SUPERCRITICAL FLUID EXTRACTION OF OILS FROM DIFFERENT BIOLOGICAL MATERIALS

Abstract

Supercritical fluid extraction plays a vital role across various industries, and its significance is particularly noteworthy in the food industry. This technique represents an innovative extraction method that not only increases yield but also reduces extraction time, ensuring higher quality and precise extraction of beneficial compounds from oils. Critical factors for successful SFE encompass temperature, pressure, the use of co-solvents, particle size, and moisture content. These factors allow for the selective extraction of desired components from seed oils and essential oils, ensuring top-notch quality. This approach is not only widely accepted but also aligns with environmentally sustainable practices, offering promising solutions to the challenges faced by industries seeking efficient and eco-friendly methods for extracting valuable compounds from seeds and other raw materials.

Keywords: Supercritical fluid extraction, seed oils, essential oils, spices, oil seeds

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I. INTRODUCTION

Seed oils, also known as vegetable oils or plant oils, are oils extracted from the seeds of various plants. These oils find widespread utility in cooking, industry, cosmetics, and medicine. Seed oils constitute a crucial dietary fat source, exhibiting variations in taste, nutritional makeup, and application depending on the specific plant source of extraction. Oil extraction from seeds is a crucial process with significant importance in various industries and for several reasons. Lately the researchers have been focusing on different extraction techniques of bioactive compounds of essential and seed oils and utilization of these extracted compounds from different seeds and spices to form a functional foods.

The simplest and most widely used technique for extraction of oil is solvent extraction using the petroleum based solvents like hexane, toluene, dichloromethane, chloroform etc. The cold pressing and expeller pressing is the mechanical methods for pressing the seeds or cakes to extract the oil. Problem in these methods are lower yields, energy intensive, time consuming, leaves chemical residues in extracted oil and inability of doing selective extraction of certain health promoting compounds in oils. Newly developed techniques i.e. enzyme assisted extraction, microwave assisted extraction and ultrasound assisted extraction and super critical fluid extraction solves the problems caused by traditional techniques. Among these techniques, Supercritical fluid extraction is gaining popularity as a solvent in the extraction of seed oils. In SFE, CO2 is pressurized above its critical point, allowing it to act as both a gas and a liquid. It is a cleaner and more selective method, often used for high-value oils and in industries where solvent residue is a concern.

The present chapter focuses on the supercritical fluid extraction of oils from seeds and essentials oils from spices, different parameters affecting the supercritical fluid extraction and application in SFE in food industry.

II. SUPERCRITICAL FLUID EXTRACTION (SFE)

Supercritical Fluid Extraction (SFE) is a separation technique employed across diverse sectors, including food, pharmaceuticals, and environmental science, to extract valuable substances from solid or liquid substances. This process hinges on utilizing a supercritical fluid, usually carbon dioxide (CO_2), thanks to its mild critical point conditions, as the extraction medium.

In 1978, the initial commercial application of supercritical fluid extraction in food was carried out in Germany by Hag A.G for the purpose of decaffeinating green coffee beans. Subsequently, two years later, Carlton and United Breweries in Australia introduced a technique that utilized liquid carbon dioxide for the extraction of hop flavours. Both of these applications proved to be commercially viable and have since served as the basis for the development of various adaptations and enhancements, many of which have been implemented at an industrial level (Kazlas *et al.*, 1994). Since then SFE technique have been used in different food products.

Supercritical fluid extraction offers several advantages in terms of mild critical control point conditions i.e. low critical temperature and pressure range, use of non-toxic and non-flammable and environmentally friendly solvent, selective extractability, residue free extraction and compatibility with sensitive compound. The most commonly used in solvent in this technique is carbon dioxide (critical conditions = 30.9 ◦C and 73.8 bar). Other supercritical fluid like ethane, propane and water are also used for specific applications depending on their properties and the desired extraction results.

III. BASIC PRINCIPLES OF SUPERCRITICAL FLUID EXTRACTION

A supercritical fluid is a matter that exists at conditions of temperature and pressure beyond its critical point, exhibiting characteristics of both a gas and a liquid simultaneously. In the context of SFE, CO_2 is frequently preferred due to its adaptability in transitioning to a supercritical state by manipulating pressure and temperature. In this supercritical state, CO_2 possesses a density and solvating capacity akin to that of a liquid, yet it permeates solids like a gas, rendering it an exceptional solvent for extracting a wide array of substances.

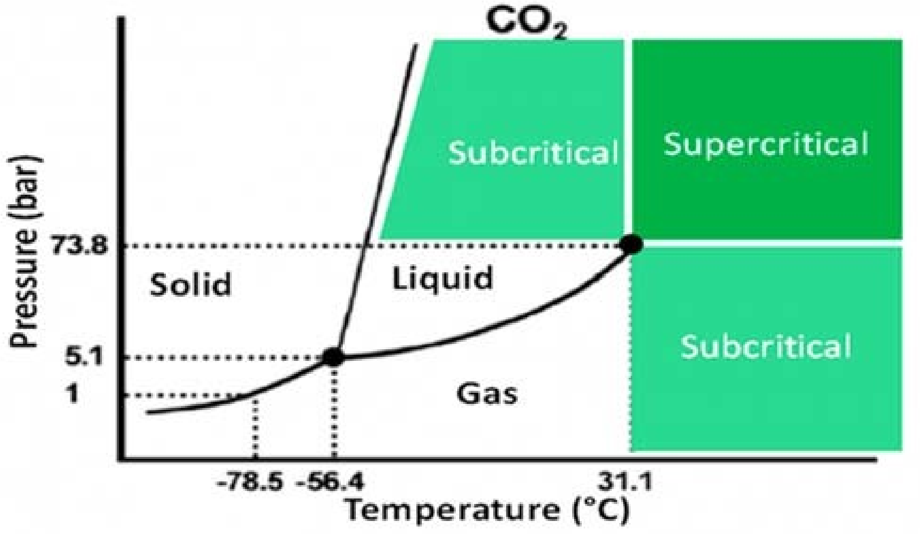

Figure 1: Diagram of Pressure-Temperature Phase of CO_2 (Gandhi *et al.*, 2017)

Supercritical Fluid Extraction (SFE) is a method that employs a fluid phase with properties that lie between those of a gas and a liquid. At the critical point on the pressure-temperature phase diagram, the gas's liquid state becomes permanently fixed regardless of the applied pressure (as shown in Figure 1). At this juncture, the substance exhibits characteristics of both a liquid and a gas. The densities of gases surpass their critical limits as pressure increases, leading to a desirable enhancement in the solvent capabilities of liquids. This heightened solvating ability of CO_2, for example, encourages solutes to dissolve within the supercritical solvent medium. As the fluid's density shifts, so does diffusivity, promoting more efficient mass transfer between the solute and the solvent. In contrast, the viscosity values of supercritical fluids remain consistent with those of normal gases and liquids. Supercritical fluids possess an augmented solvent capacity akin to that of a liquid while also mimicking gases in their absence of surface tension.

Substances that surpass their critical temperature and pressure become pure supercritical fluids. Beyond the critical temperature, they do not undergo condensation to form a liquid but exist as a fluid (a dense gas), with their properties continuously transitioning from gas-like to liquid-like as pressure rises at a fixed temperature (Kiran *et al*., 2009). The selectivity of extraction can be somewhat controlled since the solvating power (influenced by density) of SCFs can be adjusted significantly by modifying pressure, temperature, or both.

Supercritical CO_2 exhibits a tendency to preferentially interact with substances that have lower molecular weights (less than 250) or possess relatively weak polar characteristics (Ravantos *et al*., 2002). These substances include lipids, cholesterol, aldehydes, ethers, esters, and ketones. Conversely, high molecular weight compounds (greater than 400) or those with strong polar features, such as hydroxyl, carboxyl, and various sugars, polysaccharides, amino acids, proteins, phosphatides, glycosides, as well as inorganic salts, tend to have limited solubility in dense carbon dioxide. The solubility of different compounds in supercritical phase of carbon dioxide is categorized (Table 1).

Table 1: Solubility of Different Compounds in Supercritical CO_2 (Ravantos *et al*., 2002)

Highly Soluble	Moderately Soluble	Almost Insoluble
Organic compounds of low polarity and low molecular weight (< 250	Polar organic compounds of molecular weight lower than 400	Highly polar organic compounds of molecular weight above 400
Highly volatile substances, used for aromas and flavouring in foods	Substances with low volatility	Non-volatile substances
Thiols, pyrazines, thiazoles, acetic acid, benzaldehyde, hexanol, glycerol and acetates	Water, terpenes, oleic acid, glycerol and saturated lipids with chains of up to 12 carbons	Proteins, sugars, olysaccharides, amino acids, inorganic salts, nitrates, waxes

IV. EQUIPMENT USED IN SUPERCRITICAL FLUID EXTRACTION AND ITS COMPONENTS

A standard setup for Supercritical Fluid Extraction (SFE) comprises various essential elements, safety measures, and recent advancements in equipment. The extraction vessel or high-pressure container serves as the receptacle for the supercritical fluid and the sample material (e.g., plant matter, biomass, or other substances). It is specifically engineered to endure high pressures and temperatures. The function of this pump is to compress and circulate the supercritical fluid, usually carbon dioxide, into the extraction vessel. It maintains the required pressure and temperature conditions crucial for supercritical extraction.

Pressure control system comprises pressure transducers and control valves that work together to sustain the desired pressure within the extraction vessel. Precise pressure control is imperative for achieving consistent and reproducible outcomes. A temperature control unit is responsible for regulating the temperature inside the extraction vessel. Its purpose is to ensure that the supercritical fluid remains in its supercritical state throughout the extraction process. In specific situations, a co-solvent like ethanol or methanol may be introduced into the supercritical fluid to enhance the extraction of particular compounds. This co-solvent is typically delivered via a separate system.

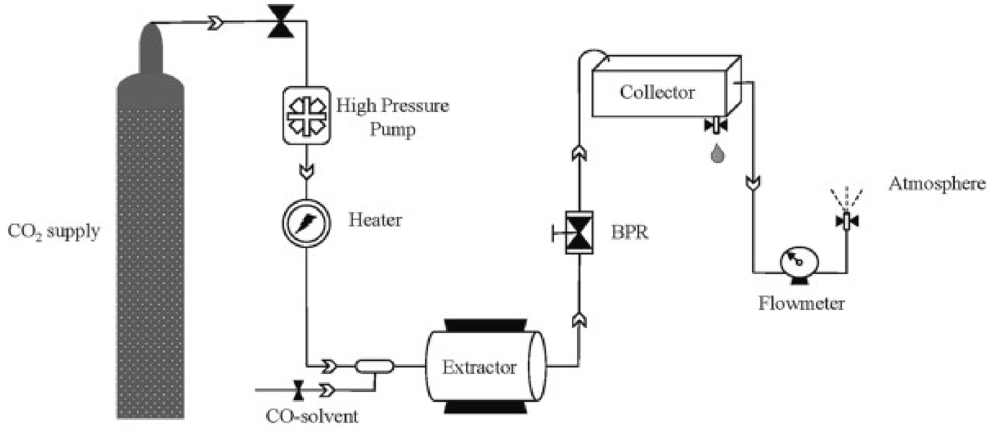

Figure 2: Flow Diagram of Supercritical Fluid Extraction System (Ahangari *et al.,* 2021)

Following the extraction process, the extracted compounds are separated from the supercritical fluid. This collection system usually incorporates a separator or fraction collector. SFE systems are equipped with safety mechanisms, including pressure relief valves, rupture discs, and pressure interlocks, designed to prevent overpressure occurrences and ensure the safety of operators. Depending on the application, analytical instruments such as gas chromatographs (GC) or mass spectrometers (MS) can be linked to the SFE setup for the real-time analysis of the extracted compounds.

V. FACTORS AFFECTING SUPERCRITICAL FLUID EXTRACTION

The crucial factors governing the Supercritical Fluid Extraction (SFE) of seed oils include temperature, pressure, the rate of CO_2 flow, seed particle size, the potential addition of co-solvents, and the duration of the extraction process.

Temperature regulation in supercritical fluid extraction (SFE) is achieved through a thermostatic bath or chamber, and in larger-scale operations, by employing concentric fluid heat exchange tubing. Maintaining precise temperature control is critical during the extraction of seed oils due to their sensitivity to temperature fluctuations. Temperature variations can impact both the solubility of seed oils and the prevention of oxidative reactions caused by elevated temperatures. Typical temperature ranges commonly applied for the extraction of various seed oils typically span from 40°C to 80°C (Ahmaad *et al*., 2019). The solubility of many seed oil components in CO_2 also increases as temperature increases. Increasing the temperature decreases the CO_2 density, resulting in the decrease of the solubility of oil in SC-CO_2 up to the cross-over point of the seed oil yield versus extraction pressure as various isotherms, due to raise of the vapor pressure of the oil (Montanes *et al.,* 2018).

The pressure of the supercritical fluid also affects the efficiency of the extraction process. Higher pressures can increase the solubility of the oil in the supercritical fluid, but too high of pressure can cause the oil to degrade or change its chemical properties. General pressure in SFE ranges from 100-400 bar (Fornanri *et al*., 2012).

Products parameters such as particle size and moisture content also play critical role in extraction. The size of the particles in the oil being extracted can affect the extraction efficiency. Smaller particles have a larger surface area and are more easily extracted using supercritical fluids. The moisture content of the oil can also affect the efficiency of the extraction process. Oils with high moisture content may require additional processing steps to remove the water before extraction.

Other than these parameters, the flow rate of the supercritical fluid can impact the extraction efficiency. High flow rates may result in lower extraction efficiency due to limited contact time between the fluid and the oil. Co-solvents, such as ethanol or methanol, can be added to the supercritical fluid to improve the solubility of the oil. The type and amount of co-solvent used can affect the extraction efficiency and the quality of the extracted oil. The duration of the extraction process can impact the extraction efficiency. Longer extraction times may result in higher extraction yields but can also result in the extraction of unwanted compounds, such as chlorophyll.

VI. APPLICATIONS OF SUPERCRITICAL FLUID EXTRACTION

Supercritical fluid extraction finds vast application in different industries i.e food industry, pharmaceutical industry, healthcare and nutraceutical industry, cosmetics and isolation and analytical systems and environmental analysis (Ahmad *et al.*, 2019). Supercritical Fluid Extraction (SFE) is a versatile method widely used in the food industry. It serves to extract natural flavours and fragrances from a variety of sources, including spices, herbs, and botanicals. SFE stands out as the preferred technique for decaffeinating coffee and tea, utilizing supercritical carbon dioxide to selectively remove caffeine from coffee beans or tea leaves while preserving other flavour components (Gandhi *et al.*, 2018). SFE holds significant value in the extraction of oils from seeds, nuts, and seafood, yielding top-quality edible oils like olive oil without resorting to chemical solvents. SFE is employed to extract bioactive compounds, encompassing antioxidants and polyphenols, from fruits, vegetables, and plant materials. These extracted compounds serve as functional ingredients in food products and dietary supplements.

The extraction of different seed oils by supercritical fluid extraction is shown in Table 2. To ensure the safety and quality of food items, SFE is utilized for the elimination of contaminants like pesticides, mycotoxins, and unwanted flavours. Additionally, SFE is employed to derive essential oils from aromatic plants, enhancing the flavour and aroma of food products. This method is also applied to extract lipids from food sources like fish oils and lipid-rich microorganisms, finding use in dietary supplements and fortifying food items. Furthermore, SFE is employed to extract nutraceutical components such as vitamins, phytosterols, and fatty acids from food sources, facilitating their incorporation into functional foods and dietary supplements.

VII. CONCLUSION

Supercritical fluid extraction offers many roles in different industries. Particularly for food industry, the techniques serve as a novel extractive technique which enhances yield with shorter extraction time and greater quality with control extraction of desired health benefitting compounds from extracted oils. The critical factors in SFE includes temperature, pressure use of co solvent and particle size and moisture content through which we can selectively extract the desired quality of extracted seed oils and essential oils. It can also be coupled with other techniques like microwave, ultrasound and enzyme assisted extraction to enhance product quality. It is also widely accepted and environmentally sustainable method which offers promising solutions to the challenges faced by industries seeking efficient and sustainable methods for extracting valuable compounds from seeds and other raw materials.

Table 2: Review of Different Oils extracted through Supercritical Fluid Extraction

Sr. No.	**Product**	**Material Condition**	**Process conditions**				**Maximum yield (%w/w) in SFE at Optimized Condition**	**Other Methods**	**Reference**
			Flow Rate	**Temperature**	**Pressure**	**Co-solvent**			
1.	Almond (*Amygdalus scoparia*)	0.25-0.3 mm	0.6 g/min	40-80°C	20-40 MPa	Ethanol (5% and 10%)	42.35% (10% EtOH, for 40°C, 40 MPa Pressure and 0.6 g/min)	55.26% (PLE)	Balvardi *et al.* (2015)
	Almond	-	10-30 kg/h	35-50°C	350-550 bar	-	54.5% (powder), 29.8% (milled), 15.1% (broken), 5.5% (whole)	-	Leo *et al.* (2005)
	Peach almond (*Prunus persica*)	35% w/w 882 and 3360 µm	3.3 and 10 g/min	40°C	150 and 250 bar	-	19.08% (250 bar pressure, 880 µm particle size, 10 g/min flow rate after 420 min ET)	-	Mezzomo *et al.* (2009)
	Peach almond (*Prunus persica*)	26.1% d.b. 985 µm	8.3 g/min	30-50°C	100-300 bar	Ethanol (2% and 5%)	24% (50 °C and 300 bar,5% EtOH)	24% (Maceration) 21% (Soxhlet)	Mezzomo *et al.* (2010)
	Chanar almond (*Geoffroea decorticans*)	0.82 mm	3.62 g/min	40 and 60°C	20-40 MPa	-	40% (60°C and 40 MPa)	49.6% (Soxhlet)	Salinas *et al.* (2020)
	Baru almond (*Dipteryx alata*)	<0.85 mm	3 ml/min	50-70°C	10-30 MPa	Water (0.3-10%) Ethanol (0.3-	31.06% (50°C, 30 MPa and 0.3% Ethanol)	4.61% (Cold Press)	Peixoto *et al.* (2022)

						10%) Water+Ethanol (5%)			
2.	Beech (*Pongamia pinnata* L.)	0.5-1.00 mm	5-15 g/min	60-100°C	200-300 bar	Ethanol (5% and 10%)	36% (60 °C, 333 bar, 1.0 mm, 7 g/min and 9 % Ethanol in 250 min)	-	Suryavanshi and Mohanty (2018)
3.	Canola (*Brassica campestris*)	12.7-42.5%	2.5 g/min	35-75°C	20.7-62 MPa	-	7.1% (30%, 75°C and 62 MPa)	-	Dunford and Temelli (1997)
	Canola	1.64% 473.9 µm	70 g/min	40-60°C	300-500 bar	Ethanol (2.3% and 10%)	10.3% (40°C, 300 bar and 10% Ethanol in 240 min)	21.06% (Soxhlet)	Li *et al.* (2010)
	Canola	250 µm	70 g/min	50°C	400 bar	Ethanol (4.7%)	33.61%	45.78% (Soxhlet)	Khattab *et al.* (2009)
4.	Carrot	0.25-0.5 mm	0.5-2 L/min	40-70°C	27.6-55.1 MPa	Canola oil (2.5% and 5%)	2.69% (70°C, 55.1 MPa, 2 L/min and 5% Canola oil)	2.46% (Soxhlet)	Sun and Temelli (2006)
5.	Celery	210-490 µm	1.1- 3 kg/h	45-55°C	100-200 bar	-	21.9% (210 µm, 1.1 kg/h, 45°C and 150 bar)	-	Papamichail *et al.* (2000)
6.	Chia	800 µm	8 mL/min	70°C	28 MPa	Acetone (2,6 and 10%)	33.90% (8 ml/min, 70°C, 28 MPa and 10% Acetone after 5 hr)	33.90% (Soxhlet)	Dabrowski *et al.* (2018)

	Chia (*Salvia hispanica* L.)	5.3% d.b.	4 mL/min	40-80°C	220-340 bar	-	30.7% (45°C, 335 bar and 100-400 µm using 24 s grinding time)	35.5% (Soxhlet)	Ishak *et al.* (2021)
	Chia	0.54 mm	1.8 g/min	40-80°C	136-408 bar	-	7.18% (80°C and 408 bar	-	Uribe *et al.* (2011)
7.	Coconut	-	10 g/min	30-60°C	200-300 bar	-	28.84% (60°C, 300 Bar, 1 h)	20.75% (Cold Press) 30.23% (Soxhlet)	Aytac (2021)
8.	Coffee	4.0% d.b. 0.273 µm	1.5-2.2 g/min	40-60°C	20-50 MPa	Ethanol (5-10%) isopropanol(5-10%) Ethyl lactate (5-10%)	10.4% (40°C, 50 MPa and 10% Ethanol)	12% (Soxhlet)	Coelho *et al.* (2020)
9.	Cottonseed	0.25-0.6 mm	0.2 L/min	60-80°C	350-550 MPa	-	43.16% (80°C, 550 MPa	40% (Soxhlet)	Bhattacharjee *et al.* (2007)
	Cottonseed	9.5% 0.25 mm		80°C	48.3 MPa	Ethanol (5%) isopropanol (5%)	33% (80°C, 48.3 MPa and 5% Ethanol)	-	Kuk and Hron (1994)
10.	Eucalyptus	12.3% 400 µm	2 L/min	40-80°C	10-50 MPa	-	4.78% (70°C, 40 MPa and 120 min)	3.8% (HD) 36.3% (Soxhlet)	Zhao *et al.* (2014)
11.	Fennel	18-100 mesh	0.033-0.43 g/s	30-57°C	100-300 bar	-	4.2% (35°C, 80 MPa and	-	Hatami *et al.* (2018)
12.	Flaxseed	6.2% 0.25-1 mm	1-3 L/min	50-70°C	35-55 MPa	-	28.1% (70°C, 55 MPa and 180 min)	38% (Soxhlet)	Bozan and Temelli (2002)

	Flaxseed (*Linum usitatissium* L.)	40 mesh	20 g/min	50°C	350 bar		32.16%	36.26% (Soxhlet) 35.73% (Solvent)	Chauhan *et al*. (2015)
	Flaxseed	3.4% <0.85 mm	2-4 g/min	50-70°C	30-50 MPa	-	26.7% (70°C, 50 MPa, 4 g/min and 22 min)	32% (Soxhlet)	Ozkal (2009)
13.	Gourd seed	0.36 mm	-	25-35°C	18-20 MPa	-	40% (40°C, 19 MPa and 130 min)	43.5% (Solvent)	Bernardo-Gil *et al*. (2009)
14.	Grapeseed	10-60 mesh	0.4 mL/min	35-40°C	30-40 MPa	Ethanol (10%)	6.2% (20-40 mesh, 40°C, 40 MPa and w/o 10% Ethanol)	10.6% (Solvent)	Cao and Ito (2003)
	Grapeseed	0.5 mm	6 g/min	50°C	50 MPa	-	13.9% (50°C, 50 MPa and 1.5 h)	16.1% (Soxhlet)	De Sauza *et al*. (2020)
	Grapeseed	0.75 mm	0.17 g/s	40°C	160-200 bar	-	16.5% (40°C and 180 bar)	-	Passos *et al*. (2009)
15.	Jojoba	2.1% 0.21-2.36 mm	0.5-2 mL/min	70-90°C	200-600 bar	Hexane (0-10%)	52.2% (70°, 300 bar and 5% Hexane)	51.8% (Soxhlet)	Salgin *et al*. (2004)
16.	Linseed	1-4 mm	2 L/min	25°C	41.37-57.85 MPa	Ethanol (0-1 mL)	40.95% (57.85 MPa, 54 extraction time and 0.8 mL Ethanol)	41.28% (Soxhlet)	Ivanov *et al*. (2012)
17.	Mango	0.28 mm	6.7 g/min	40-60°C	25-35 MPa	Ethanol (5-15%)	6.25% (60°C,30 MPa and 15% Ethanol)	-	Sanchez-camargo *et al*. (2019)

18.	Proso Millet bran (*Panicum miliaceum* L.)	7-8% 290-1200 µm	2-10 ml/ml/h	40-60°C	300-500 bar	-	7% (60°C and 400 bar)	-	Devittori *et al*. (2000)
19.	Moringa	3.5-4.6%	2.2-2.8 mL/min	40-70°C	40-80 MPa	Ethanol (1 mL)	39.6% (57°C and 80 MPa)	-	Belo *et al*. (2019)
	Moringa	15.2% 250 µm	2 L/min	40-80°C	30-50 MPa	-	6.34% (60°C,50 MPa and 120 min dynamic time)	9.27% (Soxhlet)	Zhao and Zhang (2013)
20.	Nutmeg	< 1 mm	1 mL/min	40-50°C	20.7-41.4 MPa	-	33.7% (40°C, 41.4 MPa and < 1 mm sample size)	-	Al-Rawi *et al*. (2011)
	Nutmeg	0.556-2.117 mm	2.78×10^{-5} m^3/s - 13.9 $\times10^{-5}$ m^3/s	40-50°C	10-20 MPa	-	5% (50°C, 15 MPa, 8.33×10^{-5} m^3/s and 0.556 mm)	-	Machmudah *et al*. (2006)
21.	Oat bran	75-750 µm (<250 µm and >250 µm)	-	35-80°C	14-55 MPa	-	4% (35°C, 55 MPa, 5 min static time, 5 min dynamic time and <250 µm)	7.4% (Soxhlet)	Fernández-Acosta *et al*. (2019)
22.	Okra	0.519 mm	6 kg/h	40-60°C	150-450 bar	-	15.9% (50°C and 450 bar)	16.3% (Solvent)	Andras *et al*. (2005)
23.	Olive	28%	50 g/min	40-60°C	200-300 bar	-	29.01% (40°C, 250 bar and 180 min ET)	33% (Soxhlet)	Belbaki *et al*. (2017)
24.	Palm	1-2 mm	-	51°C	19.8 MPa	Ethanol (0-100 mL)	3.67 % (51°C, 19.8 MPa and 100 ml Ethanol)	-	Krishnaih *et al*. (2012)

25.	Peach	250-350 µm	0.69-2.37 g/min	40-51°C	15-19.8 MPa	Ethanol (2.5-5%)	32% (51°C, 19.8 MPa and 5 % Ethanol)	-	Sanchez-Vicente *et al*. (2009)
26.	Peanut	425 µm	3 mL/min	40-70°C	10-30 MPa	Ethanol (5%)	15.47% (70°C, 30 MPa and 5% Ethanol)	36.28%	Putra *et al*. (2018)
27.	Pennyroyal	9% d.b. 0.3-0.7 mm	1.6 kg/h	40-50°C	90-100 bar	-	2.43% (50°C, 100 bar and 0.3 mm)		Reis-Vasco *et al*. (1999)
28.	Pepper	60 mesh	0.14-0.77 g/min	30-50°C	150-300 bar	-	2.05% (50°C, 300 bar and 0.77 g/min)		Ferreira *et al*. (1999)
	Pepper	175 µm	1.1-3.0 kg/h	40°C	90-150 bar	-	13% (40°C, 100 bar and 3 kg/h)		Perakis *et al*. (2005)
29.	Pomegranate	0.3-0.9 mm	6.6-23.4 L/h	33.2-66.8°C	13.2-46.8 MPa	-	14.02% (60°C, 40 MPa and 20 L/h)		Liu *et al*. (2009)
	Pomegranate	40 mesh	-	40-60°C	200-350 MPa	Water, Hexane and Ethanol (9-18 mL/100g)	3.39% (40°C, 275 atm and 18 Ethanol mL/100g)		Abbasi *et al*. (2008)
30.	Quinoa	1.0-1.4 mm	10.5-27 L/h	30-130°C	12.5-28.5 MPa	-	45.63% (75°C, 28.5 MPa and 55 min ET)		Przygoda and Wejnerowska (2015)
	Quinoa	0.05-0.80 mm	10.5-27 L/h	40-80°C	18-30 MPa	Methanol and Ethanol (1.3-20%)	6.3% (40°C, 25 MPa, 80 min and 20% Ethanol: Methanol 1:1 w/w)		Wejnerowska and Ciaciuch (2018)

31.	Raspberry	3.25-5.13% 200-400 µm	0.2-0.4 kg/h	40-60°C	250-350 bar	-	18.29% (50°C, 350 bar, 0.4 kg/h and Willamette var.)		Maric *et al.* (2020)
32.	Rice bran	0.5% 202 µm	10 g/min	30-50°C	10-30 MPa	-	39% (30°C and 30 MPa)		Jesus *et al.* (2010)
33.	Rosehip	0.556-2.112 mm	2-4 mL/min	40-80°C	150-450 bar	-	15.76% (80°C, 300 bar and 3 mL/min)		Machmudah *et al.* (2007)
34.	Sage	0.3-0.8 mm	0.72-1.32 kg/h	40-50°C	90-100 bar	-	1.87% (40°C, 90 bar, 0.8 mm and 1.32 kg/h)		Langa *et al.* (2009)
35.	Sesame	2.1% 0.72 mm	3 cm^3/min	40-60°C	19-25 MPa	-	35% (40°C, 25 MPa and 510 min ET)		Corso *et al.* (2010)
36.	Soybean	-	0.8-1.8 L/min	40-60°C	200-300 bar	-	19.5% (40°C and 300 bar		Dobarganes *et al.* (2002)
37.	Sunflower	0.23-2.18 mm	1-6 cm^3/min	40-80°C	20-60 MPa	-	88.8% (0.23 mm, 40°C, 40 MPa and 4 cm^3/min)		Salgin *et al.* (2006)
38.	Tea seed	7%	1 mL/min	60-80°C	300-400 bar	Ethanol (7.5-15%)	31.6% (60°C, 350 bar and 15% Ethanol)		Rajaei *et al.* (2005)
39.	Thyme	0.84-6.00 mm	2 mL/min	40-60°C	80-120 bar	-	0.70% (40°C,100 bar and 90 min)	1.47% (SD)	Sonsuzer *et al.* (2004)
40.	Turmeric	6.93% 0.2-0.73 mm	5-15 g/min	40-60°C	20-40 MPa	Ethanol (0-15%)	5.5% (53.72°C, 25.54 MPa, 13.6 g/min, 0.54 mm and 14.67% Ethanol)	5.96% (Soxhlet)	Priyanka and Khanam (2018)

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