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Oil Presses

Anna Leticia M. Turtelli Pighinelli and Rossano Gambetta
Embrapa Agroenergy,
Brazil

1. Introduction

For human nutrition, vegetable oils and animal fats play an important role, acting as an energy source and supplying the human body with more than twice the calories per unit weight than those provided by proteins and carbohydrates. Other benefits of fats are that they are suppliers of essential fatty acids, which are not synthesized by the human body, but are of great importance for our organism. Vegetable oils act as carriers of group of vitamins (A, B, E and K), help the body to absorb other vital elements from food and are also used to give more flavors to food (Bachmann, 2004).

Regarding oilseed materials, they can be divided into those for the production of edible vegetable oils and protein such as soy, sunflower, canola, palm and olive; those where the oil is a byproduct of fiber production, i.e. cottons; crops for food purposes which also produce oil, like corn, coconut, peanuts and nuts; crops which produce non-edible oils such as castor and Jatropha and finally, sources as microbial products, like algae, that can produce oil (Walkelyn & Wan, 2006).

Although the main use of vegetable oils and animal fats is for human consumption, recently there has been an increased interest in vegetable oils due to its use as feedstock to produce biodiesel, a renewable and less polluting fuel when compared to diesel of fossil origin. Other applications comprise its use as animal feed due to their high protein meal, in medicinal purposes, as lubricant, fuel for lamps and wood preservatives (World Bank Group, 1998).

According to Gunstone (2005), the main components of crude vegetable oils are triacylglycerols, corresponding to approximately 95% of its composition along with some free acids, monoacylglycerols, and diacylglycerols. They also contain variable amounts of other components such as phospholipids, free and esterified sterols, triterpene alcohols, tocopherols and tocotrienols, carotenes, chlorophylls and other coloring matters, and hydrocarbons as well as traces of metals, oxidation products, undesirable flavors, and so on. An important classification of vegetable oils is related to its fatty acid composition. Table 1 shows some vegetable oils with their fatty acid composition. Depending on the concentration of fatty acids present in vegetable oils, they can be classified as follows: lauric oils, palmitic oils, oleic/linoleic oils, high oleic oils, linolenic oils and erucic oils.

An interesting article reviews several important catalytic functionalisations, i.e. heterogeneous and homogeneous catalysis, like additions, reductions, oxidations and metathesis reactions of fatty compounds and glycerol resulting in new attractive products,

Oil source	C16:0 (Palmitic)	C18:0 (Stearic)	C18:1 (Oleic)	C18:2 (Linoleic)	C18:3 (Linolenic)
Cocoa butter	26	34	35	-	-
Corn	13	3	31	52	1
Cottonseed	27	2	18	51	Tr
Groundnut	13	3	38	41	Tr
Linseed	6	3	17	14	60
Olive	10	2	78	7	1
Palm	44	4	39	11	Tr
Canola	4	2	56	26	10
Rice bran oil	20	2	42	32	-
Safflower	7	3	14	75	-
Safflower (high oleic)	6	2	74	16	-
Sesame	9	6	41	43	-
Soybean	11	4	22	53	8
Sunflower	6	5	20	60	Tr
Sunflower (high oleic)	4	5	81	8	Tr

Table 1. Fatty acid composition (Gunstone, 2005)

besides biodiesel. Those products have emerging properties, so they could find a rapid introduction into the chemical market. The fatty acid (methyl or ethyl esters) and glycerol can be directly used after separation units as raw materials. Furthermore, they can build a new basis for new, valuable and sustainable bulk and fine chemicals (Figure 1) (Behr & Gomes, 2010).

In the book "Oilseed crops", Weiss (1983) notes that the history of the processes and methods of extracting oil from oilseeds is fascinating. The earliest record of the oilseed processing is attributed to the Assyrians in 2000 BC, who listed the components of a press to extract oil from sesame seeds. Another interesting historical fact is related to oil milling invention that is attributed to the Apollo´s sons, according to Pliny, who describes in detail the methods employed by his Roman contemporaries to obtain olive oil.

There are two main types of processes for obtaining oil: physical and chemical. The physical process, or expression, involves the use of mechanical power to remove oil from the seed, such as batch hydraulic pressing and continuous mechanical pressing (screw presses). Chemical processes, or extraction, are based in solvent extraction. These processes can be combined in commercial operation, i.e. continuous mechanical pressing (expelling) with continuous solvent extraction, and batch hydraulic pressing followed by solvent extraction (Walkelyn & Wan, 2005; Weiss, 1983). New technologies are emerging, related to the production of vegetable oils, such as supercritical-fluid extraction (Pradhan et al., 2010). "Expression" means the process of mechanically pressing liquid out of liquid-containing solids and "extraction" is the process where a liquid is separated from a liquid-solid system with the use of a solvent (Khan & Hanna, 1983).

The main idea of this chapter is to focus on the processing of oil by continuous mechanical pressing (screw presses), which is a technology widely used today by small oil producers. Though fats can be derived from both vegetable oils and animal fats, in this chapter only

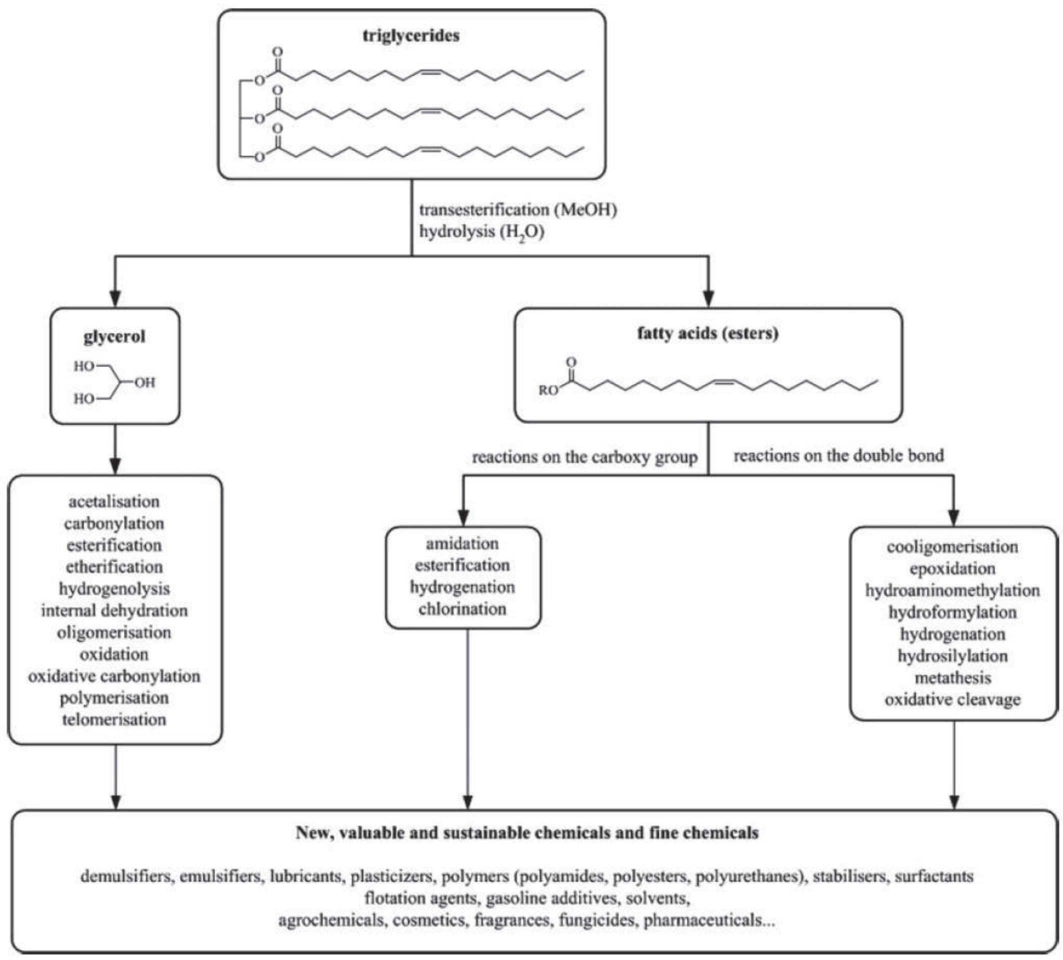

Fig. 1. Overview of possible reactions in oleochemistry (Behr & Gomes, 2010).

vegetable oil will be discussed, due to its healthier aspects when compared to animal fats, leading to an increase in consumption of plants-derived products.

This chapter is organized in three parts:

1. Processes for obtaining vegetable oils
2. Detailing the continuous mechanical pressing; and
3. Examples on the application of pressing for obtaining oil from cotton, peanut and sunflower.

In the first part of this chapter, the commercial methods for the extraction of vegetable oils are reviewed, including: batch hydraulic pressing, solvent extraction and continuous mechanical pressing (also known as screw press). A brief explanation will be given for the new method of producing oil: supercritical extraction. In the second part, the continuous mechanical pressing is detailed. A complete picture of continuous mechanical pressing will be presented, showing how this technology can be optimized for attaining larger oil volumes, having in sight, mainly, small producers of vegetable oils. In the last part of the chapter, some experimental results related to the pressing of cotton, peanut and sunflower seeds are presented. Experiments were optimized in order to obtain a higher volume of oil. The variables studied were speed of rotation of screw press axis, and the best conditions of the raw material, such as moisture content and temperature (Pighinelli, 2010).

2. Processes for obtaining vegetable oils

Commercially, there are three methods used for the production of vegetable oils: batch hydraulic pressing, continuous mechanical pressing and solvent extraction. Each of these technologies will be detailed below

The first step of the process, common to all technologies, is the preparation of raw material. The main unit operations used are shown in Figure 2: scaling, cleaning, dehulling (or decorticating), cracking, drying, conditioning (or cooking), and flaking (Anderson, 2005). Although cooking operation is not included in the flowchart, it is a very important step in the processing of oilseeds. The flowchart below may be altered depending on raw material to be processed.

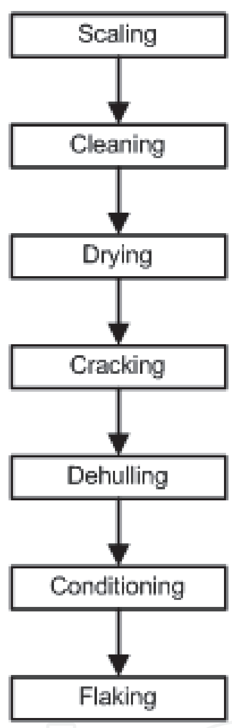

Fig. 2. Unit operations for raw materials preparation (adapted from Anderson, 2005).

Initially the oilseeds are weighed and sent to the cleaning step. A good quality oilseed has around 2% of impurities when it comes from the field. These foreign materials are removed when the oilseeds reach the storage unit and also before starting the extraction of oil. Some examples of foreign materials are a combination of weed seeds, sticks, pods, dust, soil, sand, stones, and tramp metal. Tramp metal is considered hazardous to storage facilities and also for the oil processing operations, so it is the first impurity to be removed, using a magnetic force that pulls these metals from the mass of grain. Sticks and pods are larger and lighter than the oilseeds and can easily be removed by airflow equipment. Weed seeds, sand, and soil are smaller than the oleaginous materials, so those materials can be removed by screening equipment. In the case of peanuts, there are large amounts of stones in grains, and these foreign materials have similar geometry, being necessary to use a gravity separation system to remove impurities (Kemper, 2005).

Due to the high oil content in its composition, oilseeds must have a low moisture content in order to prevent deterioration during storage and also to ensure that downstream unit operations are efficient. This operation is conducted in a dryer (Kemper, 2005).

The main goal of size reduction operation is to increase surface area to facilitate oil removal from the seed inside. This operation must be conducted at proper moisture content. If the moisture level is too low, the seeds are "conditioned" with water or steam to raise the moisture to about 11%. A solvent extraction operation is going to have a higher yield if the flakes are about 0.203 to 0.254 mm. Thinner flakes tend to disintegrate during the solvent extraction process and reduce the miscella percolation rate (Wakelyn & Wan, 2006). Cracking mill is the equipment used to crack oilseeds. This equipment consists of two sets of cylindrical corrugated rolls in series, operating at differential speeds to assist in breaking the oleaginous materials apart (Kemper, 2005).

Another unit operation is dehulling because some oilseeds present outer seed coat known as hull, rich in fiber and poor in oil and protein. The removal of these hulls will produce a better cake with high protein content by weight (Kemper, 2005). Another problem observed with hulled seeds is that the hull will reduce the total yield of oil by absorbing and retaining oil in the cake (Wakelyn & Wan, 2006). Dehulling process removes the lighter hull fraction by aspiration and also the fines, separated from the hulls through various means of hull agitation and screening. A dehulling process can be considered effective if the levels of residual fiber content (from hulls) and residual oil content in the meal fraction were low (Kemper, 2005).

Solvent extraction demands a flaking operation that distorts the cellular structure of the seed and facilitates the percolation of the solvent in the oleaginous material cells. The equipment that performed flaking operation is named flaking mill. Two large diameter rolls in parallel, turning in opposing direction at approximately 250 to 300 rpm., and forced together by hydraulic cylinders. As the oilseeds are pulled through, they are stretched and flattened, forming flakes, in the range of 0.3 to 0.4 mm thick and 8 to 18 mm in diameter (Kemper, 2005).

Cooking is performed prior to extraction and has the following purposes: (1) break down cell walls to allow the oil to escape; (2) reduce oil viscosity; (3) control moisture content (to about 7% for expanding operation); (4) coagulate protein; (5) inactivate enzymes and kill microorganisms; and (6) fix certain phosphatides in the cake, which helps to minimize subsequent refining losses. Cooking temperatures are around 87.8°C during 120 min. An excess in the cooking time will result in a meal with lower nutritional value and can darken both the oil and meal (Wakelyn & Wan, 2006).

2.1 Batch hydraulic pressing

In the late nineteenth century, oilseeds were processed in manual presses, where layers of grains were placed into the equipment, separated by filter cloths and filter press plates and force was applied via a hydraulic cylinder. When the oil has stopped flowing, the workers opened the machine, removed the mass of crushed grain and put more fresh material. At the beginning of the twentieth century the vegetable oil industry worked basically with the hydraulic presses but even making use of a hydraulic cylinder, work with this type of equipment was considered labor intensive. With the emergence of the continuous screw-press, the only application that still requires the hydraulic press is the one that requires gentle handling, such as processing and production of cocoa butter. Presses from this category can be divided into two main groups: open and closed type (Williams, 2005).

Open-type presses: the fresh material, previously prepared and wrapped in press-cloths, is placed between the plates that should be corrugated to assist drainage and overcome cake creepage. In a standard process, it takes 2 minutes to feed the press, 6 minutes to reach maximum pressure, 20 minutes to drain and 2 minutes to remove solids, a total of 30 minutes per batch.

Closed-type presses: in this type, the oilseed is enclosed by a strong perforated steel cage that can apply much more pressure than an open press. Removing oil from the interior of the grain is attained by the pressure applied by a piston placed close to the cage and hydraulically operated. Oil flows through channels that increase in size from inside to outside the cage, thus avoiding any clogging with solid particles (Williams, 2005).

In a typical hydraulic pressing there are three stages as can be identified in Figure 3 (Mrema and McNulty, 1985 in Owolarafe et al., 2008). Initially the loading stage happens before the oil begins to leave the mass of grain (oil point). The application of compressive load causes the seeds to force the air out of the macro pores. This process continues until a critical point that occurs when the seeds respond to pressure through their points of contact. This causes the change in volume and starts the output of oil (initial stage). When the first drop of oil leaks out of the mass, it begins the second stage (dynamic stage), where the air is displaced by the liquid and an air/fluid mixture is extracted. The oil flow increases rapidly to its maximum, which is when the second stage ends. The last stage (final stage) begins when the maximum instantaneous flow rate, i.e. the volume is completely filled with fluid, is reached. Z_1, Z_2 and Z_3 indicate the height of grain layer inside the extractor; P_T is the applied force by the extractor, t_0 is the initial time, taken when the oil starts flowing and T is final time, indicating that the process ends.

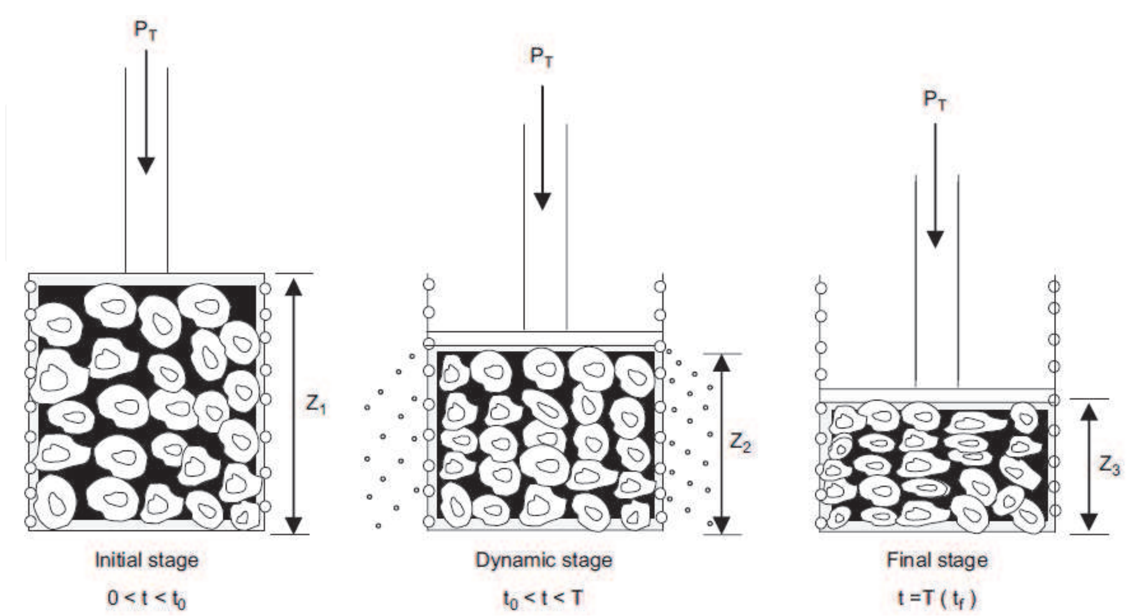

Fig. 3. Stages of hydraulic expressions (Mrema and McNulty, 1985 in Owolarafe et al., 2008).

In 1942 an article entitled "Expression of vegetable oils" was published where a concern in the scientific study and optimization of the hydraulic pressing of oilseeds was expressed (Koo, 1942). For the study, the author used soybean, cottonseed, canola, peanut, tung nut, sesame seed and castor bean. The author evaluated the influence of pressure, temperature and moisture content in oil yield. As the final result it was possible to define an empirical model (on the dry basis) that describes the process (Equation 1).

$$W = CW_o \frac{\sqrt{P\sqrt[6]{\theta}}}{\sqrt{\vartheta^z}} \quad (1)$$

Where: W is the oil yield; C is a constant for one kind of oilseed; W_o is the oil content of the seed; P is the pressure applied; θ is the pressing time; υ is the kinematic viscosity of the oil at press temperature; and z is the exponent on viscosity factor varying from 1/6 to 1/2. Press efficiency can be calculated from the relation W/W_0.

In 2008 an article was published which focused on determination and modeling of yield and pressing rates for the hydraulic press type (Willems et al., 2008). The authors evaluated the influence of pressure profile, temperature, cake thickness and moisture content on the oil yields and rate of pressing for a variety of seeds (sesame, linseed, palm kernel, jatropha and rapeseed). The results showed that when the pressure is increased using a temperature of 100 °C and using the optimum moisture content (close to 2% dry basis), the oil yield increases for all tested oilseeds. The oil yield obtained for the dehulled seeds were considerably higher than that obtained for the hulled seeds. This can be explained by the absorption of oil by fibers present in the hulls. As a final conclusion, the authors stated that when using a press capable of applying a higher pressure (> 45 MPa), the oil yield is increased by 15% (oil / oil) compared with conventional presses.

2.2 Continuous mechanical pressing (screw press)

Among the physical processes for the extraction of vegetable oils, the continuous mechanical pressing emerges as the best technology to serve small farmers. That´s because this type of equipment associates both small scale and low cost when compared to the other methods cited. Another important advantage is the possibility of using cake resulting from the pressing as fertilizer or animal feed, since it is free of toxic solvents.

The operating principle of this equipment consists a helical screw which moves the material, compressing it, and at the same time, eliminating the oil and producing the cake. Optimization of the continuous mechanical pressing consist of defining the optimum parameters, such as temperature and moisture content of grain, or adjustments on the press, in order to reach optimum yields of oil, using a minimum value of pressure applied by the press.

Figure 4 shows the flowchart for the processing of oil by mechanical pressing. More details about continuous mechanical pressing are presented in the next section. Oilseed preparation has already been presented in section 2.

2.3 Solvent extraction

Extraction with solvents is the most effective method for the recovery of oil (almost 98%), especially with materials with low oil content, like soybeans. This method is not indicated to

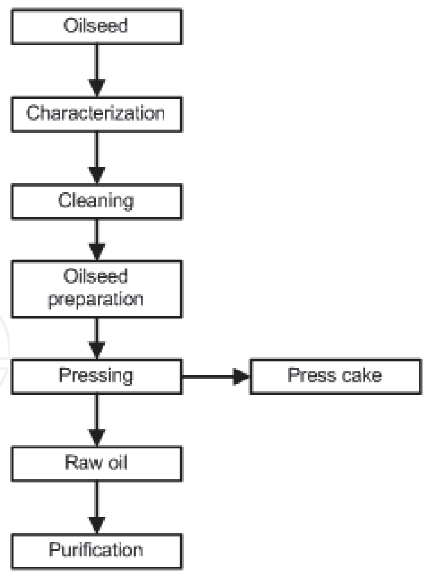

Fig. 4. Screw press scheme (adapted from Jariene et al., 2008).

oilseeds with high oil content, like peanut and sunflower, requiring a prior step of pressing of the seeds and then the cake produced is extracted with a solvent. When performed at low temperature, the solvent extraction has another advantage over screw-pressing: better quality of oil produced. This is because during expelling a sudden heating of the oil can occur, changing some parameters of its quality (Williams, 2005).

One of the disadvantages of the extraction is that the solvent extracts some nontriglycerides, which does not occur in the expelling (Williams, 2005). Another serious problem is the presence of volatile organic impurities in the final product, which can compromise the quality and go against the new profile of consumers who are seeking for natural products aiming to have a healthier diet (Michulec & Wardenki, 2005).

The process known as pre-press is designed to prepare the high oil content raw material to the solvent extraction. Mechanical pressing reduces the oil by half to two thirds of its original level facilitating solvent extraction by reducing the amount of oil to be extracted, the size of extractor equipment and also the volume of solvent used (Walkelyn & Wan, 2006).

The principle of the method is to perform successive washing of oleaginous material with solvent until equilibrium is reached or near equilibrium between the oil content of the solid and that of the solvent, i.e., when the solvent absorbed by the solid and solvent in the free miscella containing the same amount of oil dissolved. When this occurs, the miscella is drained and another washing takes place.

The choice of solvent takes into account a number of factors, notably, solvent extraction capacity, effects of solvent on oil properties, process safety, solvent volatility and stability, and economic considerations (Attah & Ibemesi, 1990).

In 1947, it was published a study evaluating the various types of solvents such as benzene, aviation gasoline, methanol, ethanol, isopropanol, carbon disulfide, diethyl ether, ethylenedichloride, carbontetrachloride, trichloroethylene and the various petroleum naphthas. However, in 1947, the most commonly used solvents in the United States were light paraffinic petroleum fractions, such as the hexanes, heptanes and pentanes. The hexane was finally chosen because of its ease to evaporate and left no residual obnoxious odors or tastes. There are two types of hexane: normal, also known as n-hexane; and commercial, named extraction-grade hexane. The n-hexane is pure and boils at 69°C, while the extraction-grade hexane is not pure. The Clean Air Act of 1990 (public law) considered hexane as one of 189 hazardous air pollutants, encouraging research to seek alternative solvents for the extraction of oil. Examples of alternative solvents studied are halogenated solvents, water as a solvent, enzyme-assisted aqueous extraction, acetone as a solvent, alcohols as solvents and supercritical solvents (Williams, 2005).

The ability to extract an oil from an oilseed depends on the nature of the oil, the nature of the solvent, the temperature and the contact time between solvent and grain mass, flake thickness and conditions of pretreatment of the seeds. Attah & Ibemesi (1990) evaluated the solvent capacity and solvent effects in the extraction of oils from four native plants. The following solvents were used: petroleum benzene (60-80 °C), cyclohexane, isopropyl ether, ethyl acetate, tetrahydrofuran, propan-2-ol and acetone. The authors found that oil extraction performance of each solvent appears to be generally dependent on the nature of the oil, *i.e.* ethyl acetate and tetrahydrofuran gave the highest oil yields in rubber, their oil yields in melon gave next to lowest value. Another important consideration was that solvent did not affect the increase in the level of free fatty acid of extracted oils.

2.4 Supercritical CO_2 extraction

Although solvent extraction is efficient and has high oil yield, the problems presented by this technique have made scientists to research for new routes. One technique that has been used is the supercritical-fluid (SCF) extraction. A fluid is considered supercritical when it presents diffusivity similar to gas and density comparable to liquids.

Cagniard de la Tour had discovered the critical point of substances in the 1820s when it was observed the disappearance of the gas-liquid meniscus at temperatures higher than critical values under pressure, and in 1879 the solvent power of SCFs was reported. Since the 1930s, several potential applications of SCFs and liquefied gases had been proposed for extraction and separation processes, and purification of fatty oils. The technology only was brought into commercial focus in the 1960s by the work of Zosel at the Max-Planck Institute in Mannheim, Germany, which eventually led to its commercialization for coffee decaffeination and hops extraction purposes in Germany in the late 70s and early 80s (Temello & Guçlu-Ustundag, 2005).

In the 1980s, the use of supercritical CO_2 for the extraction of oilseeds such as soybean, cottonseed, corn germ, rapeseed, and sunflower. The oils obtained were shown to have similar quality compared with hexane extracts; they also had lighter color and lower iron and phospholipid content, resulting in a lower refining loss and reduction of subsequent refining steps. Another advantage is related to protein quality of the extracted meal that can be comparable with that of hexane-extracted (Temello & Guçlu-Ustundag, 2005).

Despite the many advantages of $SCCO_2$ extraction and also the high volume of research carried out, commercial-scale $SCCO_2$ extraction of oilseeds was not readily accepted. The process based on $SCCO_2$ extraction is simpler than conventional hexane extraction in terms of eliminating the need for hexane evaporators and meal desolventizer, but $SCCO_2$ process has some disadvantages such as high equipment costs and the inability to achieve continuous processing of high volumes of oilseeds under SCF conditions. Those two reasons are considered major impediments to commercialization of the $SCCO_2$ process. However, new research and developments in equipment design (i.e., the coupling of CO_2 with expeller technology) and government regulations on the use of hexane may render this system commercially possible in the near future (King, 1997 in Temello & Guçlu-Ustundag, 2005).

The main motivation for commercialization of SCF technology is the concern over the use of organic solvents, which was reflected in government regulations (in Germany the use of methylene chloride is forbidden) as well as changes in consumer attitude, who demands a product with high quality and also “natural”. Other advantages are mild operating conditions for heatsensitive compounds (compared with distillation), and a solvent-free extract and residue (compared with solvent extraction). In addition, it provides an oxygenfree environment and limits oxidative degradation of the product (Temello & Guçlu-Ustundag, 2005).

Pradhan et al. (2010) compared supercritical CO_2 extraction method with conventional ones, such as solvent extraction and mechanical pressing, for flax seed. Supercritical-fluid extraction system used is shown in Figure 5.

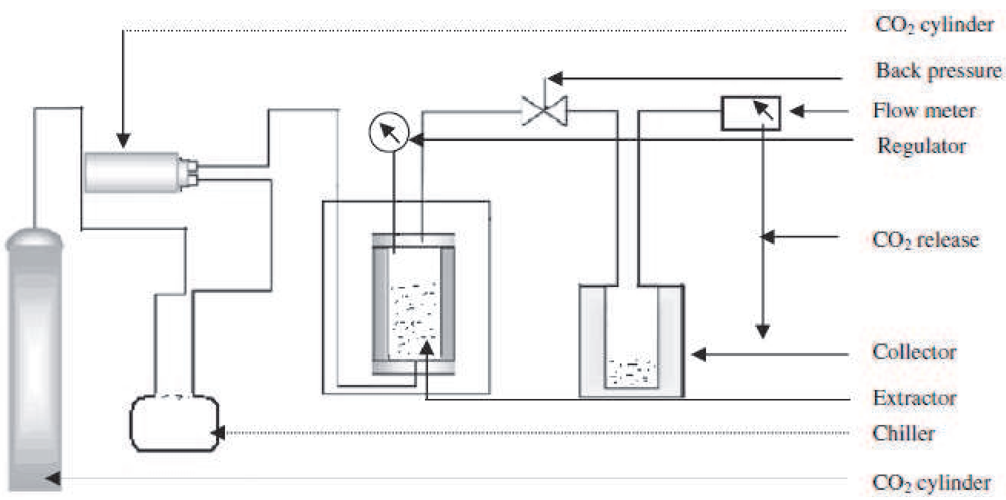

Fig. 5. Supercritical CO_2 apparatus (Pradhan et al., 2010).

The working principle of this system is presented briefly. A diaphragm compressor was used to compress the CO_2 to the desired pressure. Grains were placed in the preheated vessel and then the extraction with CO_2 began at a rate of 40 g / min for 3 hours. The extraction was held at 50 ^oC and pressure of 30MPa. Extracts were collected in another vial attached to the depressurization valve and cooled in a bath maintained at 0 ^oC (Pradhan et al., 2010).

The results showed that the oil yields were 38.8% to solvent extraction, 35.3% for the supercritical extraction and 25.5% for expelling. In terms of extracting the components omega-6-fatty acid and omega-3-fatty acid, supercritical extraction was more efficient than solvent and expelling extractions. The chemical composition of oil obtained from expelling is similar to that obtained by supercritical extraction, although the yield was lower. Extraction with hexane resulted in a higher oil yield but the quality of oil was lower in terms of its acid value and peroxide values, as well as presenting a lower concentration of omega fatty acids. They also observed that the solvent extraction also removed some waxy components and that oil produced contains traces of solvent.

2.5 Comparison of processes

The three processes discussed in this chapter, solvent extraction, supercritical CO_2 and mechanical extraction (screw press and batch hydraulic pressing) can be compared and evaluated under three main parameters: environmental, economic and oil yield.

Today, the process most commonly used commercially is solvent extraction. This process has the advantage of high oil yield (over 98%) and the total domination of the technological process. However, it has as a great disadvantage, the fact of using chemical solvents. After oil extraction, the remaining solvent should have a proper disposal to prevent environmental damage and avoid additional costs to the process, as well having higher investment cost (*i.e.* costly equipments). Another serious problem is the removal of the solvent from vegetable oil, ensuring adequate levels that are not harmful to human health. Besides oil, the meal is obtained, a co-product of solvent extraction, which depending on the feedstock source is rich in proteins, which could be used for animal feed, if high levels of solvent aren´t present. If necessary, one more step could be done, removing the solvent from the meal so it can be used. This process is not recommended for oilseeds with high oil content in its composition. The energy consumed to operate a plant for solvent extraction is high, and requires skilled labor to deal with this complex operation.

The method of extraction by supercritical CO_2 is still relatively new and is not widely used in commercial scale for the extraction of vegetable oils. It has the advantage of presenting a pure oil, without the presence of the solvent used. The oil yield is close to that obtained via solvent extraction and quality, close to that obtained via screw press methods. Studies are still being made in order to optimize the process and reduce costs. Here also the energy consumed to operate the equipment is high, and due to the complexity of the system, skilled labor is necessary.

Mechanical methods are the oldest methods of oil extraction. The great advantage of these methods is not using any kind of chemical products, producing a crude oil with high quality and ready for consumption, in some cases. Other important advantages are the low cost of acquisition of equipment, low power consumption for the operations and manpower do not need to be skilled. Despite the environmental advantages, the economics are unfavorable, since although the facilities have lower costs than those in the chemical process, the low oil yield, and high oil content in the cake, can make the process unprofitable.

3. Detailing the continuous mechanical pressing

3.1 Operating principle

The continuous mechanical pressing or simply screw press is shown in Figure 6. The process begins by putting the oilseeds inside the feed hopper. The screw press has a horizontal main shaft that carries the screw composition which is formed integrally with the shaft. The rotation of the screw occurs inside the cage or barrel that is a structure formed by steel bars. Spacers are placed between the lining bars allowing the drainage of oil as the pressure over the grains is increased. A movable cone or choke control is installed at the discharged end. This device has the function of operating pressure by changing the width of the annular space through which cake must pass. It is possible to adjust the choke by a hand-wheel on the opposite end of the screw (Khan & Hanna, 1983). Some machines have a device capable of removing heat generated by friction of the grains, making use of cold water circulation.

Both choke size and axis rotation speed should be adjusted when pressing different kinds of seeds (Jariene et al., 2008).

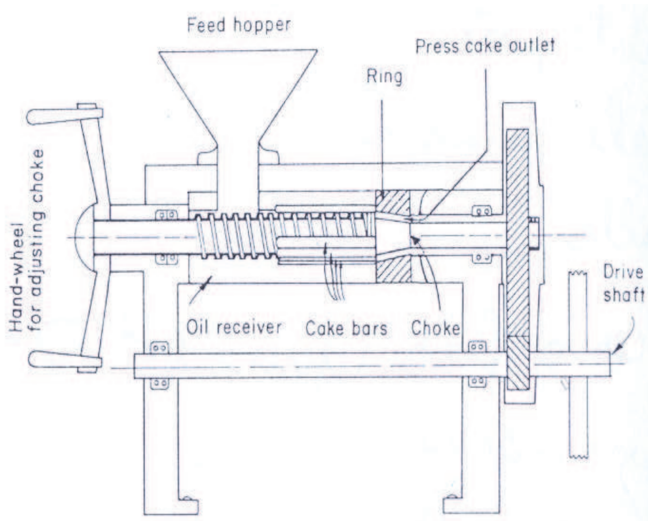

Fig. 6. Screw press (Khan & Hanna, 1983).

The working principle of the continuous mechanical pressing is to force the oilseed mass through the barrel by the action of the revolving worms. The volume of the mass is being reduced as the transition takes place through the barrel, causing compression of the cake and the resulting output of oil by the perforation of the lining bars of the barrel while the de-oiled cake is discharged through the annular orifice (Akinoso et al., 2009).

Screw presses can be powered with electric motors, diesel or even be operated manually (Jariene et al. 2008). Some researchers mentioned the application of photovoltaic cells to power screw presses (Mpagalile et al., 2007), as will be detailed below.

An important parameter related to the pressing efficiency is the determination of residual oil in the cake. High pressures can lead to cakes with less than 10% of oil content, which leads to higher crude oil production. A reduction in speed of rotation of the shaft, for example, can reduce the oil yield, increasing the oil content in the cake and solids in the oil (Jariene et al., 2008).

After pressing, the crude oil must be purified. A very common method of purification, especially for small producers, is to allow the oil to stand undisturbed for a few days, removing the upper layer (purified oil) and discard the bottom layer, consisting of fine pulp, water and resins. If this step is not enough, one can filter the oil using a press filter or using a centrifuge, but both methods are costly (Bachmann, 2004).

In addition to obtaining the oil, mechanical expelling produces a very important by-product named cake or meal. Some oilseeds cakes have high nutritional value and can be used as human food. Some are not suitable as food, but serve to complement the diet of chickens, pigs and cattle. It is important to emphasize the need for proper storage of seeds and cakes. They must be protected against the action of moisture, rodents and insects. High moisture content will generate mold, which can alter the taste of cakes, being rejected by the animals. Another problem is the development of mycotoxins such as aflatoxin, which in high concentrations can be poisonous to humans and animals. (Bachmann, 2004).

3.2 Optimization studies

According to Bargale (1997), despite the many advantages of mechanical extraction as previously mentioned, the low oil yield is still a limiting factor. In his thesis Bargale mentioned that US$ 57 million of edible oil are annually left in the deoiled cake because pressing extraction efficiencies rarely exceed 80%, compared to more than 98% obtained by solvent extraction. So, many studies are being conducted to increase the oil yield and also to perform the optimization of the process, defining the best values for the process variables, like applied pressure and axis rotation speed, as well as raw materials preparation by a number of unit operation like cleaning, heating, decorticating, cracking, flaking, cooking, extruding and drying. Khan & Hanna (1983) add to this list heating time, heating temperature, moisture content and pressing time, as variables that affect the oil yield during expression.

Ward (1976) reported that cooking and drying are the factors which most affect the performance of the screw press. Heating before pressing increases oil yield due to the breakdown of oil cells, coagulation of protein, adjustment of moisture content to the optimal value for pressing, and decreased oil viscosity, which allows the oil to flow more quickly.

Bamgboye & Adejumo (2007) developed a screw press to extract oil from decorticated (dehulled) sunflower seeds. The main components of their equipment are frame, cake outlet, expeller housing, heating compartment, auger, hopper, auger pulley and shaft. The seeds are steam heated by a heating compartment and the cake outlet is located at the end of the equipment where the seeds are compressed and the oil is forced out of the grains. Equipment performance was evaluated by testing three speeds of the axis (30, 40 and 50 rpm) and three levels of throughputs (1, 2 and 3), representing the number of times the material passes through the machine. The best oil yield (73.08%) was obtained for 50 rpm speed and 3 throughput of the cake. The lower oil yield was obtained for the conditions of 30 rpm and 3 throughput of the cake. The authors observed that oil yield increases with the increase in screw speed and throughput.

Pradhan et al. (2011) studied the effects of cooking (*i.e.*, heating by oven) and moisture content on pressing characteristics of dehulled Jatropha seeds. The effect of moisture content (7.22, 9.69 and 12.16% wb – wet basis), cooking temperature (50, 70, 90, 110 and 130 ^{o}C) and cooking time (5, 10, 15 and 20 min.) on parameters such as oil recovery, residual oil content, pressing rate and sediment content were evaluated. Oil recovery was affected by moisture content: as its increase leads to an increase in oil recovery. For cooked seeds, the highest oil yield was obtained for 8.19 % (db – dry basis) while for uncooked seeds, 9.86 % (db). Subsequent increases in moisture content resulted in a rapid drop in oil yield, probably due to mucilage development on oil cells that makes difficult the oil flow. The best cooking temperature was 110 ^{o}C during 10 minutes. The first conclusion was that oil recovery from uncooked samples was lower than the cooked samples at same moisture content. When the seeds are cooked their tissues become softer and the oil has a lower viscosity; softer tissues tend to weaken the cellular structure, causing a rupture under pressure, while the low viscosity facilitates the flow of oil, contributing to higher oil yields. Higher temperatures can lead to a brittle seeds and oil degradation. In seeds with a high-protein content such as Jatropha seeds, protein coagulation due to heat treatment may have had a significant effect on oil recovery. The pressing rate from uncooked seed was higher than that from cooked seed and the sediment content of screw press oil was lower.

Effects of processing parameters on oil yield of finely and coarsely ground Roselle seeds were studied (Bamgboye & Adejumo, 2011). The study variables were the pressure applied during pressing, heating temperature of the grains, pressing time and heating time. Both processing parameters and size of the material affected the oil yield, which increased with an increase in the processing parameters of pressure up to 30 MPa and temperature of 100 ^{o}C and decreased beyond these points. Also it can be observed that oil yield increases with an increase in moisture content. Finely ground samples showed a higher oil yield for different process parameters.

Deli et al. (2011) reported the influence of three types of accessory factors (nozzle size - the size of the choke section, speed and shaft screw press diameter) of the screw machines on the extraction of *Nigella sativa* L. seeds oils. The highest oil yields, 22.27% and 19.2%, were obtained for nozzle size of 6 mm, shaft screw diameter of 8 mm and a rotational speed of 21 rpm and 54 rpm, respectively. The lowest oil yield, 8.73%, was obtained for nozzle size of 10 mm, diameter of shaft screw of 11 mm and rotational speed of 21 rpm. The percentage of oil yield was decreased with the increase on the speed of the machine. When a slow rotation was used an increase in the pressing process time and in the heating of the grain mass was observed. That heating allows the oil to flow more easily and so, more oil is expelled. Nozzle size is directly related to applied pressure. Small openings add pressure to the seeds, thereby providing a higher temperature of the mass of grains due to friction between shaft screws and the seeds. As conclusions, the authors state that the oil yield increases with decreasing nozzle sizes, diameter of screw, speed and temperature.

The effects of compressive stress, feeding rate and speed of shaft screw press on palm kernel oil yield were evaluated by Akinoso et al. (2009). They used an expeller with a rated capacity of 180 kg/h. The experiments were conducted by using a factorial experimental design with 3 variables at 3 levels: compressive stress (10, 20 and 30 MPa), feeding rate (50, 100 and 150 kg/h) and shaft screw press speed (50, 80 and 110 rpm). A maximum efficiency, 94.5 %, was obtained at 30 MPa compressive stress, 150 kg/h feed rate and 110 rpm of speed of shaft screw press. A minimum express efficiency, 33.6 %, was obtained at 10 MPa compressive stress, 150 kg/h feed rate and 50 rpm of shaft screw press speed. For the studied range, oil yield increases with increase in speed of shaft screw press and in feeding rate. Oil yield is directly proportional to compressive stress while influence of speed is marginal, and also it is possible to predict a further increase in oil yield with an increase in compressive stress.

Evangelista & Cermak (2007) studied the effects of moisture content of cooked flaked seeds of *Cuphea* (PSR23) on continuous screw pressing characteristics of the seed and quality of crude press oil. Press cake analysis showed that there was a significant decrease in the residual oil content when the moisture content was reduced. For moisture content of 9 and 12%, the difference in residual oil content was not significant. There was a decrease of 0.4% in the residual oil present in the cake when the moisture content was reduced by 1%. The lowest value of residual oil in the cake, 5.6%, was achieved at 3.1% of moisture content. Oil yield ranged from 79.4 to 83.6% as the cooked seed moisture content decreased from 5.5 to 3.1%. Despite the dry seeds at 3% present the best oil yield, the authors highlighted that long periods of drying and high pressures applied increase energy consumption of the process.

Olayanju (2003) studied the effects of speed of shaft screw press (30 to 75 rpm) and moisture content (4.10 to 10.32 % wb) on oil cake qualities of expelled sesame seed. As conclusions, the author found that the color of the oil was darkened as the speed increased from 30 to 75 rpm and with higher initial moisture content. With a higher moisture content, the residual oil in the cake increased. The lowest residual oil in cake, and hence, the highest oil yield, was obtained at 45 rpm and moisture content of 5.3%.

Screw pressing of crambe seeds was studied by Singh et al. (2002). They evaluated the influence of moisture content and cooking on oil recovery. For cooked seeds, the oil yield increased from 69 to 80.9% with the decrease in moisture content, while for the uncooked seeds, the oil yield increase was from 67.7 to 78.9%. Low moisture content, i.e. 3.6%, resulted in plugging of the screw press. Cooked seeds had higher oil recovery (7%) than uncooked (3.6%). They also concluded that drying was much more beneficial than cooking in terms of oil recovery for the range of conditions in their study but cooking is highly recommended in case of crambe to inactivate the enzyme myrosinase, making the cake suitable for livestock feed.

4. Examples on the application of pressing for obtaining oil from cotton, peanut and sunflower

In this last part of the chapter some practical examples are shown. Results were obtained from the author's thesis developed at the Campinas State University. The objective of this work was to evaluate the production of vegetable oils, i.e. cotton, peanuts and sunflower, for biodiesel production. The process adopted is small screw press with capacity of 40 kg of oilseeds per hour. For a better evaluation of the process and results, experimental design and the methodology of surface response was chosen to use to analyze the results. The parameters chosen to evaluate the oil yield were shaft screw press speed, moisture content and temperature of the grains. Based on the lipid content found for each grain, it was possible to calculate the mass of oil corresponding to 5 kg of kernels that was pressed and so, the oil yield.

4.1 Peanut (*Arachis hypogaea* L.)

The peanuts used in the experiments have 18.25% of hulls and 81.75% of grains, with a moisture content of 6.20% and lipid content, determined only for the grain of 39%. The experiments were conducted with the grain in its initial moisture content (6.20% wb) and with hulls. Table 2 shows the yields of crude oil, obtained experimentally.

For higher temperatures and smaller speeds, yields are higher. In the speed range between 80 and 90 rpm, the oil yield tended to increase, regardless of the temperature range used. What was observed in the experimental design was confirmed by observations during pressing. At lower screw press speeds, the grains had more time inside the press and the contact of grain with an additional heating provided by the equipment favors oil expelling. High speeds render difficult to the press to crush the grains properly, undermining the elimination of the oil from inside the seeds. It is important to note that there is a minimum permissible speed, which was the one used in this work. Values less than this minimum generate an increase in particulates in the oil.

No.	Speed (rpm)	Temperature (°C)	Oil yield (%)
1	90	72	54.67
2	90	107	45.49
3	114	72	46.67
4	114	107	25.90
5	85	85	61.69
6	119	85	44.41
7	102	60	23.74
8	102	110	40.26
9	102	85	32.36
10	102	85	34.56

Table 2. Oil yields from peanut (*Arachis hypogaea* L.)

Regarding the screw press speeds, a value between 80 and 90 rpm showed the better performance in oil yield and also at this range it was possible to observe an improved performance of the press, producing a cake with a proper consistency and oil with no particulates. Tests 7 to 10 showed that for the same speed an increase in temperature leads to increase in oil yield. However, the temperature factor was not considered significant from a statistical viewpoint. Although temperature, statistically did not influence the oil yield, it was observed that the press worked better with the grains heated, reducing the pressing time and the press operation cost. As the heating step is costly, it is recommended to heat the grains at lower temperatures, between 40 and 50 °C. The moisture content which favored the press, without contaminating the oil with water, is within the range of peanut commercialization (8 and 12 % wb), thus not requiring any step prior to pressing, such as drying.

4.2 Cottonseed (*Gossypium* L.)

The cottonseed with lint has moisture content of 5.58 % (wb) and 16.9 % of lipid content. Data analysis according to the methodology of surface response indicated that none of the studied variables significantly affected the oil yield of cottonseed. However, based on the experiments it was possible to define an operating range suitable for processing this type of cottonseed in small equipment. The proposed operating conditions for better pressing of cottonseed was 85 rpm speed of shaft screw press, 9 % (wb) moisture content, the same of commercialized cottonseed, and temperatures between 110 and 120 °C.

4.3 Sunflower (*Helianthus annuus* L.)

The sunflower seeds used in the pressing had an initial moisture content of 7.5% (wb) and 46.8% of lipid content. During preliminary tests of sunflower pressing it was observed that grains with moisture contents other than 7.5% did not have good performance. For this reason, the experimental design took into account only the temperature and the speed of shaft screw press, which proved to be the most important factors. The results are shown in Table 3.

The highest yield, 67%, was achieved for 90 rpm speed and 72 °C grain temperature, while the lowest yield, 48.81%, was obtained at the speed of 114 rpm and of 72 °C. During the

No.	Speed (rpm)	Temperature (°C)	Oil yield (%)
1	90	72	67.28
2	90	107	53.96
3	114	72	48.81
4	114	107	59.45
5	85	85	67.23
6	119	85	62.17
7	102	60	66.89
8	102	110	54.94
9	102	85	66.60
10	102	85	65.45

Table 3. Oil yields from sunflower (*Helianthus annuus* L.)

experiments it was observed that at higher RPMs, the oil yield attained was higher even when the temperature was kept constant. Since the statistical analysis showed that for lower values of temperature the oil yield was higher, a new experimental design was proposed with another temperature range (Table 4).

No.	Speed (rpm)	Temperature (°C)	Oil yield (%)
1	90	30	54.77
2	90	55	61.49
3	114	30	68.38
4	114	55	64.38
5	85	42.5	51.70
6	119	42.5	62.72
7	102	25	61.11
8	102	60	64.85
9	102	42.5	68.04
10	102	42.5	66.13

Table 4. Oil yields from sunflower (*Helianthus annuus* L.) – new design.

The analysis of all experimental data obtained for sunflower oil expelling help to define value ranges for each operating variables. Regarding the screw press speeds, sunflower requires higher RPMs than the peanuts and cottonseed, around 100 to 115 rpm. This difference can be explained by the geometry of the grain and the absence of a significant element of friction, such as the hulls of peanuts and cottonseed lint. During the pressings it was possible to observe how the operation was better conducted at faster speeds, allowing a shorter pressing time. Temperatures close to room temperature (25 and 30 °C) are appropriate, leading to energy saving in the process.

5. Conclusion

Vegetable oils are of great importance to human health as well as to the development of oil chemistry. It can be produced from many technological processes, chemical and mechanical.

Solvent extraction technology is still the most widely used process and the one with higher oil yield, but due to the use of chemicals which affect the environment and human health, new technologies have been researched, such as supercritical extraction. Methods not as new as supercritical extraction, such as screw press, have been the object of study, in order to optimize this simple process so it can produce more oil, with high quality at a lower cost. Several studies focusing on a wide range of oilseeds and technologies, all of them saying the same thing. An extraction process should provide economic and environmental advantages to become an winner technology.

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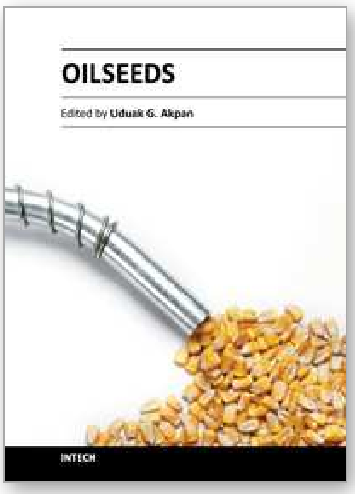

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