions and parameters to allow extraction by $SCCO_2$.
Product and process of making low-calorie nuts (1992) [90]	- Partial defatting and roasting. - Combination with a low-calorie edible triglyceride material that is "nondigestible".	Partially defatted nuts	- Improved flavor and crunchiness.
Process of making low-fat nuts (1992) [91]	- Mixing with peanut oil slurry of salt. - Defatting: up to 80% by hydraulic press at ~359 bar for 10 min. - Hydration and roasting.	Partially defatted nuts	- Preparation of low-fat nuts.

Table 5. *Cont.*

Title/Year/Reference	Treatment Process	Target Products	Improvements/Innovations
Method of producing a reduced-fat peanut butter without non-peanut supplements (1997) [92]	- Defatting to 80% by screw process to make peanut flour. - Mixing with peanut oil to produce peanut paste. - Add sweeteners, flavoring agents, and/or fiber, and blend the paste. - Milling the peanut product.	Low-fat peanut Butter	- 30% fat reduction compared to conventional peanut butter. - Nutritionally equivalent to its standard counterpart without the addition of supplements. - Peanut butter is shelf stable.
Method for treating various products and installations (1998) [93]	- Heating in the treatment chamber - Cooling by depressurization towards a vacuum tank.	Various products	- Reconstitution of the peanuts to their original shape. - Improved quality of the finished products. - Reducing energy consumption and rejects.
Production of soy sauce using defatted peanuts (2000) [94]	- Defatting peanuts. - Steaming with mold without the introduction of microorganisms within the product.	Soy Sauce	- Producing soy sauce from defatted peanuts. - Avoiding the integration of microorganisms within the soy sauce.
Low-fat nut spread composition with high protein and fiber (2004) [95]	- Preparing a protein-containing oil suspension. - Preparing a sugar-containing oil suspension. - Combining the two suspensions to form the nut spread.	Low-fat nut spread	- Spread has a protein-to-fat ratio of greater than about 0.68:1. - Spread has a fiber-to-fat ratio of greater than about 0.18:1. - Minimises nut spread flavor loss.
The treatment process for biological products MEPSI aims at modifying their lipid content and their texture. Settings and methods for the implementation of such a process (2014) [55]	N/A	Partially defatted food products	- Reconstitution of the products to their original shape. - Low-calorie products
Seeds and nuts are defatted by pressing and reconstituted by methods preserving their appearance and organoleptic properties (2014) [56]	- Defatting by mechanical pressing. - Reconstitution.	Partially defatted nuts	- Reconstitution of the products to their original shape. - Preserve the organoleptic characteristics of the products. - Low-calorie products

Table 5. *Cont.*

Title/Year/Reference	Treatment Process	Target Products	Improvements/Innovations
Low-calories, low-fat snack nuts (2014) [96]	- Defatting by mechanical pressing. - Reconstitution of shape using water. - Annealing using cold water to harden the nuts. - Drying and Roasting.	Partially defatted peanuts	- Uncoated peanuts have a hardness, texture, taste, aroma, and physical appearance close to natural peanuts. - Improved shelf life.
Chewing-resistant semi-defatted leisure peanut and preparation method (2021) [97]	- Preparation of semi-defatted peanuts. - Precooking. - Drying: 8 < W < 13% d.b.	Partially defatted leisure peanuts	- Leisure peanuts are flexible in taste, palatable in elasticity, and chewy.
Semi-defatted crispy peanuts with a high whole grain rate and preparation method (2022) [98]	- Squeezing - Defatting under the protection of protective material. - Reshaping	Partially defatted crispy peanut	- Reconstitution of the nuts to their original shape. - Good hardness and brittleness, and are crisp in taste - Semi-defatted peanut leisure food with high protein and reduced calories.

Reconstitution of the nuts to their original shape and even 25% greater than their original shape.

The patents highlighted in Table 5 present a range of inventions and methods related to the processing and modification of nuts. However, several observations can be made regarding the information provided. Firstly, the lack of specific details and scientific principles supporting the methods described makes it difficult to assess their efficacy and reliability. Moreover, the absence of experimental data and comparative analysis with traditional methods for the dated patents limits the evaluation of the inventions' effectiveness in retaining nutritional value and sensory properties. The optimal characteristics to produce any of the peanut products described above, such as flavor, texture, and nutritional value, can vary depending on the method of preparation, thus requiring careful evaluation. Additionally, the preparation of semi-defatted peanut kernels with high whole grain content is a complex process that may have an impact on the nutritional composition of the final product. Overall, further research and validation are necessary to fully assess the effectiveness, feasibility, and potential impact of these inventions in the field of nut processing and modification, especially in the partially defatted peanut industry.

7. Peanut Proteins Valorization

The forthcoming table (Table 6) offers a concise examination of the protein-rich by-products resulting from peanut oil extraction. Emphasizing key aspects such as nutritional value and experimental parameters, the table elucidates the diverse protein constituents found in these residues. The table is followed by a critique that has the purpose of providing valuable insights into the potential applications and significance of these protein-rich materials in various industries.

Table 6. Valorization of peanut proteins.

Target Product(s)	Nutritional Value	Parameters	Reference
1-4 PPI and PDPM	- 30–50% protein in oilseed substrates. - Increase of protein yield by 10.6% at pH = 6.8	- Ultrasound configuration: 20 KHz. - Power density: 30 W/g, 15 min. - Solvent: Water and Alkali: pH = 8.5. - Highest solubility: pH = 9 during isolate preparation.	[80]
1-4 PPC	- PPC: 85% protein vs. - PDPF: 50% protein	- Minimum solubility: pH 3.5–4.5. - Maximum solubility: pH > 10. - Sharp increase of viscosity: 90 °C, 30 min - PPC source of protein fortification for a variety of food products.	[51]
1-4 PPC	PPC has more than 70 g protein/100 g product	- Solubility, foaming capacity, and stability of protein prepared by alkali solution and isoelectric precipitation were the best. - Water holding/oil binding capacity was best when prepared by alcohol precipitation.	[99]

Table 6. *Cont.*

Target Product(s)	Nutritional Value	Parameters	Reference
1-4 PPI and PPC	- Protein isolates: 90%. - Protein concentrates 70%.	- Atmospheric cold plasma treatment led to improving the water solubility, emulsion stability, and water-holding capacity. - Best emulsifying ability was obtained after 3 freeze–thaw cycles. - At a pH of 10, water holding capacity was improved. - At a pH of 12 gel ability was lost. - Partial hydrolysis of protein combined with extrusion pretreatment, improved peanut functional properties.	[100]
1-4 Peanut, peanut oil, peanut butter, peanut flour	Peanuts: ≈50% fat and 45% carbohydrate and protein. Protein (% of total energy): - Peanut: 14.6 ± 0.1 - Peanut oil: 12.7 ± 0.3 - Peanut butter: 14.6 ± 0.1 - Peanut flour: 16.6 ± 0.1	- Energy analyses by bomb calorimetry. - Fat content was determined by a modified method of Folch extraction. - Centrifugation: 2000 rpm	[101]
1-4 PDPM	Fish diets: - isonitrogenous: crude protein 36% - isoenergetic: 20 kJ/kg	- PDPM: - Protein content: 36.6 ± 0.1% - Oil content: 8.8 ± 0.8%. - Optimal quantity incorporated: DPNM10%	[102]
1-4 PPI and PPC	- Heat-processed peanut isolates: 84.20% protein - PPIs High water absorption capacity (135%). - PPC: Low foam capacity (32.6%). - Highest digestibility score of 94%.	- Good emulsifying activity and stability. - Good foaming capacity. - Excellent water retention. - High solubility. - The Protein Digestibility Corrected Amino Acid Score: Method of evaluating protein quality and its digestibility.	[103]
1-4 PDPM	- Protein content in the defatted meal: 50% - Peanuts contain all 20 amino acids. - The biggest source of Arginine.	- Good emulsifying activity and stability. - Good foaming capacity. - Excellent water retention. - High solubility.	[104]

The growing global interest in plant-based protein highlights the need to make the most of existing corresponding sources. Oilseed substrates have protein-rich components that generally makeup 30–50% of their mass [80]. The health risks associated with excessive meat consumption are worrying some health-conscious individuals who are opting to either reduce their meat intake (known as flexitarians) or eliminate it from their diets by becoming vegans or vegetarians [100]. Plant-based proteins are not only nutritious storage proteins, but they also contain bioactive proteins such as trypsin inhibitors and Kunitz and Bowman–Birk inhibitors [80]. Peanut proteins are a valuable nutritional source owing to their elevated levels of essential amino acids [105]. They are also known to be devoid of cholesterol, thus rendering PPIs [105] and PPCs [106] more versatile for incorporation into a broader array of food products. Some of the functional properties of peanut proteins are water/oil binding, emulsification [107], foam formation [108], viscosity, and gelation [52,98]. These properties can be constrained by their inherent globular structure and the conditions during extraction, resulting in underutilization. Consequently, it becomes imperative to investigate methods aimed at enhancing both their functional properties and nutritional value [100].

The feasibility of creating a PPC using PDPF was assessed [51]. The functional properties of PPC were further investigated [99]. Various techniques were employed to isolate the concentrates from PDPF. The PPCs that were produced using alkali solution and isoelectric precipitation demonstrated superior solubility, foaming capacity, and stability, which make them ideal for food applications requiring foamings, such as ice cream and cake. Furthermore, the protein obtained through alcohol precipitation had a greater capacity for binding water and oil, making it suitable for use in food formulations like weaning foods, dry mixes, baked goods, whipped toppings, and salad dressings [99]. Ultimately, PDPF can be considered a suitable raw material for creating PPC. When used to make protein-rich foods, PPCs exhibit excellent solubility under alkaline conditions, high viscosity when briefly heated, and a strong ability to bind water and oil when subjected to alcohol-based chemical treatments.

The effects of regular consumption of portions of various peanut products, including oil, flour, butter, and whole peanuts, as part of a balanced, non-vegetarian diet on human subjects were examined [101]. The findings indicated that the consumption of whole peanuts led to a significantly greater loss of fecal fat and energy when compared to peanut butter, oil, or flour. Additionally, it was observed that proteins present in the peanut products contributed to a certain percentage of the overall energy content [101]. The results of the study could potentially inform dietary recommendations for individuals seeking to manage their weight or reduce their risk of developing obesity-related health conditions. Another subsequent study aimed to evaluate the protein content and properties of nuts, with a particular focus on defatted PPC and PPI [104]. The results revealed that heat-processed peanut isolate might be a suitable ingredient for aqueous food formulations, particularly those involving dough handling. However, the study indicated that peanut proteins may not be ideal whipping agents in food formulations [104]. While the findings of the two studies are promising, further research is necessary to fully understand the effects of regular peanut consumption on human health and the risk of developing an allergic reaction in susceptible individuals [109].

The potential of partially including PDPM in the diets of certain species of fish was analyzed [102]. The study indicated that peanut meal can be used as a partial replacement for fish meal in tilapia diets at rates up to 10% without significantly affecting the fatty acid composition of the fish fillet. This substitution could potentially reduce feed costs in the aquaculture industry [102]. While peanuts exhibit comparable true protein digestibility to animal protein, the presence of anti-nutritional factors can impair protein digestion and absorption [103]. It can be argued that although peanuts offer promising attributes as a protein source, further research is needed to optimize their utilization in food products, and the presence of anti-nutritional factors in peanuts warrants careful consideration when incorporating them into the diet. Moreover, their extraction using high temperatures may negatively impact their structure and functions [80].

The impact of various techniques and parameters on the quality of protein isolate and protein concentrate was evaluated in a review recently published [100]. It can be argued that extraction often causes damage to the protein, thereby defeating the purpose of the extraction process. It may be more beneficial to keep the protein in its original matrix and focus instead on optimizing the physical and functional characteristics of the by-product to fully utilize its nutritional value for human consumption.

8. Conclusions

Conventional oil extraction methods present significant challenges in terms of health, environmental impact, cost, and oil quality. In response, novel extraction methods have been proposed, but few have been adopted on an industrial scale, largely due to low specificity, high manufacturing costs, potential toxicity, low oil and by-product quality, and negative environmental and economic impacts. While some methods, such as organic solvent extraction, Soxhlet extraction, aqueous extraction, mechanical cold pressing, and supercritical fluid extraction using CO_2, have shown promise, environmental and economic considerations have hindered their widespread use. Newer methods, including MEPSI, enzyme-assisted aqueous extraction, microwave and infrared radiation-assisted extraction, and ultrasonic-assisted extraction, have demonstrated higher oil yields and improved quality, but still require further research to validate their effectiveness and practicality for large-scale production operations. Extraction methods have also been used to produce nonedible oils for biofuels and by-products such as peanut butter, partially defatted peanut flour, partially defatted peanut meal, and peanut protein concentrate and isolate that can be used in food formulations. Despite progress, no single method has emerged as the best overall solution, and ongoing research is needed to evaluate oil quality, profitability, environmental factors, and oil yield under multiple conditions for a variety of techniques. This review provides a comprehensive reference for peanut oil extraction and the valorization of protein-rich by-products and will aid in future method exploration and development.

Funding: This research received no external funding.

Data Availability Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

Abbreviations

AF	AFLATOXIN
AEP	Aqueous Extraction Processing
CNS	Central Nervous System
D.B.	Dry Basis
PDPM	Partially Defatted Peanut Meal
EAAE	Enzyme-Assisted Aqueous Extraction
IR	Infrared Radiation
IVDV	Intensification of Vaporization by Decompression to the Vacuum
MAEE	Microwave-Assisted Enzymatic Extraction
MEPSI	Mechanical Expression Preserving Shape Integrity
MF	Microfiltration
MIS	Microwave Integrated Soxhlet
POB	Peanut Oil Body
OSI	Oxidative Stability Index
P	Pressure
PDPF	Partially Defatted Peanut Flour
PPI	Peanut Protein Isolate
PPC	Peanut Protein Concentrate
PV	Peroxide Value
RPM	Round Per Minute
RSA	Radical Scavenging Activity
RSM	Response surface methodology
SC-CO^2	Supercritical CO_2
SCP	Semi-Continuous Process
SFE	Supercritical Fluid Extraction
T	Temperature
UF	Ultrafiltration
VOC	Volatile Organic Compound
W	Water Content
W.B.	Water Basis

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