CZECH UNIVERSITY OF LIFE SCIENCES PRAGUE

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Department of Mechanical Engineering

BACHELOR THESIS ASSIGNMENT

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A review of oil point identification and experimental determination of oil content of selected oilseeds

Supervisor

doc. Ing. Abraham Kabutey, Ph.D.

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Dipl.-Ing. Achyuth Hanumanthappa meti, Dipl. Ing., dipl. tech.

Agricultural Engineering

Thesis title

A review of oil point identification and experimental determination of oil content of selected oilseeds

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Objectives of thesis

(i) review scientific published articles describing oil point pressure of some oilseeds.
(ii) discuss the significance of oil point identification in oilseed expression.
(iii) determine experimentally the oil content of selected oilseeds using soxhlet extraction method.
(iv) determine the oil yield and oil expression efficiency of selected oilseeds in linear pressing.

Methodology

The Thesis will be in two folds. The first part will focus on a review of scientific articles indexed in Web of Science related to the objective(s). The second part will perform laboratory experiments which will be in two folds. The first part will apply a Soxhlet extraction method at different extraction cycles (6h, 8h and 24 h) for selected oilseeds whereas the second part will use the universal compression testing machine (ZDM 50, Czech Republic) and a pressing vessel of diameter 100 mm with a plunger under a preset load, speed and pressing height of the input material to determine the oil yield of selected oilseeds. The data will be analysed statistically using Statistica software (Statsoft, 2013).

Code for compiling the Bc. Thesis

1. Introduction

1.1 Research problem statement

1.2. Objectives

2. Literature review

2.1 Oilseeds extraction methods.

2.2 Effects of processing conditions on oil-point pressure.

2.3. Mathematical theories of oil-point of oilseeds.

3. Materials and Methods

4. Results and Discussion

5. Conclusions and Recommendations
6. References
7. Appendixes

The proposed extent of the thesis

60–70 pages

Keywords

Oil point, soxhlet extraction, compression test, oil yield, oil expression efficiency

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Recommended information sources

Ajibola, O.O., Okunade, D.A., Owolarafe, O.K. 2010. Oil point pressure of soyabean. Journal of Food Proces Engineering, 25(5):1-10.

Danlami, J.M., Arsad, A., Zaini, M.A.A. 2015. Characterization and process optimization of castor oil (Ricinus communis L.) extracted by the soxhlet method using polar and non-polar solvents. Journal of the Taiwan Institute of Chemical Engineers, 47: 99–104.

Herak, D., Kabutey, A., Hrabe, P. 2013. Oil point determination of Jatropha curcas L. bulk seeds under compression loading. Biosystems Engineering, 116: 470–477.

Hernandez-Santo et al., 2016. Effect of oil extraction assisted by ultrasound on the physiochemical properties and fatty acid profile of pumpkin seed oil (Cucurbita pepo). Ultrasound Sonochemistry, 31:429-436.

Identification and significance of the oil-point in seed-oil expression. Journal of Agricultural Engineering Research, 65:335-345.

Niu, L., Li, J., Chen, M-S., Xu, Z-F. 2014. Determination of oil contents in Sacha inchi (Plukenetia volubilis) seeds at different developmental stages by two methods: Soxhlet extraction and time-domain nuclear magnetic resonance. Industrial Crops and Products, 56: 187–190.

Ogusina, B.S., Owolarafe, O.K., Olatunde, G.A. 2008. Oil point pressure of cashew (Anacardium occidentale) kernels. International Agrophysics, 22:53-59.

Owolarafe, O.K., Adegunloye, O.O., Ajibola, O.O. 2007. The effects of some processing conditions on oil point pressure of locust bean. Journal of Food Proces Engineering, 26(5):1-9.

Perrier, A., Delsart, C., Boussetta, N., Grimi, N., Citeau, M., Vorobiev, E. 2017. Effect of ultrasound and green solvents addition on the oil extraction efficiency from rapeseed flakes. Ultrasonics Sonochemistry, 39:58-65.

Tunde-Akintunde, T.Y. 2010. Determination of oil point pressure for melon seeds. Journal of Food Proces Engineering, 33(1):1-11.

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Dean

Prague on 19. 05. 2021

ABSTRACT

The Bachelor Thesis is focused on the theoretical and experimental analyses of oil point and oil content of selected oilseeds namely pumpkin, rape and sunflower. The oil point analysis was based on a literature review where the effects of processing conditions on oil point pressure and mathematical models of oil point of oilseeds were discussed. The oil content analysis was based on an experimental determination using the Soxhlet extraction procedure for cycles between 6 and 24 hrs. The moisture content of the seeds was also determined based on the conventional oven method. Compression of the oilseeds was done at 80 mm pressing height with the vessel diameter of 100 mm with a plunger, speed of 5 mm/min and force of 400 kN where the oil yield, oil expression efficiency and deformation energy were calculated. The percentage oil content of pumpkin seeds increased from 31.60 to 38.34 % at 12 hr to 24 hr cycles and slightly increased from 33.63 to 34.45% at 6 hr to 10 hr cycles. However, at 10 and 12 hr cycles, the oil content of 34.45 % decreased to 31.60%. In comparison with rapeseeds and sunflower seeds, the oil content at the 6 hr cycle was known to be 31.87 ± 2.40 and 33.12 ± 0.87 % respectively. The moisture content at 24 hr of pumpkin, rape and sunflower oilseeds was calculated to be 6.35 ± 0.05, 5.29 ± 0.05 and 4.78 ± 0.01 (% w.b.). Oil expression efficiency of sunflower seeds was the highest (46.74 ± 0.73%) followed by rapeseeds (33.03 ± 1.36 %) and then pumpkin seeds (20.31 ± 0.80 %). The corresponding energies were 2010.79 ± 40.47 J, 2143.51 ± 35.98 J and 1858.42 ± 0.27 J. It was observed that higher energy was required for processing rapeseeds than sunflower and pumpkin seeds. The results of the study provide vital information for conducting comprehensive research on the selected oilseeds among others under uniaxial compression to improve the commonly used mechanical screw oil pressing.

KEYWORDS:

Oil point, Soxhlet extraction, compression test, oil yield, oil expression efficiency

DECLARATION

I hereby declare that I have done this Bachelor Thesis entitled ‘**A review of oil point identification and experimental determination of oil content of selected oilseeds**’ independently and all texts in this Thesis are original. However, literature information used has been acknowledged through a complete list of references according to Citation rules of the Faculty of Engineering.

In Prague Date:

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Achyuth Hanumanthappa Meti

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1. INTRODUCTION

1.1 Background

Recent growths in population along with industrial development are important factors that contribute towards the reduction of fossil fuel reserve of the world (Bokhari et al., 2014). Different types of energy sources such as water, solar, wind and biofuels have the potential to replace fossil fuel (Ahmad et al., 2014a). These fuels are largely utilized as a transportation fuel (Chuah et al., 2015 a). Currently, biodiesel is mainly prepared conventionally (Chuah et al., 2015 b) grown edible oils such as rapeseed, soybean, sunflower, and palm thus leading to alleviate food versus fuel issue (Yusup et al., 2015). About 7% of global vegetable oil supplies were used for biodiesel production in 2007 (Ahmad et al., 2014b). The uses of seeds from Ceiba pen Tandra (kapok tree) as one of the non-edible oil sources have become important studies in finding the alternative in replacing edible oil and fossil fuel. Ceiba pen Tandra, or locally known as kekabu is native in tropical America and West Africa (Kumar et al., 2015). There are many new sources for biodiesel that have been discovered from current research.

Oil extracted from both edible and non-edible oil sources has been proven to reach the standard of existing commercial biodiesel (Bokhari et al., 2012). The selection of kapok seed as the source will lead to the selection of the best method that can be used for producing biodiesel. In the standard procedure before pursuing the transesterification reaction, oil extraction from the seed itself is also very important and many studies have been done by research to find the best extraction method that can give the optimum conditions to obtain the maximum extraction yield (Bokhari et al., 2012). The most common method that has been for extraction purposes is a Soxhlet extraction method.

Soxhlet extraction is the ability of a solute to distribute itself between an aqueous solution and an immiscible organic Soxhlet. The organic Soxhlet separates and purifies the solutes by extracting them into the organic phase, leaving unwanted substances in the aqueous phase. A Soxhlet is used selectively to extract the base oil component from the waste lubricant oil. The additives and carbonaceous impurities that are normally present in used oil should be rejected by extracting Soxhlet. These impurities settle and flocculate based on gravity. The Soxhlet is then recovered by distillation for reuse. However, a portion of this Soxhlet is lost due to evaporation during treatment. Petroleum Ether is the Soxhlet of choice for oil extraction mainly due to its efficiency and ease of recovery. Petroleum Ether is obtained from a non-renewable source and is being consumed faster to the emergence of new sources. It has become necessary to find an alternative Soxhlet for oil extraction. The extractability of oil depends on the nature of the Soxhlet and oil, extraction temperature, contact time between solvent and the feed, pre-treatment conditions of the oil-bearing resource. Key properties such as solubility are necessary to evaluate the solvent performance, showed that an increase in solubility parameter difference further enhances the Soxhlet capability to extract the additives and impurities from used oil. The steady decline in valuable petroleum commodity against ever-increasing demand has driven researchers to search for alternative resources for energy and chemicals. This includes recycling these hydrocarbons using sustainable methods. The used lubricant contains a large proportion of valuable base oil that may be used to formulate new lubricants if unwanted pollutants are removed.

1.2. Research problem statement

The study of mechanical oil-seed expression requires the measurement of some physical and mechanical properties during compression (Faborade and Favier, 1996). Mechanical expression of oil involves the application of pressure by either using a hydraulic press or screw press to force the oil out of the oil-bearing material such as rapeseeds, sunflower seeds, pumpkin seeds among others. The effective pressure to be applied to an oilseed for the cells to start discharging the oil content is determined by first identifying the oil-point pressure (Ogunsina, Owolarafe and Olatunde, 2008). The oil point pressure being a point on the load-deformation curve could therefore be used as a first approximation to the energy per unit volume of the material before oil expression and as a measure for evaluating the relative pretreatments preparatory to oil expression (Raji and Favier, 2004). The knowledge of oil point and the estimation of the oil point parameters are useful for analyzing the design and performance of oil expression equipment. The oil expression efficiency of oilseeds under uniaxial compression needs to be estimated to fully understand the non-linear compression process of oil extraction of oilseeds involving mechanical screw presses for large scale oil production.

1.3. Objectives

The objectives of the Thesis are to:

(i) review scientific published articles describing the oil point pressure of some oilseeds.

(ii) discuss the significance of oil point identification in oilseed expression.

(iii) determine experimentally the oil content of selected oilseeds using the Soxhlet extraction method.

(iv) determine the oil yield and oil expression efficiency of selected oilseeds in linear pressing.

2. LITERATURE REVIEW

The extraction of oil from seeds represents one of the most important components of modern agriculture. This is because of the way that they give effectively exceptionally nutritious human and animal food. Nutritionally, oils got from oilseeds provide the calories, vitamins, and essential fatty acids in the human diet, while the de-oiled cake is a valuable source of protein for animal feeds (Bargale, 1997). In plants, the fatty matter is moved distinctly in some parts such as seeds, fruits and tubers, stone fruits, sprouts, representing a reserve substance that the plant uses during its development as a source of energy. Although the oilseeds field is very vast, plants that can be utilized as raw material in the vegetable oils industry are somewhat because a significant number of them have low oil content being unprofitable, others with higher oil content present challenges in oil extraction due to the special structure of the plants (Banu, 1999). The interest in determining the fact that, mineral oils and their components has increased considerably over the past ten years. Historically, until the end of the 1990s, it was purely focused on the quality control of the products that are made from oils (Grob et. al., 1991). For instance, the industry that extracts the oil gave a very early the standardized method IP 346, which determined that the residue in a dimethyl sulfoxide (DMSO) extract. This method represents an initial test for the mineral oil industry that mineral oils are later to be sold as highly refined pharmaceutical-grade mineral oils. Only the mineral oil fractions containing a decreased percentage of 3% by weight of aromatics extractable with DMSO will be subjected to further processing preparation steps (e.g., refining or hydrogenation). This level has been determined by the industry as a “certain threshold” to distinguish carcinogenic from non-carcinogenic products (International Petroleum Standard Test Methods, 1992). Many studies describe the determination of the amount of the oil in the seed (Kartika et. al., 2012; Kumar and Sharma, 2008; Rathbauer et. al., 2012; Tambunan et. al., 2012) but only a few of them are published studies that focused on the determination of oil point of bulk seeds (Kabutey et. al., 2010; Karaj and Muller, 2011; Pradhan et. al., 2011; Sayyar et. al., 2009). The studies of (Faborode and Favier 1996; Omobuwajo et. Al., 1998; and Singh and Kulshreshtha, 1996) concluded that the oil point of multiple seeds is not only influenced by physical, mechanical, and chemical properties of the seeds but are also influenced by their porosity, contact pressures, gradients of pressures, compressibility and other factors that are not known yet. Therefore, there have also been some related theories describing the oil recovery of the oil-bearing crops (Fasino and Ajibola, 1990; Mrema and Mc Nulty, 1985; Herak et. Al., 2012; Raji and Favier, 2004; Shirato, Murase, Iwata, and Nakatsuka, 1986). These theories are moreover based on Darcy's Law, Terzaghi's model and the Hagen-Poiseuille law. Based on these theories, it was evident that the oil point of the seeds is a point on the deformation curve of the seeds that the first drop of oil can be observed which is given usually by two coordinates, for instance, deformation and compressive force which can be influenced by compression factors such as moisture content, pressing temperature and seed maturity stage (Herak et. al., 2010; Karaj and Muller, 2011).

2.1. Oilseeds extraction methods

Thus, for many years, multiple methods are adopted for the extraction of oil from oilseeds. The basic purpose of these extraction methods was to optimize the process by integrating the maximum quantity from the existing oil in oilseeds with the minimum costs. Currently, worldwide four basic methods are used to obtain vegetable oil: chemical extraction, supercritical fluid extraction, steam distillation and mechanical extraction.

2.1.1 Mechanical pressing

The most basic method that is usually used of extracting edible oil from oleaginous material, which has been practised for thousands of years, is mechanical pressing from the oilseeds. Oil extraction (also known as pressing) is based on the mechanical compression of oleaginous materials. Through this pressing, oil is then separated from the oleaginous material (solid-liquid mixture), under the action of this compressive external forces that then arise in special machines called the presses. This method further ensures extraction of this non-contaminated, protein-rich low-fat cake at a relatively low cost. The disadvantage of this method is that the mechanical presses do not have increased extraction efficiencies, about 8-14% of the available oil remain in the press cake (Bamgboye, 2007). Most of the plants, specifically the agricultural stock, contain extractable oil which may be of some commercial value. Since the start of human civilization, rural communities from all over the globe have used various traditional methods to extract mainly edible oil from materials of plant origin. Many edible vegetable oils such as palm, corn, soybean, peanut, coconut etc. these are used as table oils because of their increased nutritive value. For example, fats and oils are the most concentrated form of energy, providing approximately 9 kcal of energy per gram compared to only 4 kcal per gram for proteins and carbohydrates (Ali et al., 2005). This is in addition to their industrial application as raw materials for the synthesis of polyols, polymers, resins, biodiesel, pharmaceuticals etc. Irrespective of the extraction method to be used, oilseed pretreatment is necessary. Basic steps in this process are dehulling, pod or seed coat removal, winnowing, sorting, cleaning, grinding, or milling and preheating (Ogunniyi, 2006; Yusuf et al., 2015). Grinding or crushing of oilseeds before extraction is to ensure that oil-bearing minute cells embedded in fibrous structures are broken or ruptured to release the oil (Akpan et al., 2006; Tayde et al., 2011). Heat treatment further facilitates the oil release process by reducing moisture content and hardening the interior of the oilseed (Patel et al., 2016). In recent times, preheating of oilseed done conventionally by hot air oven is being replaced by microwave-assisted heat treatment, the latter offering some advantages (Mgudu et al., 2012). Additionally, grinding or size reduction before solvent extraction increases the surface area for solvent penetration to bring out the oil by leaching. Oil yield from an oleaginous seed material is generally dependent on the quality of oilseeds. However, there are certain factors like moisture content of the material, particle size and temperature that can be manipulated during pretreatment to maximize oil yield. According to Olaniyan (2010), oilseed pretreatment before oil extraction normally affects oil yield and quality. Similarly, Faugno et al. (2016) who carried out the analysis of main extraction parameters on yield of mechanically pressed tobacco (*Nicotiana tabacum*) seed oil found that the combination of seed preheating and increased extraction temperature, among the others, had a significant effect on oil yield. Thus, oilseed processing or pretreatment provides a path for manipulating key parameters and conditions for enhanced oil yield and quality. In terms of oil recovery and oil yield, the old traditional or informal wet extraction methods used by rural communities around the globe is regarded as inefficient, often yielding below the range of plant oil content found in the literature (Alonge & Olaniyan, 2006; Olaniyan, 2010). Olaniyan (2010) has delineated three significant methods for recuperating the oil from oleaginous materials of plant source as wet extraction (heated water or steam extraction), dissolvable extraction and mechanical articulation. As to the wet extraction technique, Oluwole et al. (2012) proffered nine significant tasks that are associated with the extraction of castor oil by the old conventional strategy specifically, an assortment of seed cases, shelling of the units/winnowing, heating the seeds to decrease wetness, crushing of seeds to shape glue, blending the glue in with water/bubbling to extricate oil, scooping of oil and drying the oil by warming. Olaniyan and Yusuf (2012) depicted the old conventional strategy for extraction of seed oils as including the simmering of seed parts by mortar and pestle or between two stones, blending the squashed mass in with water, cooking of the blended glue to get the oil by gliding and skimming, and afterwards drying of the oil by additional warming. They further depicted this technique as repetitive, tedious, energy-sapping, drudgery inclined, wasteful, and low in yield and quality. As such, the old customary techniques are rough, generally informal, wasteful, and yielding low quality extricated oil. The conventional strategies are the notable and broadly learnt techniques for oil extraction, in particular, dissolvable extraction and mechanical expression. Many seed oils are extricated by both two strategies and a mix of the two. This arrangement may likewise incorporate delivering (Ali et al., 2005), however maybe not as broadly utilized. Notwithstanding extraction technique, removed and refined oil should be assessed for its physic-compound properties to decide its application or utilization. The solvent extraction strategy is a regular extraction technique normally applied to oilseeds with low oil content (< 20%), like soybean. This strategy is considered as perhaps the most productive techniques in vegetable oil extraction, with less residual oil left in the cake or supper (Buenrostro and Lopez-Munguia, 1986; Tayde et al., 2011). The decision of solvent depends essentially on the most extreme filtering qualities of the ideal solute substrate (Dutta et al., 2015). Solvents generally utilized are hexane, diethyl ether, petrol ether and ethanol. Different contemplations are high dissolvable solute proportion, the relative instability of solvent to oil, oil thickness and extremity, just as cost and market accessibility (Muzenda et al., 2012; Takadas & Doker, 2017).

2.1.2. Solvent extraction

The solvent extraction technique offers various focal points. Bhuiya et al. (2015) who explored the enhancement of oil extraction measure from Australian Native Beauty Leaf Seed (*Calophyllum innophyllum*) revealed that the solvent extraction measure is a successful technique, with high return and steady execution, however, the cost of creation was moderately higher than mechanical press strategies because of significant expense of solvent. As per Muzenda et al. (2012) in their work on the streamlining of cycle boundaries for castor oil creation, they saw that oil extraction capacity of solvent during solvent extraction is upgraded with increment in extraction time; with solvent-solute proportion for the dissolvable ideally by a factor of 6:1. Ikya et al. (2013) contemplated the impacts of extraction strategies on the yield and quality attributes of oils from shea nut. They thought about aftereffects of physical, substance and tactile properties of oil separated by solvent extraction and old conventional extraction techniques. They revealed a higher oil yield of 47.5% for the solvent extraction strategy contrasted with 34.1% for the old conventional technique, and better saving quality for the dissolvable removed oil (lower humidity substance and lower blaze and fire point esteems). In their work on the extraction, portrayal, and adjustment of castor seed oil, Akpan et al. (2006) utilized the solvent extraction strategy to extricate castor seed oil from castor bean glue utilizing Soxhlet extractor. They got 33.2% oil yield, which was inside the normal reach for castor beans found in writing. They reasoned that the method of extraction and seed assortment is vital boundaries influencing oil yield. Other advantages are its repeatability and reproducibility. However, this method has some industrial disadvantages such as long extraction times, relatively high solvent consumption, high investment, high energy requirement, plant security problems, emission of volatile organic compounds into the atmosphere, high operation costs, poor product quality caused by high processing temperatures and a relatively high number of processing steps (Buenrostro and Lopez-Munguia, 1986; Del Valle and Aguilera, 1999; Dawidowicz et al., 2008; Takadas and Doker, 2017). Additionally, this process makes the use of organic solvents whose removal brings increased cost and labour (Gibbins et al., 2012). Soxhlet based solvent extraction procedure is the primary means of extracting vegetable oil from oleaginous materials. The Soxhlet process is widely used in laboratory-scale oil extraction (Abdelaziz et al., 2014), but the large-scale operation of this procedure would require a commercial solvent extractor (Ogunniyi, 2006). This major advantage of the Soxhlet procedure is solvent recycling (over and over) during the extraction period. However, disadvantages of the Soxhlet method include high solvent requirement, time and energy consumption (Takadas and Doker, 2017), as well as the sample being diluted in large volumes of solvent (Rassem et al., 2016).

2.1.3. Microwave-assisted extraction (MAE)

Microwave-assisted extraction (MAE) is one of the innovative techniques for isolating vegetable oils from oilseeds. It is also used in the extraction of essential oils (Ramanadhan, 2005; Rassem et al., 2016). The method is simple, but superior to many other thermal methods used to extract high-quality vegetable oils. Pretreatment of oilseed is done in the microwave oven, which uses radio waves to convey energy and convert it to heat at a frequency range of about 300 MHz to 300 GHz (Singh and Heldman, 2001). The use of microwave radiation in oilseeds results in the rupture of cell membranes, making it possible to obtain a higher extraction yield and an increase in mass transfer coefficients (Azadmard-Damirchi et al., 2011). MAE has been applied with increasing success in oil extraction. Moreno et al. (2003) used microwave pretreatment to oil extraction from avocado and found that extract efficiency was 97% Soxhlet-hexane extraction coupled with microwave pretreatment when compared with only the neat Soxhlet-hexane extraction (54%). In terms of the quality of microwave extracted oil, Veldsink et al. (1999) reported that oil extracted from microwave treated rapeseed showed markedly improved oxidative stability, most likely due to an increase in phenolic antioxidants. Similarly, Balasubramanian et al. (2010) found that microwave pretreated oil had a higher composition of unsaturated and essential fatty acids (FAs), thus a better oil quality. They also reported better extraction rates, high oil yields and good oil quality for the microwave extraction process. Indeed, this technique has been used for the extraction of oil from a wide variety of oilseeds including soybean, castor, peanut, canola, olive, sunflower, hazelnuts, rapeseed etc. (Mgudu et al., 2012). Kittiphoom et al. (2015) examined the impact of microwave radiation (2450 MHz), at various therapy seasons of 0-150 seconds, on mango seed as substrate pretreatment before oil extraction by the Soxhlet technique. They noticed the significant preferred position of this technique over ordinary strategies as diminished extraction time and decreased energy utilization costs. Mgudu et al. (2012) who did microwave pretreatment of castor beans before dissolvable extraction got moderately high oil recuperation of up to 44.34 % yield at 280 w microwave illumination, for 120seconds. Focal points of this strategy incorporate: improving oil extraction yield and quality, direct extraction capability, lower energy consumption, faster processing time and reduced solvent consumption (Ramanadhan, 2005; Azadmard-Damirchi et al., 2011). The method likewise considers better maintenance and accessibility of attractive nutraceuticals, for example, phytosterols and tocopherols, canola and phenolic mixes in the separated oil. It subsequently speaks to another progression forward for the creation of healthful vegetable oils with an improved period of usability because of high cell reinforcement content. One weakness of MAE is that it may not generally be appropriate for plants, since high microwave energy upsets plant structure (Uquiche et al., 2008). In addition, MAE would corrupt the polyunsaturated FAs (PUFAs) in vegetable oil, bringing about an unrepresentative FAs profile.

One issue related to applied high temperatures during oil extraction is that they may cause debasement responses that can debilitate oil quality. This is more so where oil extraction time is long. Notwithstanding, despite cases that short openness time to microwaves when contrasted with broiler warming jam most thermolabile mixes from corruption responses (Amarni and Kadi, 2009), to date there have not been thorough assessments on the security levels of microwave lights, particularly as they identify with eatable oils implied for human utilization.

2.1.4. Ultrasound-assisted extraction (UAE)

Ultrasonic-assisted extraction (UAE) is another imaginative procedure that utilizes ultrasonic sound waves to build vibration and warmth, bringing about the decimation of unbending plant cell dividers, consequently upgrading contact among dissolvable and the plant material (Takadas and Doker, 2017). At the point when combined with dissolvable extraction, the UAE technique speaks to a creative method of expanding removed oil yield by making plant cell dividers slenderer, and along these lines improving the communication of the dissolvable. This strategy has been applied by various specialists. (Samaram et al.,2014) investigated oil creation from papaya seeds by both UAE and dissolvable extraction. They revealed that regular dissolvable extraction kept going 12 hours, while the UAE technique endured just 30 minutes. This makes the UAE more reasonable regarding decreased delay and yield. (Li et al., 2004) examined oil creation from soybean by the UAE technique, utilizing hexane as dissolvable. They proposed that UAE can be utilized in oil extraction cycles to improve effectiveness and lessen the cycle time, which may significantly affect the eatable oil industry. The great presentation of these inventive procedures has lately urged scientists to investigate the possibilities of consolidating some of them, with the point of synergizing oil extraction. (Chemat et al., 2003) attempted a joined ultrasound and microwave pretreatment strategy for the extraction of fundamental oil from caraway seeds. They found that critical improvement in extraction was acquired utilizing synchronous ultrasound and microwave pretreatment.

2.2. Effects of processing conditions on oil point pressure

In the traditional cycle of oil extraction, the moringa seed parts are exposed to a progression of tasks including cooking, pounding, warming the feast in a skillet over an open fire or bubbling it in a pot containing water. The above activities as of now did are work serious and tedious, yet in addition inefficient. Therefore, there is the need to build up a suitable innovation and productive oil articulation framework for the moringa seed. Oil articulation is a union and pressure measure requiring the utilization of pressing factor. During the activity, decrease in volume happens and makes the oil leak out of the compacted seed (Sivala et al., 1991). The mechanics of oilseed articulation of rapeseed was breaking down by (Mrema and McNulty 1985) comparable to seed miniature design, while (Farabode and Favier 1997) examined it as a depleted solidification measure regarding pressure strain reaction of the seedbed and the elements of the oil stream. In Nigeria, little and medium scale handling of vegetable oil is mostly done utilizing mechanical articulation in inclination to oil extraction utilizing a dissolvable because articulation is more efficient (TundeAkintunde et al., 2001) and yields a result that is liberated from disintegrated synthetics, which makes it an innately more secure cycle (Khan and Hanna 1983). The pretreatment activities that are known to impact oil yield in mechanical oil articulation incorporate warmth treatment, dampness moulding and size decrease (Khan and Hanna 1983; Adeeko and Ajibola 1990; Ajibola et al., 1993, 2000; Oyinlola and Adekoya 2004). Warmth treatment of oilseed has been seen to burst the oil-bearing cells of the seed, coagulate the protein in the dinner, change the dampness level of the feast to ideal level for oil articulation, bring down the consistency and increment the ease of the oil to be removed and annihilate shape and microbes accordingly encouraging oil articulation from the material Adeeko and Ajibola (1990). Norris (1964) announced that size decrease, heat treatment and use of pressing factor are needed for productive oil articulation from oilseeds with huge molecule sizes. Dedio and Dornell (1977) found that expanding the dampness substance of drop seed from 8 to 16 % diminished the oil yield. The pressing factor at which oil emerges from the interparticle voids of oilseed is known as oil point pressure. It shows the limit pressure at which oil rises out of a seed portion during mechanical oil articulation (Ajibola et al., 2002). The oil point pressure decides the adequacy of an articulation activity because the resulting stream and yield of oil are set off by pressure applied past the oil point pressure Olatunde & Owolarafe (2011). A few analysts have examined the impact of handling boundaries on the oil point pressing factor of oil seeds. These remember examinations for the oil point pressing factor of assault seed (Sukumaran and Singh 1989), sesame seed (Ajibola et al. 2000), soybean Ajibola et al., (2002), insect bean (Owolarafe et al. 2003), cashew pieces (Ogunshina et al. 2008), melon seeds (Tunde-Akintunde 2010), neem seed (Olatunde and

Owolarafe 2011) and Indian almond bits (Aregbesola et al. 2012). Studies on the oil point pressing factor of moringa oleifera seed seem not to have been done. The ideal condition at which the oil point pressing factor of the seed is recognized will improve the oil articulation proficiency and give helpful data to the plan and execution assessment of the moringa seed oil expeller. The target of this examination, hence, was to decide the oil point pressing factor of moringa oleifera seed and research the impact of such preparing boundaries as dampness content, warming temperature, and warming time on the oil point pressure. Oil point pressure diminished with increment in warming temperature and warming time. The lessening in oil point pressure with increment in warmth treatment is likely because of the way that warming for significant stretches brings about dampness change (Olatunde and Owolarafe 2011), a decrease of consistency, which empowered the oil to stream simpler from the phone structure (Tunde-Akintunde 2010) and protein coagulation which is one of the elements vital for oil articulation (Khan and Hanna 1983; Adeeko and Ajibola 1990). The intelligent impacts of dampness substance and warming temperature, dampness substance and warming time, warming temperature, and warming time just as dampness content, warming temperature, and warming time on the oil point pressure, were huge at 1 % level of importance. The reaction of oil guide pressure toward dampness substance and warming temperature variety at the warming season of 15 min. The Figure uncovers that the oil point pressing factor of moringa seeds expanded with increment in dampness content and diminished with increment in warming temperature at steady warming time. A comparable pattern of oil point pressure with dampness substance and warming temperature to that was shown by the seeds at the warming occasions of 20, 25 and 30 min. The reaction of oil direct pressing factor toward dampness substance and warming time variety at the warming temperature of 50 °C uncovers that it expanded with increment in dampness content however diminished with increment in warming time at constant heating temperature.

2.3. Mathematical theories of oil point of oilseeds

The theories of mechanical expression of oil from an oilseed cake are initiated by applying pressure to the oilseed cake contained within an envelope which retains the oilseed skeleton but allows oil to escape across the envelope. The model assumes that such oil expression is a case of flow through a porous medium in contrast to previous models' which assumed that cell walls had to be ruptured before oil expression could commence. After application of the pressure the oilseed cake begins to consolidate while, simultaneously, the oil flows through the cell wall pores and into the inter-kernel voids through which it flows until it passes through the retaining envelope. It is assumed that this process can be divided into the following three components: (1) oil flow through the cell wall pores; (2) oil flow in the inter-kernel voids; (3) consolidation of the oilseed cake. Oil flow through cell wall pores Natural flow of liquid through cell wall pores or plasmodesmata has been described by using the Hagen Poiseuille equation for the flow of Newtonian fluids through a pipe as follows.

$$J_v = \frac{\lfloor \pi r4(P_1 - P_2) \rfloor}{8\eta L} = L_p \Delta P \qquad \text{Eq.1}$$

where J_v, is the flow rate of fluid; r is the pore radius; $P_1 - P_2 = \Delta P =$ pressure drop across a pore of length, L; η is the fluid viscosity; and L_p, is the hydraulic conductivity. Mrema and McNulty, (1985) applied Eq. 1 to an assembly of cells in an oilseed kernel and suggested the following simple model for oil expression into the inter-kernel voids:

$$J_v = L_p n_c \Delta P \qquad \text{Eq.2}$$

where n_c, is the number of cells on the shortest radius of the oilseed kernel, i.e., the shortest path for the flow of oil to the inter-kernel voids. Oil flow in the inter-kernel voids Flow through porous media such as an oilseed cake is commonly described by Darcy's law:

$$q = \delta_q / \delta_t = (k/pg)\delta u / \delta z \qquad \text{Eq.3}$$

where q is the flow rate of fluid; k is the coefficient of permeability; ρ is the fluid density; g is the gravitational constant; $\delta u / \delta z$ is the hydraulic gradient in the fluid, i.e., pressure difference δu over distance δz. The amount of oil expressed is given by integrating Eq. 3 and multiplying by the total cylinder area, A_c, as follows:

$$Q = A_c \int_o^t (\delta q / \delta t) dt \qquad \text{Eq.4}$$

Consolidation of the medium during oil expression According to Terzaghi the application of pressure to a medium such as a saturated soil result in a partition of pressure as follows:

$$Q\sigma_t = \sigma_i + u \qquad \text{Eq.5}$$

where σ_t is the total applied pressure; σ_i is the pressure carried by the medium skeleton; u is the pressure carried by the medium fluid, i.e., pore or fluid pressure. According to Eq.5, the application of pressure to medium results in a partition of pressure between the medium skeleton and the medium fluid, the latter being termed the pore pressure. In the oil expression process, oil is initially expressed into the inter-kernel voids which, when full, resulting in the the build-up of pore pressure, u, leading to the development of a pressure gradient, $\delta u/\delta z$. Therefore, oil flows through the porous medium according to Darcy's law (Eq. 3) and is finally expressed through the porous retaining envelope. In the experimental program, pore pressures were measured as described elsewhere. In all cases, the kernel pressure was computed as the difference between applied and pore pressures (Eq. 5). The key point to note is that the absolute magnitude of the pore pressure relative to the applied pressure was very small indeed. In contrast, pore pressures in consolidated soils are typically 20% of the total applied pressure. Originally, it was thought that this was due to the presence of air in the oilseeds. However, Mrema demonstrated that such air under conditions of the maximum load has been dissolved in the oil and that, therefore, the low value of pore pressure is due to structural differences between oilseeds and soil (Mrema and McNulty 1985).

3. MATERIAL AND METHODS

3.1 Experimental Location

The experiment was conducted at the laboratory of the Mechanical Department of Faculty of Engineering, Czech University of Life Sciences Prague.

3.2 Samples

For the experiment, samples of pumpkin, rape and sunflower oilseeds were procured from Ceska Skalice and Stredni, Prague, Czech Republic.

3.3 Determination of moisture content

The moisture content of pumpkin, rape and sunflower oilseeds was determined using the oven method at a heating temperature of 105 °C and duration time of 17 hrs and 24 hrs respectively.

Figure 1. Determination of moisture content of the selected oilseeds samples.

The percentage moisture contents on wet basis (*MC* % w.b.) and dry basis (*MC* % d.b.) of the selected oilseeds (Figure 1) were calculated according to the equation given by Blahovec (2008) as follows:

$$MC\ (\%\ w.b.) = \frac{m_i - m_e}{m_i} \cdot 100 \qquad \text{Eq. 6}$$

$$MC\ (\%\ d.b.) = \frac{m_i - m_e}{m_e} \cdot 100 \qquad \text{Eq. 7}$$

where m_i and m_e are the weights of the samples in the initial state before drying and after drying.

3.4 Determination of oil content in pumpkin, rape, and sunflower seeds

The Soxhlet extraction procedure (Figure 2) was used to determine the oil content of the oilseeds. 10 g of each sample (Figure 2a) was ground using a mini grinder (Figure 2b), then 100 ml of petroleum ether was measured using a measuring cylinder (Figure 2c) into a round bottom flask. The source material containing the compound to be extracted was placed inside the thimble, which was loaded into the main chamber of the Soxhlet extractor and then placed under a heating source (Figure 2d). Here, a reflux condenser was placed atop of the extractor chamber connected with the inlet and outlet water supply. The extracted oil is shown in (Figure 2e).

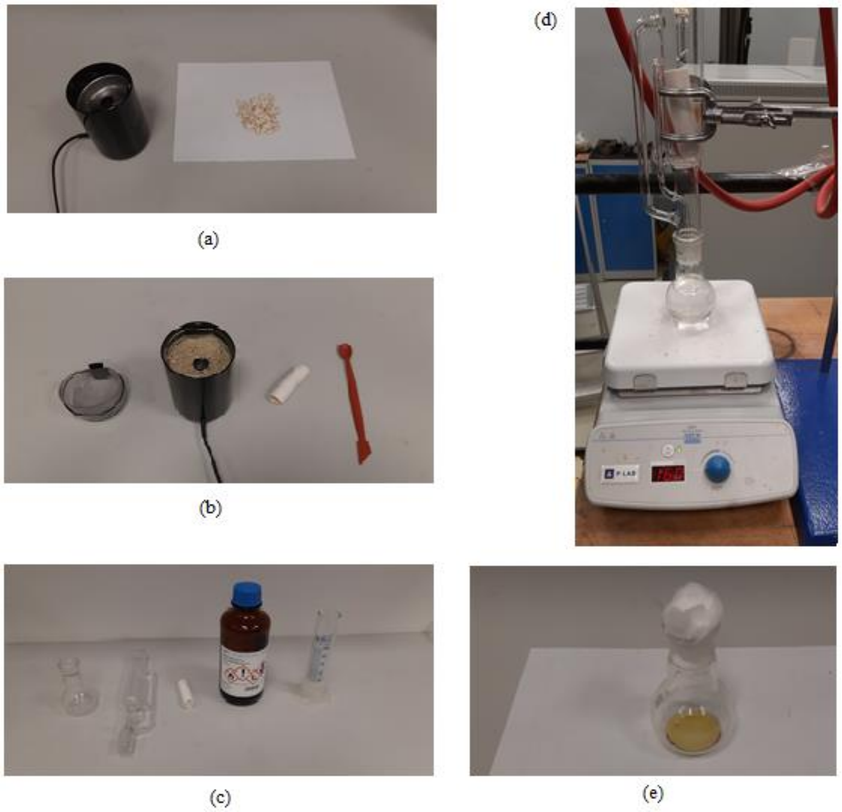


Figure 2. Oil content determination: (a) Sample of pumpkin seeds (b) sample crushed in a grinder (c) solvent and thimble among other devices (d) Soxhlet arrangement under a heat source and (e) extracted pumpkin seeds oil.

3.5 Calculation of percentage oil content

The percentage oil content of the selected oilseeds was calculated based on Eq. (8) (Danlami et al., 2015).

$$OC\ (\%) = \frac{m_O}{m_S} \cdot 100 \qquad \text{Eq. 8}$$

where, OC is the percentage oil content in seeds (%), m_O is the mass oil extracted (g) and m_S is the mass of a sample of seeds (g). The obtained results are given in Tables 1 to 5.

Table 1. Determination of percentage oil content in pumpkin seeds at 6 and 8 hrs cycle.

Test 1 (6 hrs)	**Weight (g)**	**Test 1 (8 hrs)**	**Weight (g)**
Thimble (*T*)	1.9207	Thimble (*T*)	3.484
Sample (*S*) + (*T*)	7.7833	Sample (*S*) + (*T*)	9.5166
S	5.8626	*S*	6.0326
Round-bottom flask (*F*)	61.3902	Round-bottom flask (*F*)	66.6156
F + Oil (*O*)	63.3618	*F* + Oil (*O*)	68.6934
O	1.9716	*O*	2.0778
Oil content (%)	**33.6301**	Oil content (%)	**34.4429**

Table 2. Determination of percentage oil content in pumpkin seeds at 10 and 12 hrs cycle.

Test 1 (10 hrs)	**Weight (g)**	**Test 1 (12 hrs)**	**Weight (g)**
Thimble (*T*)	3.3851	Thimble (*T*)	3.3942
Sample (*S*) + (*T*)	9.4394	Sample (*S*) + (*T*)	9.3979
S	6.0543	*S*	6.0037
Round-bottom flask (*F*)	66.6056	Round-bottom flask (*F*)	66.6063
F + Oil (*O*)	68.6914	*F* + Oil (*O*)	68.5035
O	2.0858	*O*	1.8972
Oil content (%)	**34.4515**	Oil content (%)	**31.6005**

Table 3. Determination of percentage oil content in pumpkin seeds at 18 and 24 hrs cycle.

Test 1 (18 hrs)	**Weight (g)**	**Test 1 (24 hrs)**	**Weight (g)**
Thimble (*T*)	3.294	Thimble (*T*)	3.113
Sample (*S*) + (*T*)	9.3221	Sample (*S*) + (*T*)	9.144
S	6.0281	*S*	6.031
Round-bottom flask (*F*)	66.6063	Round-bottom flask (*F*)	66.6016
F + Oil (*O*)	68.6634	*F* + Oil (*O*)	68.9136
O	2.0571	*O*	2.312
Oil content (%)	**34.1252**	Oil content (%)	**38.3353**

Table 4. Determination of percentage oil content in rapeseeds at 6 hrs cycle.

Test 1 (6 hrs) Rapeseeds	**Weight (g)**	**Test 2 (6 hrs) Rapeseeds**	**Weight (g)**
Thimble (*T*)	3.1571	Thimble (*T*)	3.1571
Sample (*S*) + (*T*)	12.129	Sample (*S*) + (*T*)	12.1976
S	8.9719	*S*	9.0405
Round-bottom flask (*F*)	61.3902	Round-bottom flask (*F*)	59.7262
F + Oil (*O*)	64.4023	*F* + Oil (*O*)	62.4539
O	3.0121	*O*	2.7277
Oil content (%)	**33.5726**	Oil content (%)	**30.172**
Mean ± SD: 31.87 ± 2.40			

Chui 2020

Table 5. Determination of percentage oil content in sunflower seeds at 6 hrs cycle.

Test 1 (6 hrs) Rapeseeds	**Weight (g)**	**Test 2 (6 hrs) Rapeseeds**	**Weight (g)**
Thimble (*T*)	3.3446	Thimble (*T*)	3.1571
Sample (*S*) + (*T*)	11.3048	Sample (*S*) + (*T*)	11.3065
S	7.9602	*S*	8.1494
Round-bottom flask (*F*)	61.3876	Round-bottom flask (*F*)	61.3902
F + Oil (*O*)	63.9752	*F* + Oil (*O*)	64.1394
O	2.5876	*O*	2.7492
Oil content (%)	**32.50672**	Oil content (%)	**33.735**
Mean ± SD: 33.12 ± 0.87			

Chui 2020

3.6 Compression process of selected oilseeds at laboratory temperature

The samples of the selected oilseeds (Figures 3 to 5) were used for the compression tests. The samples were measured at 80 mm pressing height using the vessel diameter of 100 mm with a plunger (Figure 6). The universal compression testing machine (ZDM 50, Czech Republic) (Figure 6) was used to record the force-deformation curves of the selected oilseeds under a speed of 5 mm/min and force of 400 kN.

Figure 3. Pumpkin seeds before compression (a) and after compression process (b) for recovering the oil.

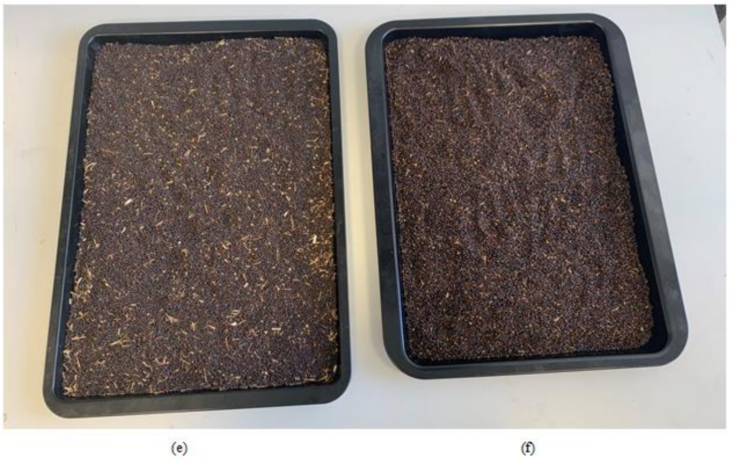


Figure 4. Rapeseeds before compression (c) and after compression process (d) for recovering the oil.


(c) (d)

Figure 5. Sunflower seeds before compression (c) and after compression process (d) for recovering the oil.


(a) (b)

Figure 6. (a) compression process and (b) extracted oil of selected oilseeds.

3.7 Compressed oil under the uniaxial compression process

The extracted oils from the pumpkin seeds, rapeseeds and sunflower seeds are shown in Figure 7.

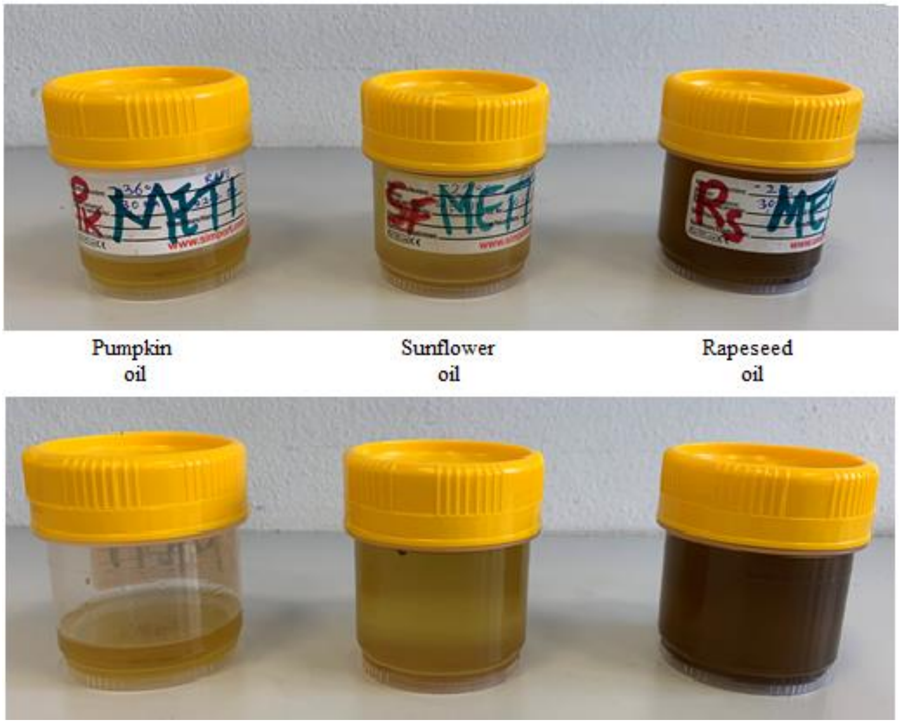


Figure 7. Extracted oil from selected oilseeds at laboratory temperature.

3.7.1 Oil yield (%)

The oil yield was calculated using Eq. 9 given (Deli et al., 2011) as follows

$$OY\ (\%) = \left(\frac{m_O}{m_S} \cdot 100\right) \qquad \text{Eq. 9}$$

where OY is the percentage oil yield (%), m_O is the mass of oil obtained as the difference of mass of seeds and initial mass of the sample m_S (g).

3.7.2 Oil expression efficiency (%)

The oil expression efficiency was calculated using Eq. (10) (Hernandez-Santos et al., (2016)) as follows:

$$OEE\ (\%) = \left(\frac{OY}{O_S} \cdot 100\right) \qquad \text{Eq. 10}$$

where OEE is the oil expression efficiency (%) and O_S is percentage of oil content (%) in the selected oilseeds samples determined by Soxhlet extraction.

3.7.3 Deformation energy

The deformation energy which is characterized by the area under the force-deformation curve (Gupta and Das 2000) was calculated using Eq. (11) (Demirel et al., 2017).

$$DE = \sum_{n=0}^{n=i-1} \left[\left(\frac{F_{n+1} + F_n}{2} \right) \cdot (x_{n+1} - x_n) \right] \qquad \text{Eq. 11}$$

where DE is the deformation energy (J), $F_{n+1} + F_n$ and $x_{n+1} - x_n$ are the compressive force (kN) and deformation (mm), *n* is the number of data points and *i* is the number of sections in which the axis deformation was divided.

4 RESULTS AND DISCUSSION

4.1. Significance of oil point identification in oilseed expression

Oil point is the point where the pressure sensor is observed firstly. This oil point indicates the beginning pressure at which the oil has emerged from the seed during the mechanical oilseed expression. This is theoretically related to the seed density of an oilseed by determining its evaluation from its bulk properties of a seed. The significance of this oil point in the oil expression measurement permits the validation of this hypothesis of oil point where the density of the bed approaches the seed density. It was found that the oilseed expression can be characterized objectively by using the compression at the oil point. It was determined that the ratio of maximum pressure was applied to positively correlate it with the oilseed content (Faborode and Favier, 1996).

4.2. Moisture content of selected oilseeds

The moisture content of the selected oilseeds at 17 hrs and 24 hrs are given in Tables 6 and 7. At 17 hrs oven drying, pumpkin seeds had a higher moisture content of 6.16 ± 0.07 (% w.b.) followed by rapeseeds of 5.04 ± 0.11 (% w.b.) and then sunflower seeds of 4.73 ± 0.06 (% w.b.). A similar trend was observed at 24 hrs oven drying (Table 7). The relationship of percentage moisture content and type of oilseeds at 17 hr and 24 hr oven drying is illustrated in Figures 8 and 9. According to Singh et al., (2002), the seed moisture content is the most important factor affecting the residual oil content in seed/press cake. The authors reported a 6 (% d.b.) moisture content of sunflower seed as the optimal for hydraulic pressing. The authors also mentioned that the screw pressing of crambe seed showed a decreased residual oil content as seed moisture content decreased. Furthermore, the authors explained that higher moisture content increases plasticity which reduces the level of compression resulting in low oil recovery. Hoffmann (1989) and Reuber (1992) cited in Sing et al., (2002) indicated that lower moisture content of seeds increases friction whereas higher moisture content acts as a lubricant during pressing. Increased friction, however, results in mechanical heating of the oil thus affecting the oil quality.

Table 6. Determination of moisture content of selected oilseeds at 17 hours.

***Selected oilseeds**	**Mass before drying, m_i(g)**	**Mass before drying, m_e (g)**	**Moisture content, MC (% w.b.)**	**Moisture content, MC (% d.b.)**
Pumpkin	11.65 ± 0.75	10.98 ± 0.71	5.80 ± 0.07	6.16 ± 0.07
Rape	15.54 ± 0.15	14.79 ± 0.16	4.81 ± 0.09	5.04 ± 0.11
Sunflower	12.41 ± 0.18	11.84 ± 0.16	4.52 ± 0.05	4.73 ± 0.06

* Laboratory temperature of 23.1 C° and humidity of 20 %; wet basis (w.b); dry basis (d.b.).

Table 7. Determination of moisture content of selected oilseeds at 24 hours.

***Selected oilseeds**	**Mass before drying, m_i(g)**	**Mass before drying, m_e (g)**	**Moisture content, MC (% w.b.)**	**Moisture content, MC (% d.b.)**
Pumpkin	11.65 ± 0.75	10.96 ± 0.70	5.97 ± 0.04	6.35 ± 0.05
Rape	15.54 ± 0.15	14.76 ± 0.15	5.03 ± 0.05	5.29 ± 0.05
Sunflower	12.41 ± 0.18	11.83 ± 0.17	4.56 ± 0.01	4.78 ± 0.01

* Laboratory temperature of 23.1 C° and humidity of 20 %; wet basis (w.b); dry basis (d.b.).

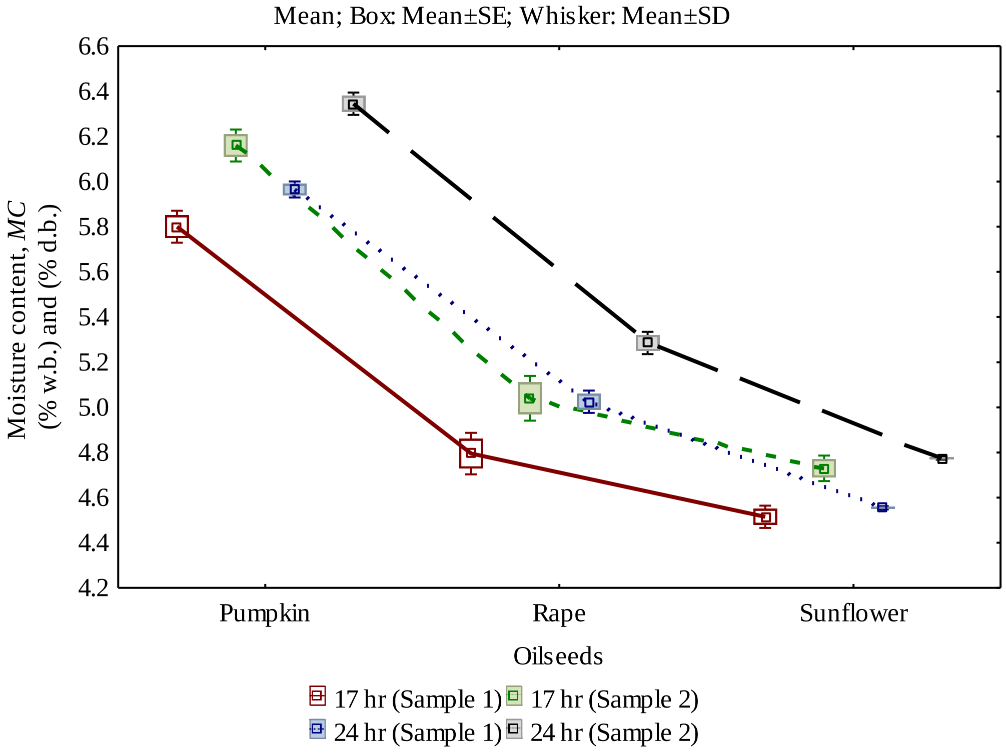


Figure 8. Moisture content of selected oilseeds in wet and dry bases for 17 hr and 24 hr.

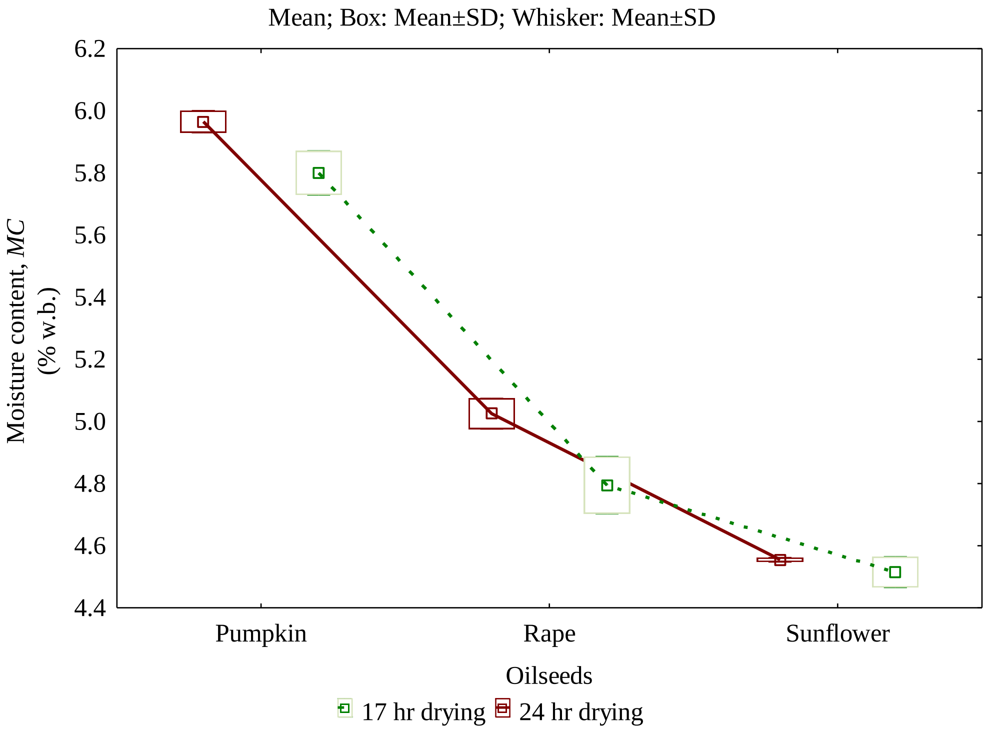


Figure 9. Comparison between moisture content of selected oilseeds and drying time.

4.3. Percentage oil content of selected oilseeds

The percentage oil content of pumpkin seeds at 6 hrs was 33.63% which increased at 8 hrs to 34.44% and further increased to 34.45% at 10 hrs but decreased at 12 hrs to 31.60%. The mean percentage oil content was 33.53±1.34%. On the other hand, the oil content was 34.13% at 18 hrs and 38.34% at 24 hrs. The mean percentage oil content at 6 hrs interval was 34.43±2.83%. The results are given in Table 8 and graphically represented in Figures 8 to 14. Due to the shortage of solvent, the procedure used for pumpkin seeds could not be used for rapeseeds and sunflower seeds. Therefore, in the literature (Chui 2020), it was reported the percentage oil content of rapeseeds of 31.87 ± 2.40% and sunflower seeds of 33.12 ± 0.87% at 6 hrs cycle. These values were lower compared to pumpkin seeds at 6 hrs reflux. Based on the results of pumpkin seeds oil content, it is better to use 8 hrs or 10 hrs reflux cycle than 6 hrs. But the 24 hrs reflux cycle produced the highest percentage oil content. Soxhlet extraction with organic solvents is a commonly used method for determining the oil content and recovering the residual oil from the seedcake after mechanical cold pressing of oilseeds (Popescu et al., 2017; Garcia-Ayuso., 2000).

Table 8. Average values of percentage oil content of pumpkin seeds on time basis.

Time (hrs)	**Oil content (%)**	**Time (hrs)**	**Oil content (%)**
6	33.63	6	33.63
8	34.44	12	31.60
10	34.45	18	34.13
12	31.60	24	38.34
Mean ± SD	***33.53 ± 1.34***	Mean ± SD	**34.43 ± 2.83**

SD: Standard Deviation

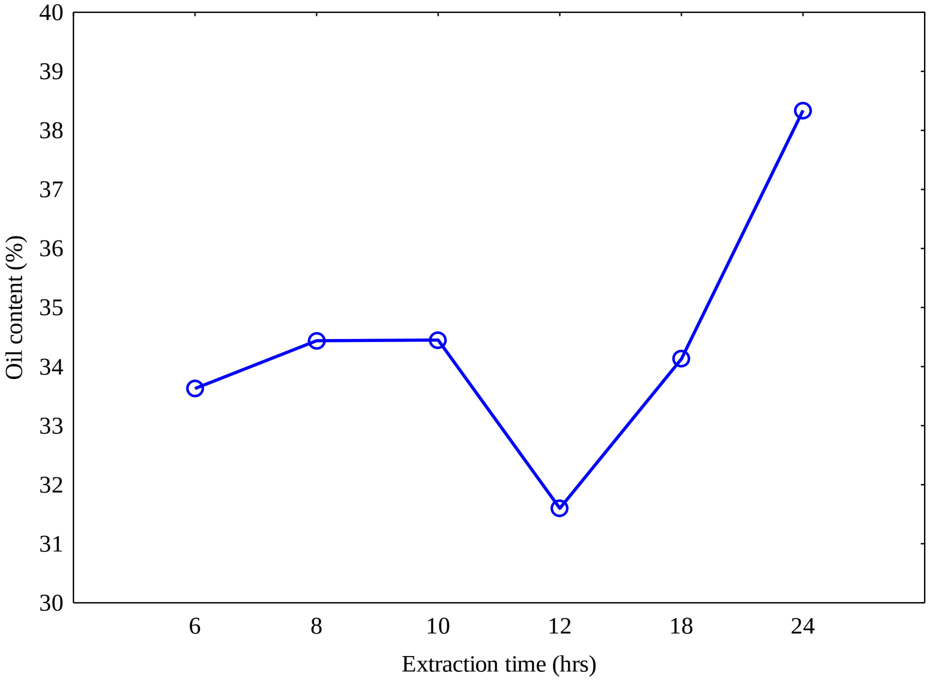


Figure 10. Percentage oil content in pumpkin seeds in relation to time.

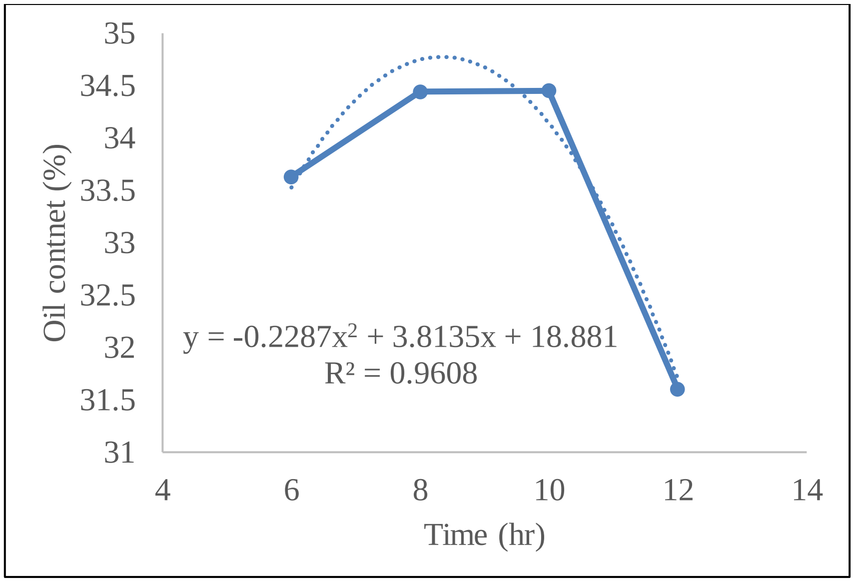


Figure 11. Percentage oil content in pumpkin seeds in relation to time from 6 to 12 hrs.

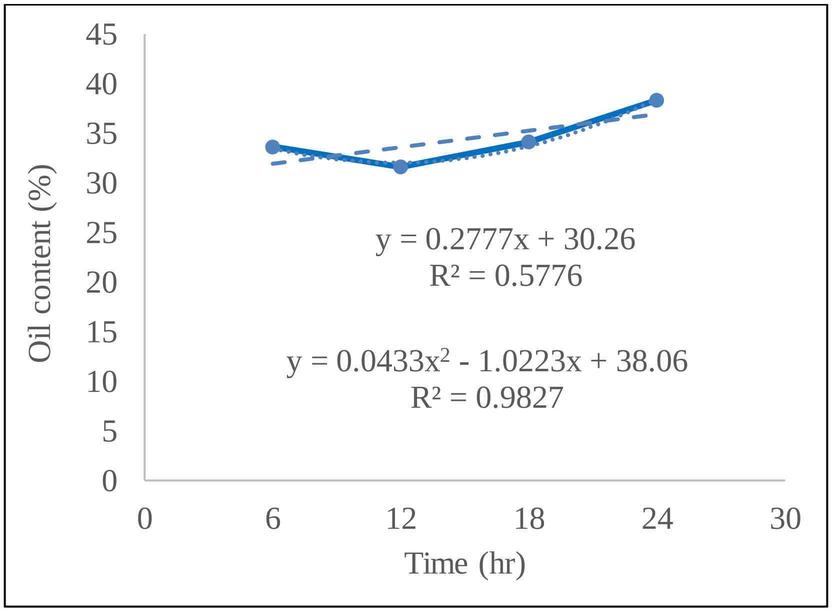


Figure 12. Percentage oil content in pumpkin seeds in relation to time from 6 to 24 hrs.

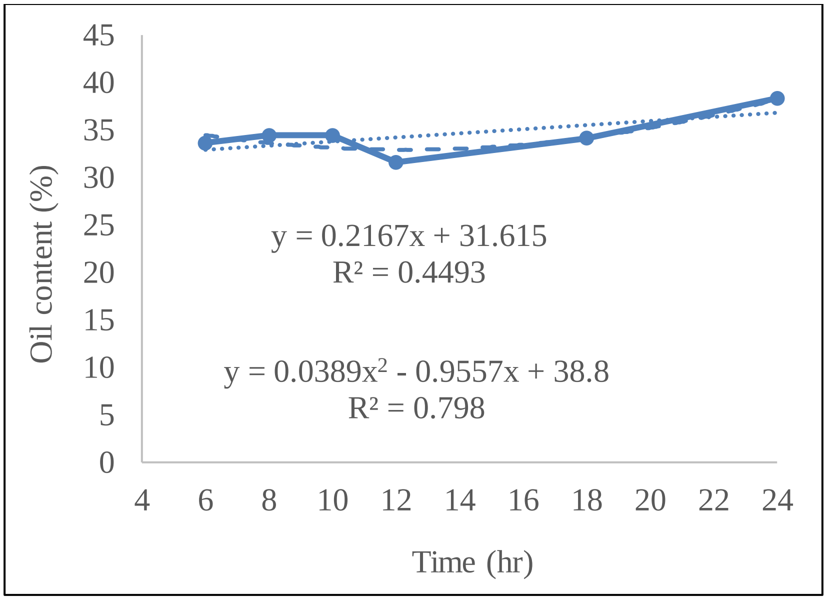


Figure 13. Overall percentage oil content in pumpkin seeds in relation to time from 6 to 24 hrs.

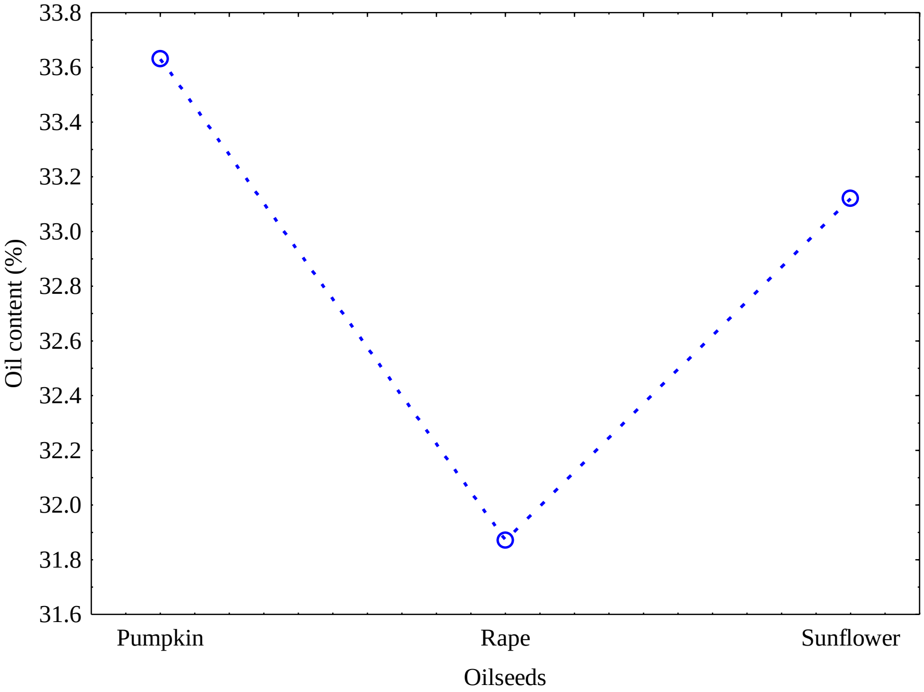


Figure 14. Comparison of percentage oil content of selected oilseeds at 6 hrs.

4.4. Force-determination curves of selected oilseeds

The force-deformation curves of pumpkin, rape and sunflower seeds are shown in Figure 15. The area under the curve is the deformation energy (Demirel et al., 2017). All the curves depicted a smooth curve behaviour without the serration effect which indicated that the maximum oil output was recovered. Divisova et al., 2014 indicated that the pressing vessel diameter, force, speed and moisture content affect the behaviour of the force-deformation curves of oil-bearing crops seeds.

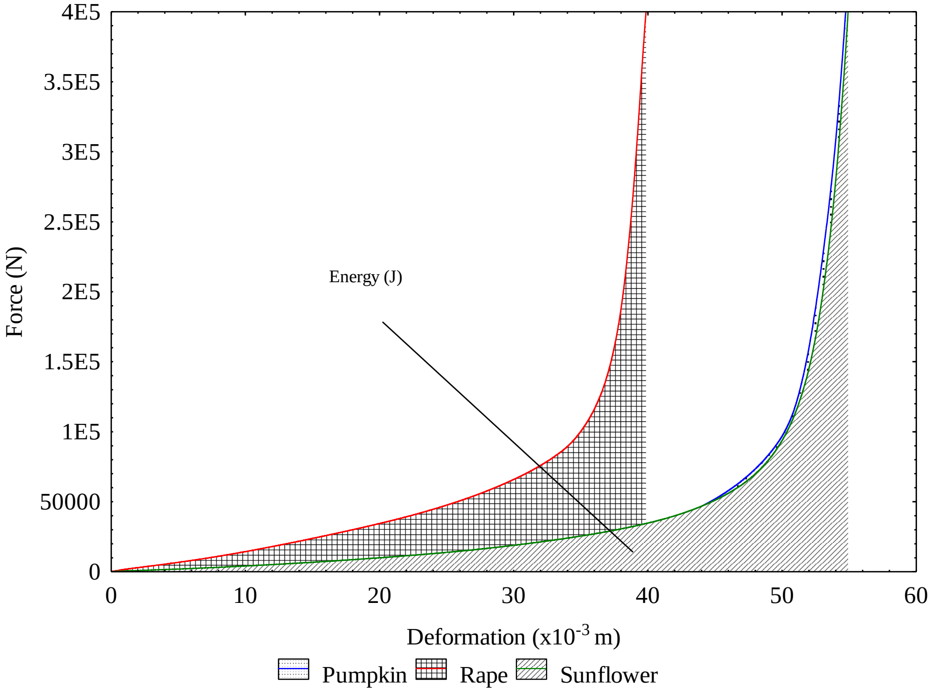


Figure 15. Force-deformation curves of selected oilseeds for oi extraction showing the energy characterized by the area under the curve.

4.5. Calculated parameters of selected oilseeds under uniaxial compression process

Based on the initial masses of the selected oilseeds and masses of the seedcake as well as the percentage oil content in the seeds, the mass of oil, oil yield and oil expression efficiency were calculated as given in Table 9 and graphically displayed in Figures 16 and 17. With the same force of 400 kN, speed of 5 mm/min and pressing height of 80 mm using the vessel diameter of 100 mm; the mass of oil, oil yield and oil expression efficiency of sunflower seeds were the highest followed by rapeseeds and then pumpkin seeds. However, rapeseeds used higher energy than sunflower seeds. Therefore, in terms of energy usage and oil recovery efficiency, it was found that it is economically viable to press sunflower and rapeseeds than pumpkin seeds. It is however important to indicate that from the input pressing parameters already mentioned, the pressure was calculated to be 50.93 MPa. Karaj and Muller, (2011) indicated that for the optimization of oil recovery, pressure is the most interesting variable to monitor because higher pressure will lead to a higher temperature and which could affect the quality of the oil. Beerens (2007) cited in Deli et al., (2011) also indicated that higher speed will lead to lower oil yield due to less residence time for the oil to flow from between the seeds.

Table 9. Calculated parameters of selected oilseeds from uniaxial compression process by applying a maximum force of 400 kN and speed of 5 mm/min.

***Selected oilseeds**	****Initial mass of sample (g)**	**Mass of seedcake (g)**	**Mass of oil (g)**	**Oil yield (%)**	**Oil expression efficiency (%)**	**Deformation (mm)**	**Deformation energy (J)**
Pumpkin	265	246.97 ± 0.71	18.04 ± 0.71	6.81 ± 0.27	20.31 ± 0.80	54.38 ± 0.51	1858.42 ± 0.27
Rape	415.28	371.56 ± 1.81	43.72 ± 1.81	10.53 ± 0.44	33.03 ± 1.36	39.94 ±0.09	2143.51 ± 35.98
Sunflower	292.06	246.85 ± 0.71	45.21 ± 0.71	15.48 ± 0.24	46.74 ± 0.73	56.02 ± 1.56	2010 .79 ± 40.47

* Laboratory temperature of 23.1 ^{o}C and humidity of 20 %; **At a pressing height of 80 mm using a vessel diameter of 100 mm with a plunger.

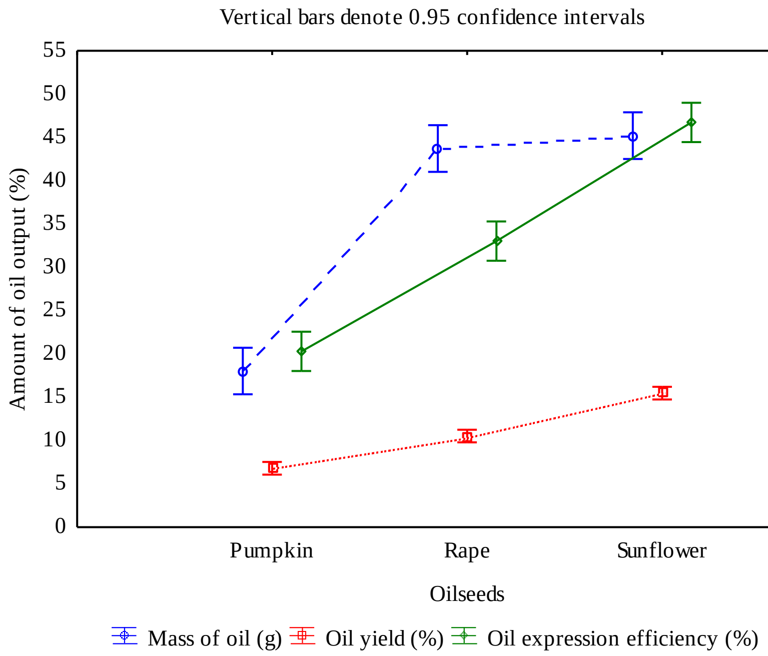


Figure 16. Percentage amount of oil output from selected oilseeds under uniaxial compression process.

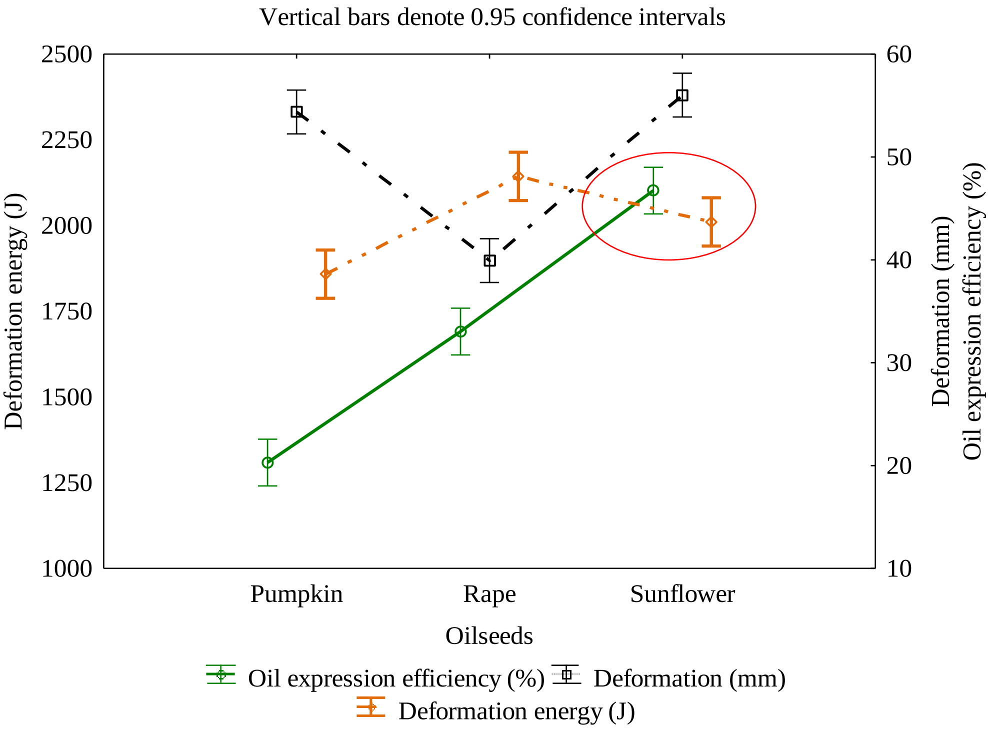


Figure 17. Deformation energy, deformation, and oil expression efficiency of selected oilseeds under uniaxial compression process.

5. CONCLUSIONS

i. The knowledge of oil point and the estimation of the oil point parameters are relevant for analyzing the design and performance of oil expression equipment.

ii. The moisture content at 24 hr oven pre-treatment of pumpkin, rape and sunflower oilseeds was determined to be 6.35 ± 0.05, 5.29 ± 0.05 and 4.78 ± 0.01 (% w.b.).

iii. The percentage oil content of pumpkin seeds at 24 hr cycle of the Soxhlet extraction procedure was determined to be 38.34%. However, between 6 and 12 hrs cycle with 2 hrs interval, the mean percentage oil content was 33.53 ± 1.34%. Again, between 6 and 24 hrs with 6 hrs interval the mean percentage oil content was 34.43 ± 2.83%.

iv. Sunflower seeds produced the highest oil expression efficiency of 46.74 ± 0.73% followed by rapeseeds (33.03 ± 1.36 %) and then pumpkin seeds (20.31 ± 0.80 %).

v. The deformation energy of rapeseeds (2143.51 ± 35.98 J) was higher than that of sunflower (2010.79 ± 40.47 J) and pumpkin seeds (1858.42 ± 0.27 J).

vi. In terms of energy usage and oil recovery efficiency, it is economically viable to press sunflower and rapeseeds than pumpkin seeds.

vii. At force 400 kN, speed 5 mm/min and pressing height of 80 mm with the vessel diameter of 100 mm, the force-deformation curves showed a smooth curve behaviour without the serration effect indicating that the maximum oil of the selected oilseeds was recovered.

6. RECOMMENDATIONS

i. The determination of oil content in rapeseeds and sunflower seeds among others at different extraction cycles or duration between 6 and 24 hrs should be carried out to determine the suitable extraction time to save cost in terms of solvent use and energy (water usage). The results should be compared with pumpkin seeds oil content.
ii. The used solvent from the Soxhlet extraction procedure should also be reused to compare the results of the unused solvent for the same oilseeds to minimize cost and energy.
iii. The relaxation process after the compression process should also be considered to recover the residual oil in the seedcake.
iv. The selected oilseeds studied here among others should be processed using the Farmet Duo screw press (laboratory scale) to understand the percentage oil expression and the residual oil in the seedcake based on different processing factors such as pressure, rotation speed and the press components (nozzles, pitch diameter of screw shaft, and cylinders with mesh sizes).

7. REFERENCES

1. Abdelaziz A.I.M., Elamin I.H.M., Gasmelseed G.A., Abdalla B.K. 2014. Extraction, refining and characterization of Sudanese castor seed oil. *Journal of Chemical Engineering*, *2*(1), 1–4.
2. Adeeko K.A., Ajibola O.O. 1990. Processing factors affecting yield and quality of mechanically expressed groundnut oil. *Journal Agricultural Engineering Research*, 45, 31–43
3. Ahmad, J., A. Bokhari, S. Yusup, 2014a. Optimization and parametric study of free fatty acid (FFA) reduction from rubber seed oil (RSO) by using response surface methodology (RSM). *Australian Journal of Basic and Applied Sciences*, 8(5): 299- 303.
4. Ahmad, J., Yusup, S., Bokhari, A. and Kamil, R.N.M., 2014b. Study of fuel properties of rubber seed oil-based biodiesel. *Energy Conversion and Management*, *78*, pp.266-275.
5. Ajibola O.O., Adetunji S.O., Owolarafe O.K. (2000). Oil point pressure of sesame seeds. *IFE Journal of Technology*, 9, 57–62
6. Ajibola O.O., Owolarafe O.K., Fasina O.O., Adeeko K.A. 1993. Expression of oil from sesame seeds. *Can. Agric. Eng.* 35, 83–88
7. Akpan, U.G., Jimoh, A. and Mohammed, A.D. 2006. Extraction, characterization, and modification of castor seed oil. *Leonardo Journal of Sciences*, *8*, 43-52.
8. Ali, F.M., Ali, B.E., and Speight, J.G. 2005. Handbook of Industrial Chemistry: Organic Chemicals. *McGraw-Hill Education, USA.*
9. Alonge, A.F. and Olaniyan, A.M. 2006. The effect of dilution volume, water temperature and pressing time on oil yield from Thevetia kernel during extraction. *Agricultural Mechanization in Asia, Africa, and Latin America, 37(2)*, 79-83.
10. Amarni, F. and Kadi, H. 2009. Kinetics study of microwave-assisted solvent extraction of oil from olive cake using hexane: comparison with the conventional extraction. *International Food Science and Emerging Technologies, 11*, 322-327
11. Aregbesola, O.A., Olatunde, G.A., Esuola, S.S. and Owolarafe, O.K., 2012. Oil point pressure of Indian almond kernels. *International Agrophysics*, *26*(3).

12. Azadmard-Damirchi, S., Alireza, K. and Achelous, B.F. 2011. Microwave pretreatment of seeds to extract high quality vegetable oil. *International Journal of Nutrition and Food Engineering, 5(9),* 508-511.
13. Balasubramanian, S., Allen, J.D., Kanitkar, A. And Boldor, D. 2010. Oil extraction from Scenedesmus obliquus using a continuous microwave system design, optimization and quality characterization. *Bioresource Technology, 102*, 3396-3403.
14. Bamgboye, A. and Adejumo A., Development of a sunflower oil expeller", Agricultural Engineering International: the CIGR Ejournal. Manuscript EE 06 015, vol IX, September 2007.
15. Bampouli, A., Kyriakopoulou, K., Papaefstathiou, G., Louli, V., Krokida, M. and Magoulas, K., 2014. Comparison of different extraction methods of Pistacia lentiscus var. chia leaves: Yield, antioxidant activity and essential oil chemical composition. *Journal of Applied Research on Medicinal and Aromatic Plants, 1*(3), pp.81-91.
16. Banu C., "Manualul inginerului din industria alimentară", vol. I şi II, Editura Tehnică, Bucureşti, 1999.
17. Bargale, P.C., 1997. Mechanical oil expression from selected oilseeds under uniaxial compression, Ph.D. dissertation, University of Saskatchewan Saskatoon, 310 pp.
18. Beerens, P. (2007). Screw-pressing of Jatropha seeds for fuelling purposes in less developed countries. Eindhoven, Netherlands: Eindhoven University of Technology, MSc thesis.
19. Bhatol, K. 2013. Castor oil obtained by cold press method. Shri Bhagwati Oil Mill (SBOM) manufacturer's Info., Banaskantha
20. Bhuiya, M.M.K., Rasul, M.G., Khan, M.M.K; Ashwath, N; Azad, A.K. and Mofijur, M. 2015. Optimization of oil extraction process from Australian Native Beauty Leaf Seed. (Calophyllum innophyllum). 7th International Conference on Applied Energy-ICAE2015. Energy Procedia, 75, 56-61.
21. Blahovec, J. 2008. *Agromatereials Study Guide*; Czech University of Life Sciences Prague: Prague, Czech Republic.
22. Bokhari, A., Chuah, L.F., Suzana, Y. and Azis, H., 2015. Kapok seed oil extraction using Soxhlet extraction method: Optimization and parametric study. *Australian Journal of Basic and Applied Sciences*, *9*(37), pp.429-431.

23. Buenrostro, M. And Lopez-Munguia, C. 1986. Enzymatic extraction of avocado oil. Biotechnology Letters, 8, 505-506.
24. Chemat, S., Lagha, A., AitAmar, H. And Chemat, F. 2003. Combined ultrasound and microwave-assisted extraction of essential oil from caraway seeds, in Conf. Rec. 2003 Application of Power Ultrasound in Physical and Chemical Processing, Besancon, France, 349-353.
25. Chuah, L.F., Yusup, S., Abd Aziz, A.R., Bokhari, A., Klemeš, J.J. and Abdullah, M.Z., 2015. Intensification of biodiesel synthesis from waste cooking oil (palm olein) in a hydrodynamic cavitation reactor: effect of operating parameters on methyl ester conversion. *Chemical Engineering and Processing: Process Intensification*, *95*, pp. 235-240.
26. Chui, Y.M. 2020. Effects of speed and heat-treatment temperature on mechanical behavior of sunflower and rape bulk oilseeds under compression loading, Diploma Thesis, Faculty of Engineering, Department of Mechanical Engineering, Czech University of Life Sciences Prague, p.1-85.
27. Danlami, J.M., Arsad, A., Zaini, M.A.A. 2015. Characterization and process optimization of castor oil (Ricinus communis L.) extracted by the Soxhlet method using polar and non-polar solvents. *Journal of the Taiwan Institute of Chemical Engineers,47*, 99-104.
28. Dawidowichz, A.L. Rado, E., Wianowska, D., Mardarowicz, M. And Gawdzik, J. (2008). Application of PLE for the determination of essential oil components from Thymus vulgaris L. Talanta, 76, 878-884.
29. Dedio W, Dornell DG (1977) Factor affecting the pressure extraction of oil from flaxseed. J Am Oil Chem Soc 54(8), 313–320.
30. Del Valle, J.M. and Aguilera, J.M. 1999. Extraction con CO_2 a attar presion. Fundamentosy aplicaciomes el na industria de alimentos. *Food Science and Technology International*. 5, 1-24
31. Deli, S., Farah, M.M., Tajul, A.Y., Wan N.W.A.2011). The effects of physical parameters of the screw press oil expeller on oil yield from Nigella sativa L seeds. International Food Research Journal, 18(4), 1367-1373.

32. Demirel, C., Kabutey, A., Herak, D., Gurdil, G.A.K. 2017. Numerical estimation of deformation energy of selected bulk oilseeds in compression loading. *IOP Conference Series, Material Science and Engininneering,*237, 1–5.
33. Divisova, M., Herak, D., Kabutey, A., Sleger, V., Sigalingging, R., Svatonova, T. 2014. Deformation curve characteristics of rapeseeds and sunflower seeds under compression loading. *Scientia Agriculturae Bohemica*, 45(3), 180-186.
34. Dutta, R., Sarkar, U., and Mukherjee, A. 2015. Soxhlet extraction of Crotalaria juncea oil using cylindrical and annular packed beds. *International Journal of Chemical Engineering and Applications, 6(2)*, 130-133
35. Faborode, M., & Favier, J. F. 1996. Identification and significance of the oil-point in seed-oil expression. *Journal of Agricultural Engineering Research*, 65(4), 335-345.
36. Farabode M.O., Favier J.F., 1997. New insight into the mechanics of seed oil expression. *Journal of Agricultural Engineering Research.* 5:9–24
37. Fasino, O. O., & Ajibola, O. O. (1990). Development of equations for the yield of oil expressed from conophor nut. *Journal of Agricultural Engineering Research*, *46*, 45-53.
38. Faugno, S., del Piano, L., Crimaldi, M., Ricciardiello, G. and Sannino, M., 2016. Mechanical oil extraction of Nicotiana tabacum L. seeds: analysis of main extraction parameters on oil yield. *Journal of Agricultural Engineering*, *47*(3), pp.142-147.
39. García-Ayuso, L. E., Velasco, J., Dobarganes, M. C., Castro, L. M. D. 2000. Determination of the oil content of seeds by focused microwave-assisted Soxhlet extraction. Chromatographia, 52, 103–108.
40. Gibbins, R.D., Aksoy, H.A. and Ustun, G. 2012. Enzyme-assisted aqueous extraction of safflower oil: optimization by response surface methodology. International Journal of Food Science and Technology, 47(5):1055 -1062.
41. Gupta, R. and Das, S. (1997). Physical Properties of Sunflower Seeds. Journal of Agricultural.
42. Herak, D., Gurdil, G., Sedlacek, A., Dajbych, O., & Simanjuntak, S. 2010. Energy demands for pressing Jatropha curcas L. seeds. *Biosystems Engineering, 106(4)*, 527-534.
43. Herak, D., Kabutey, A., Sedláček, A. and Gűrdil, G., 2012. Mechanical behaviour of several layers of selected plant seeds under compression loading. Research in Agricultural Engineering, 58(1), pp.24-29.

44. Hernandez-Santos, B., Rodriguez-Miranda, J., Herman-Lara, E., Torruco-Uco, J.G., Carmona-Garcia, R., Juarez-Barrientos, J.M., Chavez-Zamudio, R., Martinez-Sanchez, C.E. Effect of oil extraction assisted by ultrasound on the physiochemical properties and fatty acid profile of pumpkin seed oil (Cucurbita pepo). Ultrasound Sonochem. 2016, 31, 429–436.
45. Hoffmann, G. 1989. The Chemistry and Technology of Edible Oils and Fats and Their High-Fat Products, Academic Press, New York, pp. 63-68.
46. Ikya, J.K., Umenger, L.N. and Iorbee, A. 2013. Effects of extraction methods on the yield and quality characteristics of oils from shea nut. *Journal of Food Resource Science, 2*, 1-12.
47. International Petroleum Standard Test Methods. IP 346: Determination of Polycyclic Aromatics in Unused Lubricating Base Oils and Asphaltene Free Petroleum Fractions Dimethyl Sulphoxide Extraction Refractive Index Method. London, England: Energy Institute; 1992.
48. Kabutey, A., Herak, D., & Hanus, J. 2010. Screw press performance for oil extraction from Jatropha curcas L. seeds of different moisture content. *Scientia Agriculturae Bohemica, 41(4)*, 225-230.
49. Karaj, S., & Muller, J. 2011. Optimizing mechanical oil extraction of Jatropha carcass L. seeds with respect to press capacity, oil recovery and energy efficiency. *Industrial Crops and Products, 34*, 1010-1016.
50. Karaj, S., Muller, J. 2011. Optimizing mechanical oil extraction of *Jatropha curcas* L. seeds with respect to press capacity, oil recovery and energy efficiency. *Industrial Crops and Products*, 34, 1010-1016.
51. Kartika, A. I., Yuliani, S., Kailaku, S. I., & Rigal, L. 2012. Moisture sorption behavior of jatropha seed (Jatropha curcas) as a source of vegetable oil for biodiesel production. *Biomass and Bioenergy, 36*, 226-233.
52. Khan L.M., Hanaa M.A., 1983. Expression of oil from oilseeds - a review, *Journal of Agricultural Engineering Research*, 28, 495-503.
53. Kirk-Othmer Encyclopedia of Chemical Technology, vol. 5, John Wiley & Sons, New York (1979).

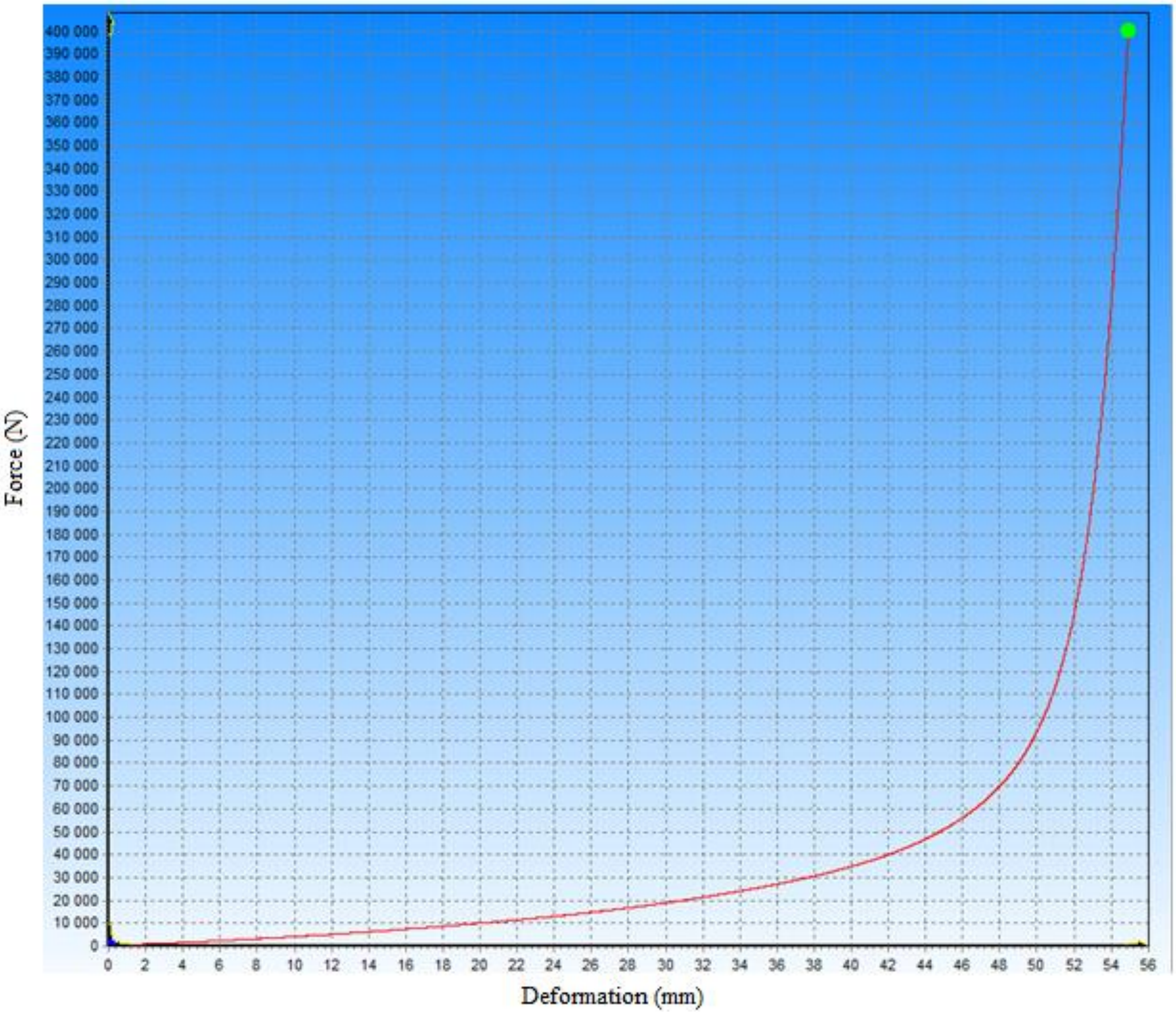
54. Kittiphoom, S. and Sutasinee, S., 2015. Effect of microwaves pretreatments on extraction yield and quality of mango seed kernel oil. *International Food Research Journal*, 22(3).
55. Kumar, A., & Sharma, S. (2008). An evaluation of multipurpose oil seed crop for industrial uses (Jatropha curcas L.): a review. Industrial Crops and Products, 28(1), 1-10.
56. Kumar, T.S., P.S. Kumar, K. Annamalai, 2015. Experimental study on the performance and emission measures of direct injection diesel engine with kapok methyl ester and its blends. Renewable Energy, 74: 903-909.
57. Li, H., Pordesimo, L. and Weiss, J., 2004. High intensity ultrasound-assisted extraction of oil from soybeans. *Food research international*, 37(7), pp.731-738.
58. Mgudu, L., Muzenda, E., Kabuba, J. And Belaid, M. 2012. Microwave assisted extraction of castor oil. *International Conference on Nanotechnology and Chemical Engineering* (ICNCS 2012), December 21-22, Bangkok, Thailand.
59. Moreno, A.O., Dorantes, L., Galindex, J. And Guzman, R.I. 2003. Effect of different extraction methods on fatty acids, volatile compounds and physical and chemical properties of avocado (Persia americana Mil) oil. *Journal of Agricultural and Food Chemistry*, 51, 2216-2221
60. Mrema, G. C., & Mc Nulty, P. B. 1985. Mathematical model of mechanical oil expression from oilseeds. *Journal of Agricultural Engineering Research, 31(4)*, 361-370.
61. Muzenda, E., Kabuba, J., Mdletye, P. And Belaid, M. 2012. Optimization of process parameters for castor oil production. Proceedings of the World Congress on Engineering 2012 Vol. III WCE 2012, July 4-6, 2012, London, U.K.
62. Mwithiga, G. and Moriasi, L. 2007. A study of yield characteristics during mechanical oil extraction of pretreated and ground soybeans. *Journal of Applied Sciences Research, 3(10)*: 1146-1151.
63. Norris F.A. 1964. Extraction of Fat and Oil. *Bailey's industrial Oil and Fat*. Wiley Press, New York
64. Ogunniyi, D.S. 2006. Castor Oil: a vital industrial raw material. *Bioresource Technology, 97*, 1086 – 1091.
65. Ogunshina B.S, Owolarafe O.K, Olatunde G.A. 2008. Oil point pressure of cashew (Anacardium occidentale) kernels. *International Agrophysics*, 22, 53–59

66. Olaniyan, A.M. 2010. Effect of extraction conditions on the yield and quality of oil from castor bean. *Journal of Cereals and Oilseeds*, 1, 24-33.
67. Olaniyan, A.M. and Yusuf, K.A. 2012. Mechanical oil expression from groundnut (Arachid hypigaea L) kernels using a spring-controlled hydraulic press. *Journal of Agricultural Research and Development, 11(2).*
68. Olatunde, G.A., Owolarafe, O.K. 2011. Effects of processing conditions on oil point pressure of neem seed. Proc Niger Inst. Agric. Eng. 32, 412– 420.
69. Oluwole, F.A., Aviara, N.A., Umar, B. And Mohammed, A.B. 2015. Influence of variety and pre-treatment on oil properties of mechanically expressed castor oil. *Global Advanced Research Journal of Engineering, Technology, and Innovation*.
70. Omobuwajo, T. O., Ige, M. T., & Ajayi, A. O. 1998. Theoretical prediction of extrusion pressure and oil flow rate during screw expeller processing of palm kernel seeds. *Journal of Food Engineering, 38(4),* 469-485.
71. Owolarafe, O.K., Adegunloye, A.T. and Ajibola, O.O., 2003. The Effects of some processing conditions on oil point pressure of locust bean. *Journal of food process engineering*, *26*(5), pp.489-497.
72. Oyinlola A, Adekoya, L.O. 2004. Development of a laboratory model screw press for peanut oil expression. *Journal of Food Engineering,* 221–227
73. Patel, V.R., Durmancas, G.G., Viswanath, L.C.K, Maples, R. and Subong, B.J.J. (2016). Castor oil: properties, uses and optimization of processing parameters in commercial production. Lipid Insights, 9, 1-12
74. Popescu, M., Avram, M.D., Oancea, F., Lupu, C., Cornea, C.P. 2017. Bioassisted azeotropic Soxhlet extraction of mustard oilseeds. Journal of Biotechnology, 256, Supplement, p. S101.
75. Pradhan, R. C., Mishra, S., Naik, S. N., Bhatnagar, N., & Vijay, V. K. 2011. Oil expression from Jatropha seeds using a screw press expeller. *Biosystems Engineering, 109*, 158-166.
76. Raji, A. O., & Favier, J. F. 2004. Model for the deformation in agricultural and food particulate materials under bulk compressive loading using discrete element method II: theory, compression of oilseeds. *Journal of Food Engineering, 64(3),* 373-380.

77. Ramanathan, B. 2005. Microwave extraction of essential oils (from black pepper and coriander at 2.46 Ghz. MSc. Thesis, *University of Saskatchewan*, Canada.
78. Rassem, H.H.A., Nour, A.H. and Yunus, R.M. 2016. Techniques for extraction of essential oils from plants: a review: *Australian Journal of Basic and Applied Sciences, 10(16)*, 117-127.
79. Rathbauer, J., Sonnleitner, A., Pirot, R., Zeller, R., & Bacovsky, D. 2012. Characterization of Jatropha curcas seeds and oil from Mali. *Biomass and Bioenergy, 47*, 201-210.
80. Reuber, M. 1992. New Technologies for Processing *Crambe abyssinica*, M.S. Thesis, Iowa State University, Ames.
81. Samaram, S., Mirhosseini, H., Tan, C.P. and Ghazali, H.M., 2014. Ultrasound-assisted extraction and solvent extraction of papaya seed oil: Crystallization and thermal behavior, saturation degree, color and oxidative stability. Industrial Crops and Products, 52, pp.702-708.
82. Sayyar, S., Abidin, Z. Z., Yunus, R., & Muhammad, A. 2009. Extraction of oil from Jatropha seeds-optimization and kinetics. *American Journal of Applied Sciences, 6(7)*, 1390-1395.
83. Shirato, M., Murase, T., Iwata, M., & Nakatsuka, S. 1986. The Terzaghi-Voight combined model for constant-pressure consolidation of filter cakes and homogeneous semi-solid materials. *Chemical Engineering Science, 41(12)*, 3213-3218.
84. Singh, K.K., Wiesenborn, D.P., Tostenson, K., Kangas, N. 2002. Influence of moisture content and cooking on screw pressing of crambe seed. Journal of the American Oil Chemists' Society, 79(2), 165-170.
85. Singh, R.P., and Heldman, D.R. 2001. *Introduction to Food Process Engineering*, 3rd edition, Academic Press, 30-47.
86. Singh, S. and Kulshreshtha, M., 1996. Mathematical modelling of juice expression from carrots under uniaxial compression. Journal of food engineering, 27(3), pp.323-336.
87. Sinha, L.K., Haddar, S. and Majumdar, G.C. 2015. Effect of operating parameter on mechanical expression of solvent-soaked soybean grits. *Journal of Food Science and Technology, 52(5)*, 2942-2949.

88. Sivala, K., Bhole, N.G., Mukherjee, R. 1991. Effect of moisture content on rice bran oil expression. *Journal of Agricultural Engineering Research, 42*,77–84
89. Statsoft Eletronic Statistics. "How to group objects into similar categories, cluster analysis." (2013).
90. Sukumaran, C.R., Singh, B. 1989. Compression of a bed of rapeseeds - the oil point. *Journal of Agricultural Engineering Research, 42*,77–88
91. Takadas, F. And Doker, O. 2017. Extraction method and solvent effect on safflower seed oil production. *Chemical and Process Engineering Research, 51*,9-17.
92. Tambunan, A. H., Situmorang, J. P., Silip, J. J., Joelianingsih, A., & Araki, T. 2012. Yield and physicochemical properties of mechanically extracted crude Jatropha curcas L. oil. *Biomass and Bioenergy, 43*, 12-17.
93. Tayde, S., Patnaik, M., Bhagt, S.L. and Renge, V.C. 2011. Epoxidation of vegetable oils: A review. *International Journal of Advanced Engineering Technology, II (IV)*, 491-501.
94. Tunde-Akintunde, T.Y., Akintude, B.O., Igbeka J.C., 2001. Effects of processing factors on yield and quality of mechanically expressed soya bean oil *Journal of Agricultural Engineering Technology 9* ,39 - 45.
95. Uquiche, E., Jerez, M. and Ortiz, J. 2008. Effect of treatment with microwaves on mechanical extraction yield and quality of vegetable oil from Chilean hazelnuts (Gevuina avellana Mol). *Innovative Food Science and Emerging Technologies, 9(4)*, 495 – 500.
96. Veldsink, J.W., Muuse, B.G., Meijer, M.M., Cuperus, F.P., van de Sande, R.L. and van Putte, K.P., 1999. Heat pretreatment of oilseeds: effect on oil quality. *Lipid/Fett, 101*(7), pp.244-248.
97. Yusuf, A.K., Mamza, P.A.P., Ahmed, A.S. and Agunwa, U. 2015. Extraction and characterization of castor seed oil from wild Ricinus communis L. *International Journal of Science, Environment and Technology, 4(5)*, 1392-1404.

8. APPENDIXES



Appendix 1. Experimental force-deformation curve of sunflower seeds as a representation of pumpkin and rape oilseeds.

Appendix 2. Calculation of the deformation energy characterized by the area under the force-deformation curve based on the trapezoidal rule.

Deformation, *X* (mm)	**Force, *F* (N)**	***a***	***b***	***a**b***
0	**0**	**$(X_2 - X_1)$**	**$((F_2 + F_1)/2)$**	
0.01	13	0.01	6.5	0.065
0.02	13	0.01	13	0.13
0.02	17.5	0	15.25	0
0.02	17.5	0	17.5	0
0.03	26	0.01	21.75	0.2175
0.03	26	0	26	0
0.03	21.5	0	23.75	0
0.03	34.5	0	28	0
0.04	34.5	0.01	34.5	0.345
0.04	34.5	0	34.5	0
0.04	34.5	0	34.5	0
0.04	43	0	38.75	0
0.05	39	0.01	41	0.41
0.05	47.5	0	43.25	0
0.05	52	0	49.75	0
0.06	39	0.01	45.5	0.455
..	..	..	..	..
..	..	..	..	..
..	..	..	..	..
..	..	..	..	..
54.9	396418.5	0.01	396287.5	3962.875
54.9	396680.5	0	396549.5	0
54.9	396947.5	0	396814	0
54.9	397205	0	397076.3	0
54.9	397480.5	0	397342.8	0
54.9	397738	0	397609.3	0
54.91	398004.5	0.01	397871.3	3978.712
54.91	398267	0	398135.8	0
54.91	398533.5	0	398400.3	0
54.91	398800	0	398666.8	0
54.91	399066.5	0	398933.3	0
54.91	399324.5	0	399195.5	0
54.92	399586.5	0.01	399455.5	3994.555
54.92	399862	0	399724.3	0
54.92	**400000**	0	399931	0
Energy			N*mm	Sum = 1982168
			N*m = J	= **1982.168**