CZECH UNIVERSITY OF LIFE SCIENCES PRAGUE

Department of Mechanical Engineering

BACHELOR THESIS

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Analysis of mechanical behaviour and oil output of selected bulk oilseeds in uniaxial loading

Supervisor

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CZECH UNIVERSITY OF LIFE SCIENCES PRAGUE

Faculty of Engineering

BACHELOR THESIS ASSIGNMENT

Mahmud Musayev

Agricultural Engineering

Thesis title

Analysis of mechanical behaviour and oil output of selected bulk oilseeds in uniaxial loading

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Objectives of thesis

The Thesis objectives are to:
(i) determine the moisture content and percentage oil content of selected bulk oilseeds.
(ii) describe the maximum force-deformation curves of selected bulk oilseeds in relation to the input factors.
(iii) calculate the oil yield, oil expression efficiency, deformation energy, hardness and volume energy of selected bulk oilseeds.

Methodology

Three bulk oilseeds will be selected for the experiment. The initial moisture content and percentage oil content of the selected bulk oilseeds will be determined using the conventional oven and soxhlet extraction methods. The universal compression testing machine (ZDM 50/MPTest 5.050, Czech Republic) and a pressing vessel of diameter 30 mm with a plunger will be used to describe the force-deformation curves of the selected oilseeds in relation to the input factors of force, speed and an initial pressing height of the bulk oilseeds. The input parameters will either be constant or varied. The output parameters namely oil yield, oil expression efficiency, deformation energy, hardness and volume energy will be calculated based on mathematical equations used in the literature. The data where necessary will be analysed statistically using Statistica software (Statsoft, 2013).

Guidelines for compiling the BSc.Thesis

1. Introduction

1.1 Research Problem Statement

1.2. Objectives

2. Literature Review

2.1 Origin and Classification

The proposed extent of the thesis

50 – 70 pages

Keywords

Oilseeds, physical properties, uniaxial compression, processing, output oil, utilization

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Recommended information sources

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.

Demirel, C.; Kabutey, A.; Herák, D.; Hrabě, P.; Mizera, Č.; Dajbych, O. Optimizing Uniaxial Oil Extraction of Bulk Rapeseeds: Spectrophotometric and Chemical Analyses of the Extracted Oil under Pretreatment Temperatures and Heating Intervals. Processes 2021, 9, 1755.

Gürdil, G.A.K.; Kabutey, A.; Selvi, K.Ç.; Hrabě, P.; Herák, D.; Fraňková, A. Investigation of Heating and Freezing Pretreatments on Mechanical, Chemical and Spectral Properties of Bulk Sunflower Seeds and Oil. Processes 2020, 8, 411.

Gürdil, G.A.K.; Kabutey, A.; Selvi, K.Ç.; Mizera, Č.; Herák, D.; Fraňková, A. Evaluation of Postharvest Processing of Hazelnut Kernel Oil Extraction Using Uniaxial Pressure and Organic Solvent. Processes 2020, 8, 957.

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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.

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.

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ABSTRACT

This study aimed to investigate the mechanical behaviour and oil output of selected bulk oilseeds under uniaxial loading. Three types of bulk oilseeds namely hemp, pumpkin and sunflower were subjected to compression tests using a universal testing machine. The mechanical properties: force, deformation, hardness, strain and stress were determined and compared among different oilseeds. The oil yield was also measured and analyzed after compression. The results showed that the mechanical behaviour and oil output of oilseeds varied based on their structural compositions and properties. Hemp seeds had the highest oil output and moisture content. The study provides valuable information on the mechanical behaviour and oil output of bulk oilseeds under uniaxial loading which could be used for developing oil processing technologies.

KEYWORDS: Oilseeds, physical properties, uniaxial compression, processing, output oil, utilization

DECLARATION

I hereby declare that the Bachelor Thesis '**Analysis of mechanical behaviour and oil output of selected bulk oilseeds in uniaxial loading**' is the result of my work and that it has not been submitted to this University or any Institution for a degree. However, all references used in the development of the work have been duly acknowledged in the text and the list of references.

In Prague Date:

Mahmud Musayev

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1. INTRODUCTION

1.1 Background

One of the most crucial resources for humanity's sustainable progress is energy. The energy crisis is one of the major problems facing the world today. Because they can be burned to provide a considerable quantity of energy, fuels are very important. Fuels are essential to many facets of daily life, particularly the movement of people and things. The primary energy sources are fossil fuels including gasoline, coal, and natural gas. 80% of the world's energy demands are met by fossil fuels. Diesel-powered equipment is used in the majority of industries for manufacturing. Private cars, buses, trucks, and ships all utilize a lot of diesel and gasoline in the transportation industry. This condition results in a heavy reliance on fossil fuels in daily living (Huang, Zhou and Lin, 2012). However, local crude oil output cannot keep up with the population increase. Alternative energy sources can take the place of fossil fuels, including water, sun, wind, and biofuels. Most of these fuels are used in transportation. Currently, biofuels are mostly made from edible oils that are farmed traditionally, such as soybean, rapeseed, sunflower, and palm (Bokhari et al., 2015). Oils are used for a range of purposes besides making fuel. Several studies have shown how important fatty acids (FAs) are to human nutrition, including the treatment and prevention of disease, the growth and development of the human embryo, brain function, and the avoidance of many major illnesses including cardiovascular disease and inflammation. It is now recognized that several FAs have anticancer potential. As many studies are being conducted, the significance of lipids and fatty acids in human nutrition is coming to light (Kumar, Sharma and Upadhyaya, 2016).

Numerous efforts to increase the oil extraction efficiency of mechanical screw pressing of oilseeds have been undertaken in the past and are presently under consideration. The majority of research focused on the optimization of process factors such as pressure applied, pressing temperature, and moisture conditioning of the oil-bearing material. Physical (dehulling, cracking, size reduction), thermal (preheating, dry extrusion), hydrothermal (hot water soaking, steaming, blanching, flaking), and chemical (enzymatic hydrolysis) pretreatment techniques have been examined. These measures have enhanced oil recovery efficiency by up to 30 %. However, the issue of excessive oil extraction or passing persists, leading to higher energy consumption and equipment wear and tear. Also, the screw press can get clogged or stuck, which causes the cake and oil to heat up too much and burn, causing loss of energy, labour, and property (Wulfsohn et al., 2000). The selection of bulk oilseed as the source will result in the determination of the most effective biodiesel production technique. In the usual approach preceding the transesterification process, oil extraction from the seed itself is also crucial, and a great deal of study needs to be done to identify the best extraction method that provides the optimal circumstances for obtaining the highest extraction yield.

1.2 RESEARCH PROBLEM STATEMENT

The determination of mechanical properties of bulk oilseeds is important for the design of various processing machines such as oil expellers/screw presses. The force-deformation characteristic curves under the uniaxial compression loading can be used to determine the mechanical properties of bulk oilseeds. The amount of force and energy required to produce a given deformation among different agricultural materials such as oilseeds thus vary. This information is not adequately reported in the literature, and therefore, further study is required to obtain adequate knowledge for the design of new processing machines.

1.3 OBJECTIVES

The objectives of the Thesis are to:

(i) determine the moisture content and percentage oil content of selected bulk oilseeds.

(ii) describe the maximum force-deformation curves of selected bulk oilseeds in relation to the input factors.

(iii) calculate the oil yield, oil expression efficiency, deformation energy, hardness and volume energy of selected bulk oilseeds.

2. LITERATURE REVIEW

2.1 Origin and classification

Seeds that are planted mainly to produce edible oils are called oilseeds. Peanuts and soybeans are two examples of what are known as oilseeds in a more general sense. The history of human civilization is inextricably intertwined with the history of oilseeds. In the Sanskrit texts of India from 2,000 BC, rapeseed and sesame were both referenced, and it was stated that sunflowers were grown in Arizona and New Mexico 3,000 years before the present. The seeds are first pressed to extract the oil, which is the first step in the production of vegetable oil. The cake or meal that is formed after the extraction process is an abundant source of proteins. For example, sunflower and peanut meals both contain between 40 and 50% proteins. Protein content ranges from 35–45 % in other oilseed meals. Peanuts, sunflower seeds, rapeseed, and cottonseed each contribute 5% of the total global output of protein meal, with soybeans coming in at number one with a 69% share. In 2004/2005, the total output of oilseeds in the world was 380 million metric tons (Philips and Williams, 2009).

2.2 Production and consumption

There are around forty distinct oil seeds whose oil is consumable, but just a few are prominent in global commerce. Oil crops are cultivated all over the globe under a variety of agroclimatic conditions and are essential to the trade and commerce of several economies. The output growth is mostly attributable to the growing demand for oilseed products, and it has been made feasible by the expansion of cropland and the development of high-yielding cultivars. This has been augmented by modern scientific production technology, which has led to high levels of per-unit productivity, especially in nations with high agricultural production standards (Sharma, Gupta and Mondal, 2012). Soybean and palm contribute the most to the global economy of oilseeds, followed by rapeseed, mustard, cotton, peanut, and sunflower which are shown in Figures 1 and 2. The most valuable tropical oilseeds are coconut, palm kernels, and groundnut. The majority of oilseed-producing regions are temperate zones. Together, the United States and Europe produce more than 60% of the world's oil seeds, whereas tropical regions such as Africa, Malaysia, and Indonesia produce a little amount (5%). Both oilseed and oil production have expanded steadily over the years to fulfil the ever-growing demand for vegetable oils. Soybean is the principal oil seed crop among oil seeds (Lafarga, 2021). Figure 1 depicts the global trends in major oil crop production and yields over the last 10 years. The production of oilseed crops rose from 160 million metric tons to 225 million metric tons during the last decade. Noticeably, it is conspicuous that the production of palm and soybean is the highest over the years from 2012 to 2022.

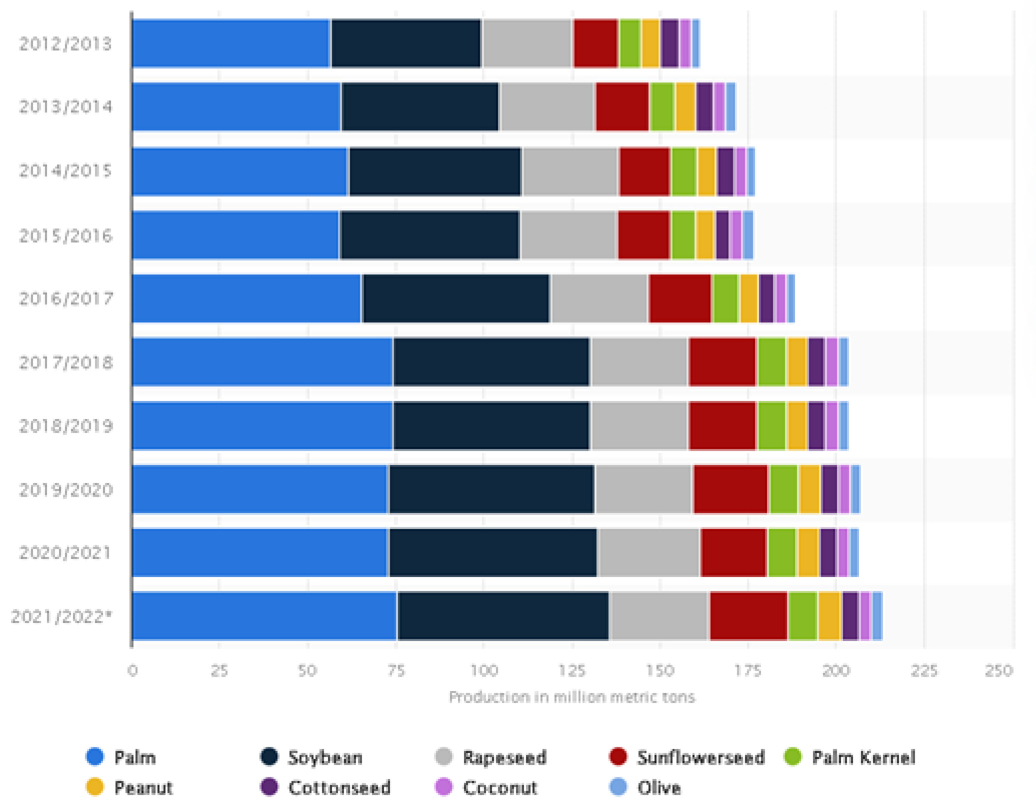

Figure 1. Production of major vegetable oils worldwide from 2012/13 to 2021/2022 (Source: Statista.com).

World trends in oilseed crop consumption are represented in Figure 2. The chart illustrates the number of consumed million metric tons of oil from the main oilseed crops. Overall, palm and soybean oils make up the majority of the world's oil consumption.

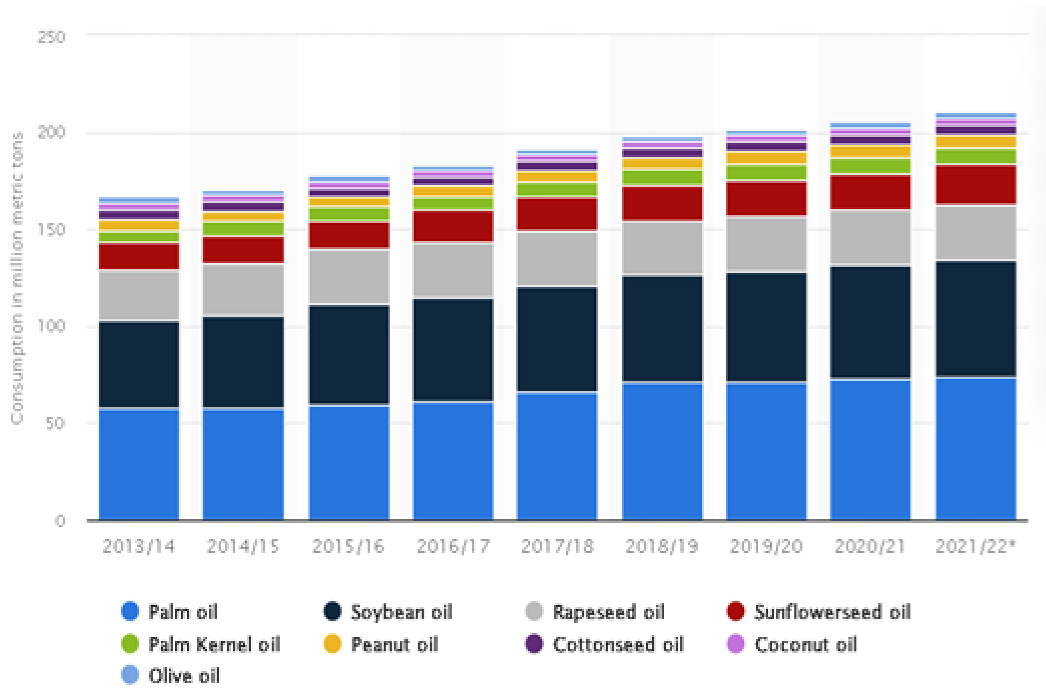

Figure 2. Consumption of vegetable oils worldwide from 2013/14 to 2021/2022, by oil type (Source: Statista.com)

2.3 Selected oilseeds

2.3.1 Hemp

Hemp is one of the oldest crops still cultivated and one of the most versatile. Hemp has been used by humans for at least 6,000 years, and in that time, it has been turned into oil, paper, rope, and fibre. In traditional oriental medicine, hemp seeds have been employed for the treatment of a wide range of conditions for over a thousand years (Callaway, 2004). A decline in demand for hemp products was caused by a combination of factors, including increased levels of competition from synthetic materials and natural fibres as well as a general slowdown in industries that previously relied heavily on hemp, such as shipping. Additionally, beginning in the 1930s and continuing onward, drug prevention acts in the United States led to international bans and restrictions placed on the production of hemp. Many other nations, except for those in the heart of Europe and the east, followed suit. Hemp strains with low levels of tetrahydrocannabinol (THC) were tolerated in certain nations on the condition that they adhered to stringent regulations; however, many of these constraints were not relaxed or lifted until the middle of the 1990s. As a direct result of this, both the production of hemp and research interest in it declined, and it was not until the middle to late 1990s that either of these activities began to pick up again. Since that time, there has been a significant uptick in both the production of hemp and the interest in developing more efficient production methods (Robson et al., 2002).

2.3.2 Pumpkin

Even though they have a high nutritional value as well as therapeutic advantages, the seeds of *Cucurbita maxima* (pumpkin seeds) are often regarded as agro-waste and thrown away. Pumpkin seeds are an excellent source of protein, fatty acids, and a significant quantity of important minerals such as potassium, magnesium, manganese, and calcium. Choline is an important building block for the brain, and this food provides a healthy dose of nutrients. Extracts and oils made from pumpkin seeds are effective in treating a variety of conditions, including benign prostatic hyperplasia (BPH), parasite infestation, acrodermatitis enteropathica, hyperlipidemia, diabetes, and depression, to mention just a few. The presence of bioactive components such as phytosterols (such as beta-sitosterol and stigmasterol), tocopherols, selenium (an antioxidant), cucurbitin, squalene, lignan, and cardioprotective unsaturated fatty acids are responsible for the reported effects. Recent studies have shed light on the expanding number of health advantages that pumpkin seeds provide as a great dietary source (Sohini and Santa, 2015).

2.3.3 Sunflower

Sunflower is one of the most significant oilseed crops, and its oil is presently the fourth most-produced vegetable oil worldwide, behind palm, soybean, and rapeseed oils. In 2014, sunflower oil output reached 15.29 million metric tons, accounting for nearly one-tenth of the world's total oil supply. The production of sunflower seeds has increased exponentially in the Black Sea region over the past ten years, with increased acreage and higher yields achieved by replacing old varieties with improved hybrid seeds. The four largest producers of sunflower seeds are Ukraine, the European Union, Russia, and Argentina. 76% of global production is accounted for by these four countries (Enrique, Dunford and Salas, 2015). The high protein content and wide availability of sunflower seeds both contribute to their allure as a food source. Sunflower seeds, in comparison to other vegetable sources of protein, have a low or non-existent level of anti-nutritional components, except for lysine, the amino acid composition of sunflower seeds is by the Food and Agriculture Organization's description of human needs (Enrique, Dunford, and Salas, 2015).

2.4 Processing and utilization

2.4.1 Extraction

Separating the oil from the source, such as soybeans, cottonseed, maize germ, dried coconut, or other oil-rich plant material, is the first stage in processing. Details of the procedure vary depending on the source, but the overall pattern is consistent. In the past, oil was extracted by pressing, with or without heating. Currently, the seed or germ is rolled into thin flakes (from which some oil is removed), which are subsequently extracted using hexane. This results in greater oil production with typically fewer contaminants and less heat damage. The hexane is removed by distillation, leaving no trace in the oil (Landers and Rathmann, 1981). The vegetable oil contains the required triglycerides and unsaponifiable as well as minor quantities of additional compounds that provide undesired qualities to the oil, such as colour, taste, odour, instability, and foaming. Pesticides are a relatively new addition to this list, but given the widespread usage of pesticides, many of which are extremely soluble in lipids (Yara-Varón et al., 2017).

2.4.2 Refining

Refining is the process of removing undesired and hazardous components from oil. For oils that cannot be used as virgin oils, refining is essentially required to produce a product with an appealing look, a neutral flavour, and greater oxidation resistance. Similarly, it enables the production of oils that are more suitable for diverse industrial applications, the elimination of undesirable substances such as pesticide residues, metal traces, polycyclic aromatic hydrocarbons, dioxin, and alteration products, and the reduction of oil loss during processing (Galanakis, 2019).

2.4.3 Bleaching

Bleaching is a crucial phase in the oil refining process, which normally begins with degumming, neutralization, and drying. Bleaching is a sophisticated physical and chemical process used in the refining of vegetable oils to lower the quantities of colourful pigments (carotenoids and chlorophylls). Additionally, it eliminates phosphatide, soap, phospholipid pollutants, lipid peroxidation products, and other contaminants. Lastly, it indirectly affects the colour of deodorized oil. Clays designed specifically for adsorption bleaching, activated carbon, particular silica, or a combination of these three are often used in the bleaching process (Gharby, 2022).

2.4.4 Utilization

From ancient times, oilseed crops have been an essential part of the agricultural economy, and they continue to play an important part in agricultural businesses and international commerce all over the globe (Abrol and Shankar, 2016). Oilseed crops are the foundation for biological systems that produce edible oils, contribute to the production of renewable energy, help stabilize greenhouse gases, and mitigate the risk of climate change (Jaradat, 2016). Oilseed crops are responsible for the production of a significant volume of edible oil. The production of oil from oilseed crops is the primary reason for their cultivation. Recent years have seen an increase in interest in oilseeds because of the growing demand for nutritious vegetable oils, animal feeds, medicines, biofuels, and other oleochemical industrial applications that may be produced from them (Rahman and de Jiménez, 2016).

2.5 Overview of uniaxial loading

The bulk oilseeds are loaded into a pressing vessel with a specified diameter that has openings at the bottom that let the oil escape while keeping the seedcake in place (a procedure known as uniaxial compression loading) (Munson-McGee, 2014). This approach requires the mechanical behaviour (force-deformation curve characteristic smooth curve and serration/undulation pattern), oil yield, oil expression efficiency, and energy demand of a certain bulk oilseed's processing to be characterized (Demirel et al., 2021). These factors include speed, heating temperature, bulk material volume, moisture content, and pressing vessel diameter. The highest recovery of the remaining oil in the seedcake is related to the stress-reduction procedure in this case. While measuring the viscoelasticity of a porous solid material, the stress relaxation behaviour of the material is often examined. The test involves measuring the stress needed to maintain the deformation as a function of time at a constant strain. Optimizing the mechanical screw press would be made easier, particularly for operations operating in rural areas, by first understanding the uniaxial compression and relaxation processes. The adoption of a suitable experimental design is crucial to minimize costs and the time-consuming nature of the traditional experimental technique. An effective statistical approach for examining the impact of several independent variables or processing factors on the replies is the response surface methodology (RSM). The design and optimization of processes as well as the enhancement of current designs are key applications for RSM. The main goal of RSM is to identify the system's ideal operating conditions and/or the threshold that fulfils the operational requirements (Salamatinia et al., 2013). The modelling and optimization of the processing variables of bulk oilseeds oil extraction under uniaxial compression loading have not utilized the RSM, according to the information that is currently accessible. Under uniaxial loading, the RSM must be used to extract oil from bulk oilseeds (Kabutey et al., 2021).

2.6 Mechanical properties of oilseeds

To build highly effective oil processing technology an in-depth understanding of mechanical qualities such as rupture force, deformation at rupture point, deformation ratio at rupture point, energy for rupture, volume energy, or toughness and hardness of bulk oilseeds or kernels is essential. Other important parameters include force, speed, moisture content, temperature, pressing vessel diameter, and types of bulk oilseeds or kernels (Herak et al., 2010). The rupture force is defined as the lowest amount of force sufficient to fracture the bulk material. This is a significant component affecting the energy requirements of vegetable oil extraction, and identifying the ideal force would improve oil recovery efficiency by decreasing energy input (Herak et al., 2010). The deformation that occurs at the point of rupture is the deformation that occurs in the loading direction, and it helps establish the gap size between the surfaces that are required for effectively compressing the kernels to dehull or shelling (Kabutey, Herak, Mizera and Hrabe, 2018). The area under the rupture force and the deformation at the rupture point may be used to calculate the energy for rupture, also known as the energy necessary to rupture the bulk material. The ratio of the energy required to rupture a sample to that of the sample's volume is the measure of its toughness. It is the amount of effort needed to induce a rupture in the bulk material, and an approximation of it may be found by finding the area that is under the force-deformation curve up to the point when the rupture occurs. Hardness may be defined as the ratio of the force of rupture to the amount of deformation that occurs at the place of rupture (Jafari et al., 2011).

3. MATERIALS AND METHODS

3.1 Experiment

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

3.2 Selected oilseeds samples

The oilseed samples used for the experiment were hemp, pumpkin and sunflower. The samples were obtained from the Czech Republic.

3.3 Determination of the sample's moisture content

The moisture content of the samples was determined using the conventional oven method by heating the samples at 105 °C for 17 h. The moisture content values for (hemp seeds: 5.70 ± 0.16 % w.b., pumpkin seeds: 6.13 ± 0.41 % w.b., and sunflower seeds: 4.63 ± 0.87 % w.b.) were calculated by Eq. (1) according to Blahovec (2008).

$$MC = [(\frac{m_b - m_a}{m_b}) \cdot 100] \quad (1)$$

where MC is the percentage of moisture content of the sample (% w.b.), $m_a$and$m_b$are the masses of the samples before and after oven drying (g).

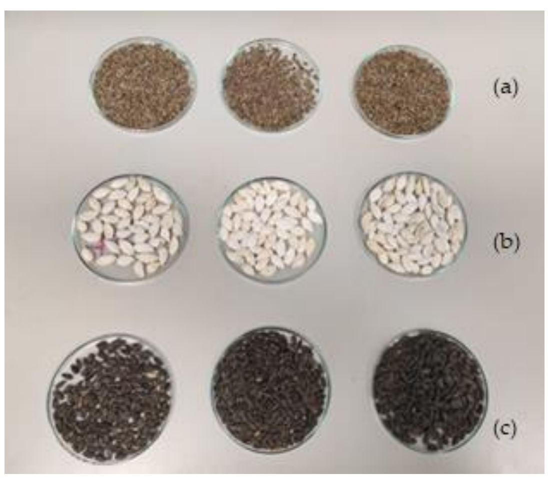

Figure 3. Prepared samples (a) hemp; (b) pumpkin and (c) sunflower for oven drying for the determination of moisture content.

3.4 Compression tests

The universal compression testing machine (ZDM 50, Czech Republic) and a pressing vessel of diameter 60 mm with a plunger were used for the compression test. The force-deformation curves of the selected bulk oilseeds were described from the test. The input speed was 5 mm/min and an initial pressing height of the bulk oilseeds samples was measured at 80 mm. The maximum force of the compression machine is 500 kN. Therefore, the maximum force for each was determined sample with the pressing speed and sample height. The compression tests of the selected bulk oilseed samples are shown in figures 2, 3 and 4 respectively.

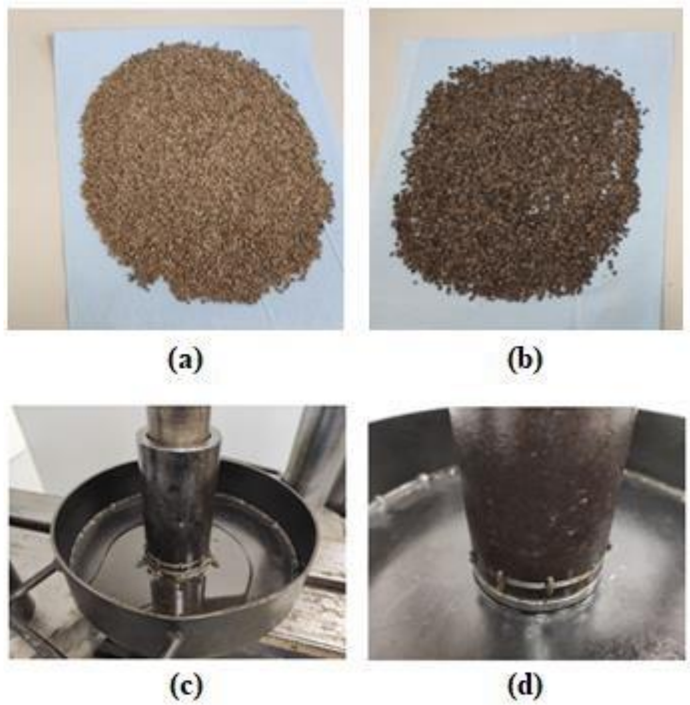

Figure 4. Compression test of hemp bulk oilseeds: (a) before the test, (b) after the test, (c) output oil after the test and (d) repeated pressing to recover the residual oil after the initial pressing.

3.5 Recovery of residual oil test

The recovery of the residual oil from the seedcakes of the selected bulk oilseeds was done using the above-mentioned compression testing machine. After the three repeated pressings of the samples (first initial pressings); the remaining seedcakes of each sample were compressed again at a pressing height of 80 mm and speed of 5 mm/min. Here, the other compression parameters were calculated.

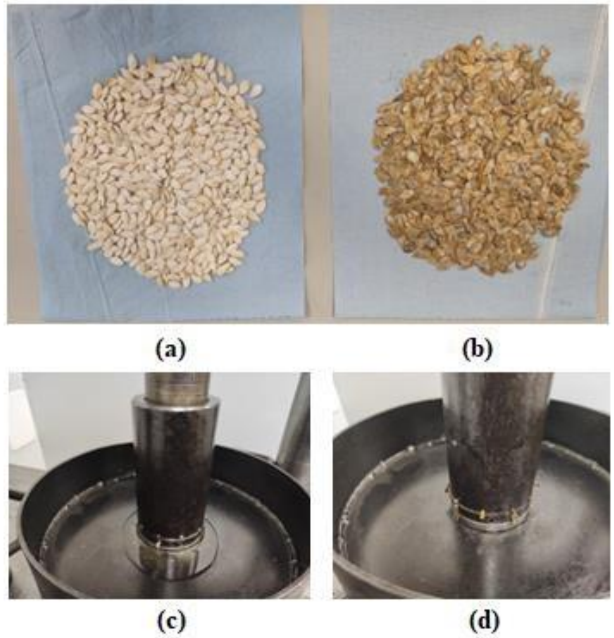

Figure 5. Compression test of pumpkin bulk oilseeds: (a) before the test, (b) after the test, (c) output oil after the test and (d) repeated pressing to recover the residual oil after the initial pressing.

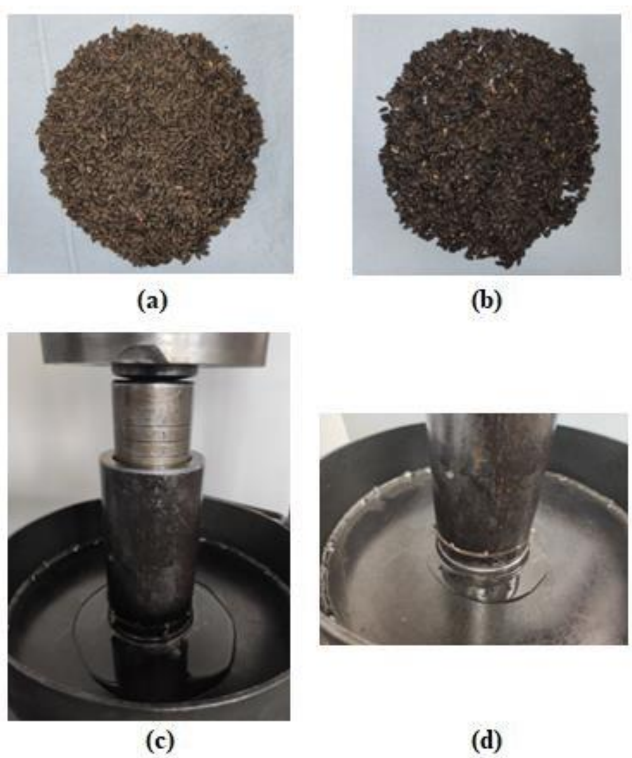

Figure 6. Compression test of sunflower bulk oilseeds: (a) before the test, (b) after test, (c) output oil after test and (d) repeated pressing to recover the residual oil after the initial pressing.

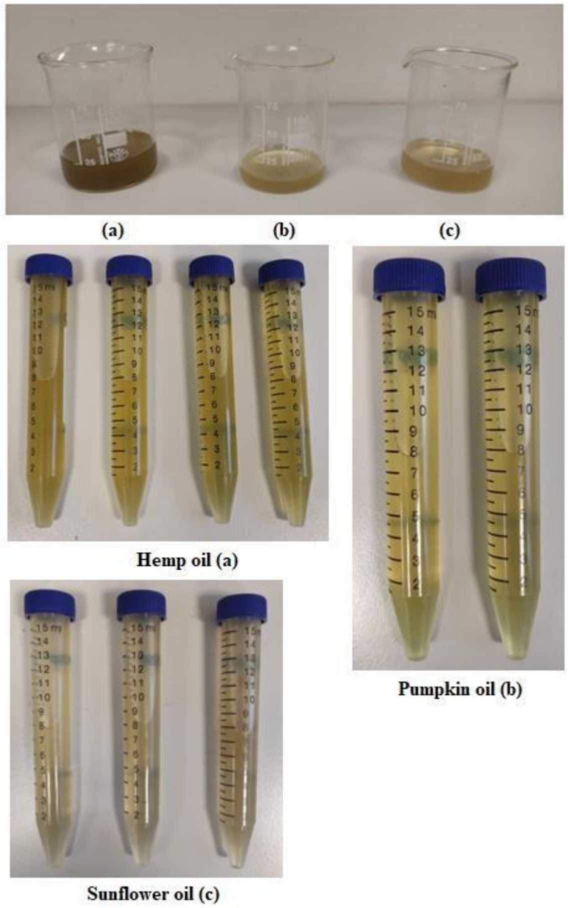

Figure 7. Oil output of the selected bulk oilseed samples during the compression test.

3.6 Calculated parameters from the compression tests

3.6.1 Oil yield

The oil yield was calculated using the equation reported by Deli et al., (2011) and Chanioti and Tzia (2017) as described in Eq. (2).

$$O_Y = \left(\frac{M_O}{M_S}\right) \cdot 100 \qquad (2)$$

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

3.6.2 Deformation energy

The deformation energy is characterized by the area under the force-deformation curve (Gupta and Das, 2000). This was calculated according to the equation reported by Herak et al., (2012) as described in Eq. (3).

$$E_N = \sum_{n=0}^{n=i-1} \left[\left(\frac{F_{n+1} + F_n}{2}\right) \cdot (x_{n+1} - x_n)\right] \quad (3)$$

where E_N 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.

3.6.3 Volume energy

The volume energy is the ratio of deformation energy to that of the volume as described in Eq. (4) and Eq. (5) according to Herak et al., (2012).

$$V_E = \frac{E_N}{V} \quad (4)$$

$$V = \left(\frac{\pi \cdot D^2}{4}\right) \cdot H_P \quad (5)$$

where V_E is the volume energy (J/m^3), V is the volume of the samples before the compression tests (m^3), D is the diameter of the pressing vessel (mm) and H_P is the initial pressing height of the samples (mm).

3.6.4 Force and deformation

The force, F_R (N) and deformation D_F (mm) values were obtained directly from the compression tests output data.

3.6.5 Hardness

The hardness of the samples was calculated by (Eq. 6) according to Chakespari, Rajabipour and Mobli (2010).

$$H_D = \frac{F_R}{D_F} \tag{6}$$

3.6.6 Strain

The strain of the samples was calculated by (Eq. 7) according to Chakespari, Rajabipour and Mobli (2010).

$$\varepsilon_T = \frac{D_F}{H_P} \tag{7}$$

where $\boldsymbol{\varepsilon_T}$ is the strain (-).

3.6.7 Stress

The stress of the samples was calculated by (Eq. 8) according to Chakespari, Rajabipour and Mobli (2010).

$$\sigma_S = \frac{F_R}{A} \tag{8}$$

where $\boldsymbol{A}$ is the area of the pressing vessel (mm^2).

3.7 Statistical analysis

The experiments were repeated three times. The descriptive statistics (the mean, standard deviation and coefficient of variation) were determined using STATISTICA 13 software (Statsoft, 2013).

4. RESULTS AND DISCUSSION

4.1 Moisture content

The conventional oven method was used to determine the moisture content of the samples by heating the samples at 105 °C for 17 hours to determine the moisture content. The moisture content of selected bulk oilseeds namely hemp, pumpkin and sunflower was calculated to be 5.70 ± 0.16 % w.b., 6.13 ± 0.41 % w.b., 4.63 ± 0.87 % w.b.

4.2 Oil content

Due to the unavailability of chemicals, the oil content of the chosen oilseeds was not determined. However, according to Fike (2016), hemp seeds oil ranges between 27 % and 38 %. In addition, Kabutey et al., (2021) determined the percentage oil content in pumpkin seeds to be 33.53 ± 1.16%. Furthermore, the oil content of sunflower oilseeds was determined to be 33.12 ± 0.87% by Gürdil et al., (2020).

4.3 Oil yield, deformation energy and mechanical properties

The values of oil yield and energy of the selected oilseeds (hemp, pumpkin, sunflower) are given in Tables 1 to 3. For oil yield, the values ranged from 12.04 ± 0.24 % to 23.76 ± 0.94 % with a coefficient of variation values between 0.94 to 3.29 %. Energy values for hemp, pumpkin and sunflower bulk oilseeds were 1349.16 ± 50.63 J, 921.35 ± 77.10 J, and 826.14 ± 34.63 J with the coefficient of variation values from 3.75 to 8.37 %. Mechanical properties of selected bulk oilseeds such as Hardness (H_D), Strain (ε_T) and Stress (σ_S) are shown in Tables 4, 5 and 6. The hardness and stress values of selected oilseeds specifically hemp, pumpkin and sunflower varied between 3280.56 ± 159.49 to 6421.06 ± 154.75 N/mm, 66.78 ± 3.22 to 120.93 ± 2.60 MPa, 92.82 ± 4.51 to 181.62 ± 4.38 MPa. The detailed descriptive statistics (number of samples, sum, minimum, maximum, SD±, CV%, SE) are given in the appendixes.

Table 1. Mass of oil, oil yield and energy of hemp bulk oilseeds sample.

Tests (T)	M_b (g)	M_a (g)	M_O (g)	O_Y (%)	E_N (J)	V_E (J/m^3) ·10^5
1	134.52	102.74	31.78	23.62	1293.45	57.18
2	134.52	102.72	31.8	23.64	1392.36	61.56
3	134.52	102.21	32.31	24.02	1361.66	60.21
Mean			31.96	23.76	1349.16	59.64
± SD			0.30	0.22	50.63	2.24
% CV			0.94	0.94	3.75	3.57
R1	134.52	132.3	2.22	1.65	717.11	31.70
R2	134.52	131.85	2.67	1.98	987.95	43.68
Mean			2.445	1.82	852.53	37.69
± SD			0.32	0.24	191.51	8.47
% CV			13.01	13.01	22.46	22.46

Table 2. Mass of oil, oil yield and energy of pumpkin bulk oilseeds sample.

Tests (T)	M_b (g)	M_a (g)	M_O (g)	O_Y (%)	E_N (J)	V_E (J/m^3) ·10^5
1	105.79	93.08	12.71	12.01	893.54	39.50
2	105.79	93.29	12.5	11.82	862.02	38.11
3	105.79	92.78	13.01	12.30	1008.49	44.59
Mean			12.74	12.04	921.35	40.73
± SD			0.26	0.24	77.10	3.41
% CV			2.01	2.01	8.37	8.37
R1	105.79	93.34	12.45	11.77	984.05	43.50
R2	105.79	92.16	13.63	12.88	1086.29	48.02
Mean			13.04	12.33	1035.17	45.76
± SD			0.83	0.79	72.30	3.19
% CV			6.40	6.40	6.98	6.98

Table 3. Mass of oil, oil yield and energy of sunflower bulk oilseeds sample.

Tests (T)	M_b (g)	M_a (g)	M_O (g)	O_Y (%)	E_N (J)	V_E (J/m^3) ·10^5
1	110.82	90.66	20.16	18.19	793.51	35.08
2	110.82	89.29	21.53	19.43	862.47	38.13
3	110.82	90	20.82	18.79	822.43	36.36
Mean			20.84	18.80	826.14	36.52
± SD			0.69	0.62	34.63	1.53
% CV			3.29	3.29	4.19	4.19
R1	110.82	102.98	7.84	7.07	516.02	22.81
R2	110.82	101.74	9.08	8.19	610.55	26.99
Mean			8.46	7.63	563.28	24.90
± SD			0.88	0.79	66.84	2.95
% CV			10.36	10.36	11.87	11.87

M_b: Mass of sample before test; M_a: Mass of sample after test; M_O: Mass of oil; O_Y: Oil yield; E_N: Deformation energy and V_E: Volume energy; SD: Standard Deviation; CV: Coefficient of Variation; and R: Residual oil recovery.

Table 4. Determined mechanical properties of hemp bulk oilseeds sample.

Tests (T)	F_R (N)	D_F (mm)	H_D (N/mm)	ε_T (-)	σ_S (MPa)
1	335724	52.94	6341.59	0.66	118.74
2	340007	53.78	6322.18	0.67	120.25
3	350032	53.04	6599.40	0.66	123.80
Mean	341921.00	53.25	6421.06	0.67	120.93
± SD	7343.52	0.46	154.75	0.01	2.60
% CV	2.15	0.86	2.41	0.86	2.15
R1	218654	43.62	5012.70	0.62	77.33
R2	352490	37.65	9362.28	0.54	124.67
Mean	285572	40.64	7187.49	0.58	101.00
± SD	94636.343	4.22	3075.62	0.06	33.47
% CV	33.14	10.39	42.79	10.39	33.14

Table 5. Determined mechanical properties of pumpkin bulk oilseeds sample.

Tests (T)	F_r (N)	D_f (mm)	H_d (N/mm)	ε_n (-)	σ_s (MPa)
1	209049	55.18	3788.49	0.69	73.94
2	180156.5	59.32	3037.03	0.74	63.72
3	211151.5	61.63	3426.12	0.77	74.68
Mean	200119.00	58.71	3417.21	0.73	70.78
± SD	17319.96	3.27	375.81	0.04	6.13
% CV	8.65	5.57	11.00	5.57	8.65
R1	300241.5	47.02	6385.40	0.67	106.19
R2	340066	45.5	7473.98	0.65	120.27
Mean	320153.75	46.26	6929.69	0.66	113.23
± SD	28160.174	1.07	769.74	0.02	9.96
% CV	8.80	2.32	11.11	2.32	8.80

Table 6. Determined mechanical properties of sunflower bulk oilseeds sample.

Tests (T)	F_r (N)	D_f (mm)	H_d (N/mm)	ε_n (-)	σ_s (MPa)
1	180278	55.51	3247.66	0.69	63.76
2	198395	57.44	3453.94	0.72	70.17
3	187746	59.79	3140.09	0.75	66.40
Mean	188806.00	57.58	3280.56	0.72	66.78
± SD	9104.90	2.14	159.49	0.03	3.22
% CV	4.82	3.72	4.86	3.72	4.82
R1	173925	47.63	3651.59	0.68	61.51
R2	216853.5	48.38	4482.30	0.69	76.70
Mean	195389.25	48.01	4066.94	0.69	69.10
± SD	30355.033	0.53	587.40	0.01	10.74
% CV	15.54	1.10	14.44	1.10	15.54

F_R : Maximum force; D_F : Deformation; H_D : Hardness; ε_T : Strain; σ_S : Stress; SD: Standard Deviation; CV: Coefficient of Variation; and R: Residual oil recovery.

4.4 Compression curves

The deformation curves obtained from the compression tests are given in Figures 8, 9 and 10. The experiments ceased at the beginning of the serration pattern as shown in Appendixes Figures 1 to 3. The area under the curve is the deformation energy. The residual test curves show that less energy is required for obtaining the oil compared to the initial test curves which required more energy for the oil output. The smooth curves explain the maximum efficiency of the energy used for recovering the oil.

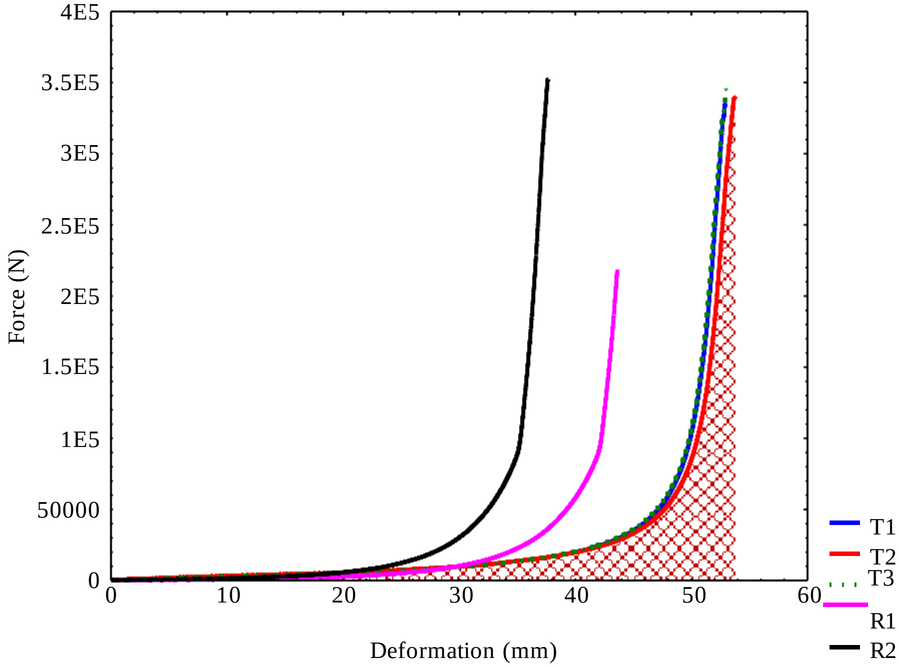

Figure 8. Force-deformation curves of hemp bulk oilseeds samples at different pressings (T: number of tests and R: number of residual tests).

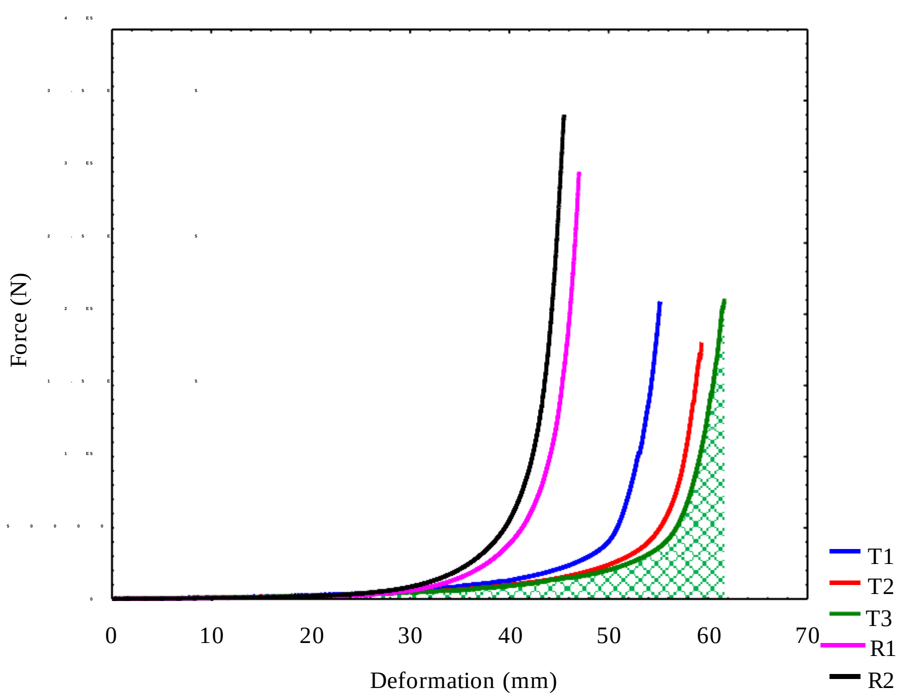

Figure 9. Force-deformation curves of pumpkin bulk oilseeds samples at different pressings (T: number of tests and R: number of residual tests).

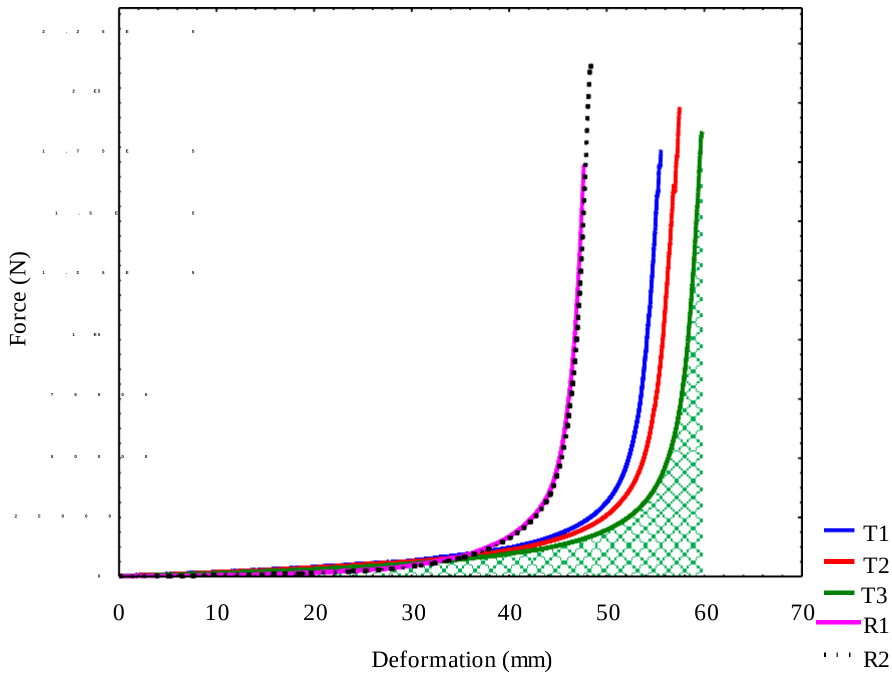

Figure 10. Force-deformation curves of sunflower bulk oilseeds samples at different pressings (T: number of tests and R: number of residual tests).

5. CONCLUSIONS

The following findings were found in the study.

i. The moisture content of hemp, pumpkin and sunflower oilseeds after 17 hours of oven pre-treatment was determined to be 5.70 ± 0.16, 6.13 ± 0.41, 4.63 ± 0.87 % w.b.

ii. The largest oil output was obtained by hemp oilseeds at 23.76 ± 0.22 %, followed by sunflower seeds at 18.80 ± 0.62 % and pumpkin seeds at 12.04 ± 0.24 %.

iii. The hardness of hemp oilseeds of 6421.06 ± 154.75 N/mm was higher than that of pumpkin seeds of 3417.21 ± 375.81 N/mm and sunflower seeds of 3280.56 ±159.49 N/mm.

iv. Hemp oilseeds produced the highest deformation energy value of 1349.16 ± 50.63 J. followed by pumpkin seeds of 921.35 ± 77.10 J and then sunflower oilseeds of 826.14 ± 34.63 J.

v. The deformation energy values corresponded to the stress values. Hemp oilseeds generated a higher stress of 120.93 ± 2.60 MPa compared with pumpkin and sunflower oilseeds obtaining values of 70.78 ± 6.13 MPa and 66.78 ± 3.22 MPa.

vi. It was estimated that the residual oil output of the chosen bulk oilseeds (hemp, pumpkin and sunflower) accounted for 1.82 ± 0.24, 12.33 ± 0.39, and 7.63 ± 0.29 % respectively.

6. RECOMMENDATIONS

In future studies, the percentage oil content, oil expression efficiency, the effect of moisture content on oil yield and the mechanical properties, moduli of elasticity values on the stress-strain relationship for biological materials and the effect of different pretreatment methods on the mechanical properties and oil output of the selected bulk oilseeds and other oilseeds under compression loading should be extensively examined.

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8. APPENDIXES

Appendix 1. Descriptive statistics of compression parameters of hemp bulk oilseeds.

Maximum oil output								
Parameters	N	Mean	Sum	Minimum	Maximum	± SD	% CV	SE
M_O (g)	3	31.96	95.89	31.78	32.31	0.30	0.94	0.17
O_Y (%)	3	23.76	71.28	23.62	24.02	0.22	0.94	0.13
E_N (J)	3	1349.16	4047.47	1293.45	1392.36	50.63	3.75	29.23
V_E $(J/m^3)\cdot 10^5$	3	59.64	178.94	57.18	61.55	2.24	3.75	1.29
Residual oil output								
Parameters	N	Mean	Sum	Minimum	Maximum	± SD	% CV	SE
M_O (g)	2	2.45	4.89	2.22	2.67	0.32	13.01	0.23
O_Y (%)	2	1.82	3.64	1.65	1.98	0.24	13.01	0.17
E_N (J)	2	852.53	1705.06	717.11	987.95	191.51	22.46	135.42
V_E $(J/m^3)\cdot 10^5$	2	37.69	75.38	31.70	43.68	0.95	33.14	0.67

N: Number of samples; M_O: Mass of oil; O_Y: Oil yield; E_N: Deformation energy and V_E: Volume energy; SD: Standard Deviation; CV: Coefficient of Variation and SE: Standard Error.

Appendix 2. Descriptive statistics of mechanical properties of hemp bulk oilseeds.

Maximum oil output								
Parameters	N	Mean	Sum	Minimum	Maximum	± SD	% CV	SE
Fr (kN)	3	341.92	1025.76	335.72	350.03	7.34	2.15	4.24
Df (mm)	3	53.25	159.76	52.94	53.78	0.46	0.86	0.26
Hd (kN/mm)	3	6.42	19.26	6.32	6.60	0.15	2.41	0.09
εn (-)	3	0.67	2.00	0.66	0.67	0.01	0.86	0.00
σs (MPa)	3	120.93	362.79	118.74	123.80	2.60	2.15	1.50
Residual oil output								
Parameters	N	Mean	Sum	Minimum	Maximum	± SD	% CV	SE
F_r (kN)	2	285.57	571.14	218.65	352.49	94.64	33.14	66.92
D_f (mm)	2	40.64	81.27	37.65	43.62	4.22	10.39	2.99
H_d (kN/mm)	2	7.19	14.37	5.01	9.36	3.08	42.79	2.17
ε_n (-)	2	0.58	1.16	0.54	0.62	0.06	10.39	0.04
σ_s (MPa)	2	101.00	202.00	77.33	124.67	33.47	33.14	23.67

N: Number of samples; F_r: Maximum force; D_f: Deformation; H_d: Hardness; ε_n: Strain; σ_s: Stress; SD: Standard Deviation; CV: Coefficient of Variation and SE: Standard Error.

Appendix 3. Descriptive statistics of compression parameters of pumpkin bulk oilseeds.

Maximum oil output								
Parameters	N	Mean	Sum	Minimum	Maximum	± SD	% CV	SE
M_O (g)	3	12.74	38.22	12.50	13.01	0.26	2.01	0.15
O_Y (%)	3	12.04	36.13	11.82	12.30	0.24	2.01	0.14
E_N (J)	3	921.35	2764.05	862.02	1008.49	77.10	8.37	44.51
V_E (J/m^3)·10^5	3	40.73	122.19	38.11	44.58	3.41	8.37	1.97
Residual oil output								
Parameters	N	Mean	Sum	Minimum	Maximum	± SD	% CV	SE
M_O (g)	2	13.04	26.08	12.45	13.63	0.83	6.40	0.59
O_Y (%)	2	12.33	24.65	11.77	12.88	0.79	6.40	0.56
E_N (J)	2	1035.17	2070.34	984.05	1086.29	72.30	6.98	51.12
V_E (J/m^3)·10^5	2	45.46	91.53	43.50	48.03	3.19	6.98	2.26

N: Number of samples; M_O: Mass of oil; O_Y: Oil yield; E_N: Deformation energy and V_E: Volume energy; SD: Standard Deviation; CV: Coefficient of Variation and SE: Standard Error.

Appendix 4. Descriptive statistics of mechanical properties of pumpkin bulk oilseeds.

Maximum oil output								
Parameters	N	Mean	Sum	Minimum	Maximum	± SD	% CV	SE
F_r (kN)	3	200.12	600.36	180.16	211.15	17.32	8.65	10.00
D_f (mm)	3	58.71	176.13	55.18	61.63	3.27	5.57	1.89
H_d (kN/mm)	3	3.42	10.25	3.04	3.79	0.38	11.00	0.22
ε_n (-)	3	0.73	2.20	0.69	0.77	0.04	5.57	0.02
σ_s (MPa)	3	70.78	212.33	63.72	74.68	6.13	8.65	3.54
Residual oil output								
Parameters	N	Mean	Sum	Minimum	Maximum	± SD	% CV	SE
F_r (kN)	2	320.15	640.31	300.24	340.07	28.16	8.80	19.91
D_f (mm)	2	46.26	92.52	45.50	47.02	1.07	2.32	0.76
H_d (kN/mm)	2	6.93	13.86	6.39	7.47	0.77	11.11	0.54
ε_n (-)	2	0.66	1.32	0.65	0.67	0.02	2.32	0.01
σ_s (MPa)	2	113.23	226.46	106.19	120.27	9.96	8.80	7.04

N: Number of samples; N: Number of samples; F_r : Maximum force; D_f : Deformation; H_d : Hardness; ε_n: Strain; σ_s: Stress; SD: Standard Deviation; CV: Coefficient of Variation and SE: Standard Error.

Appendix 5. Descriptive statistics of compression parameters of sunflower bulk oilseeds.

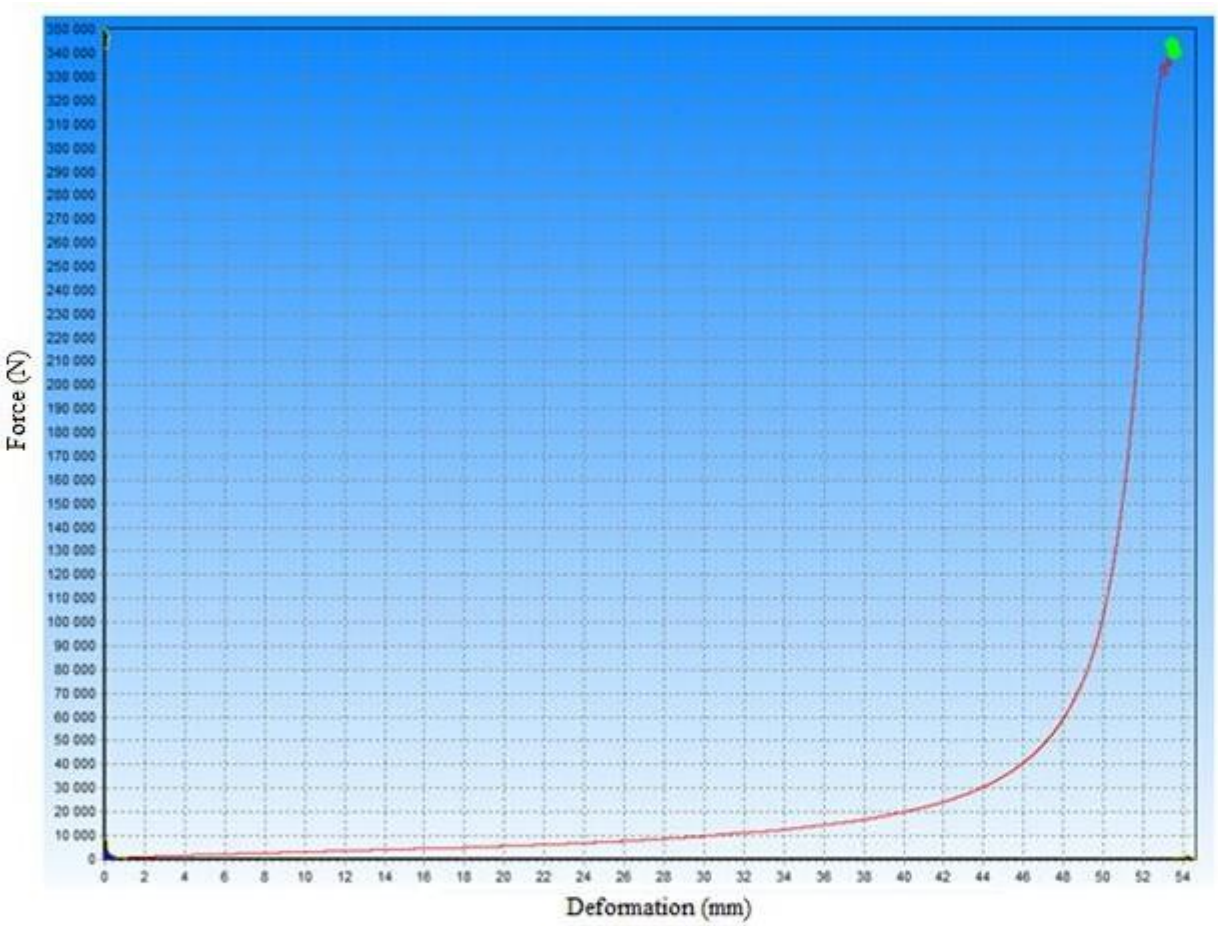
Maximum oil output								
Parameters	N	Mean	Sum	Minimum	Maximum	± SD	% CV	SE
M_O (g)	3	20.84	62.51	20.16	21.53	0.69	3.29	0.40
O_Y (%)	3	18.80	56.41	18.19	19.43	0.62	3.29	0.36
E_N (J)	3	826.14	2478.41	793.51	862.47	34.63	4.19	19.99
V_E $(J/m^3)\cdot 10^5$	3	36.52	109.57	35.08	38.13	1.53	4.19	0.88
Residual oil output								
Parameters	N	Mean	Sum	Minimum	Maximum	± SD	% CV	SE
M_O (g)	2	8.46	16.92	7.84	9.08	0.88	10.36	0.62
O_Y (%)	2	7.63	15.27	7.07	8.19	0.79	10.36	0.56
E_N (J)	2	563.28	1126.57	516.02	610.55	66.84	11.87	47.26
V_E $(J/m^3)\cdot 10^5$	2	24.91	49.81	22.81	26.99	2.95	11.87	2.09

N: Number of samples; M_O: Mass of oil; O_Y: Oil yield; E_N: Deformation energy and V_E: Volume energy; SD: Standard Deviation; CV: Coefficient of Variation and SE: Standard Error.

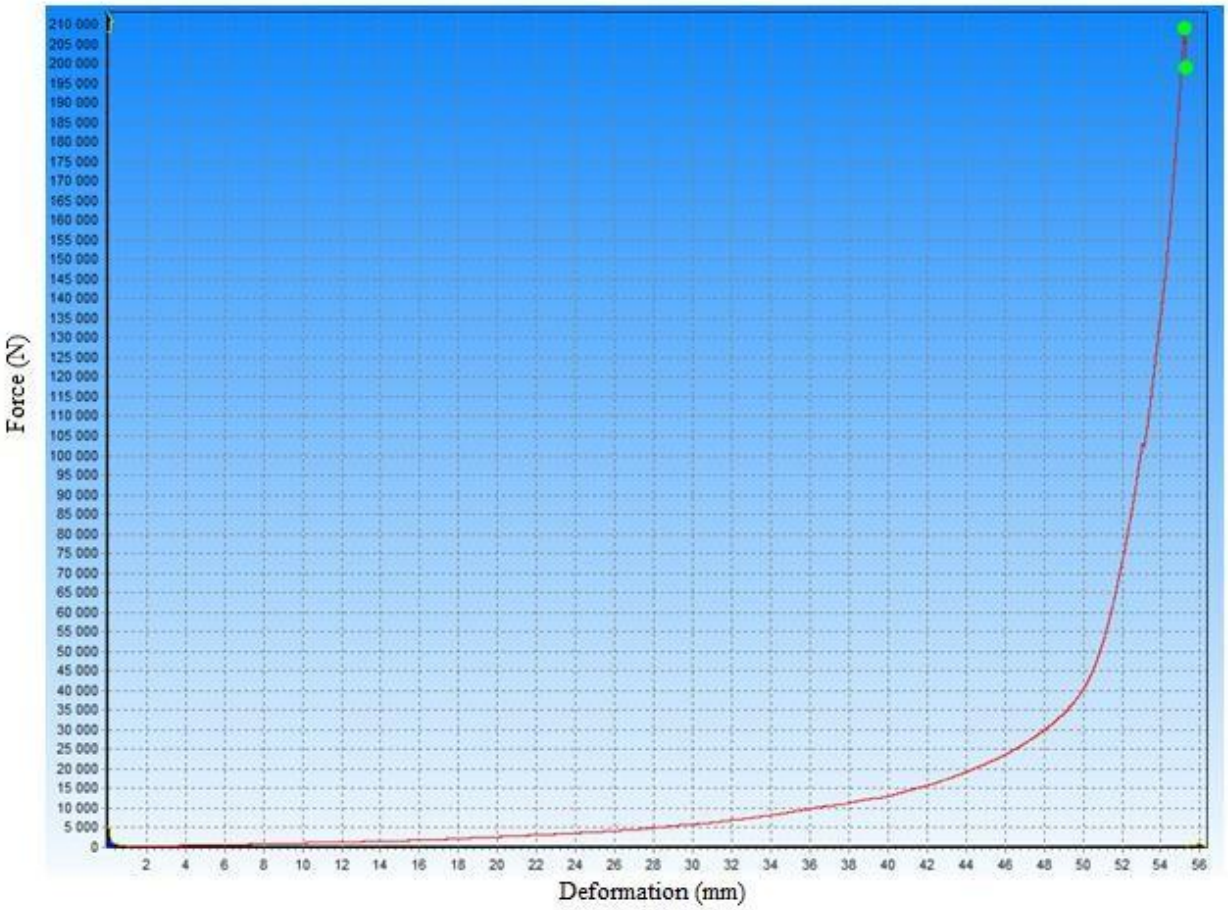
Appendix 6. Descriptive statistics of mechanical properties of sunflower bulk oilseeds.

Maximum oil output								
Parameters	N	Mean	Sum	Minimum	Maximum	± SD	% CV	SE
F_r (kN)	3	188.81	566.42	180.28	198.39	9.10	4.82	5.26
D_f (mm)	3	57.58	172.74	55.51	59.79	2.14	3.72	1.24
H_d (kN/mm)	3	3.28	9.84	3.14	3.45	0.16	4.86	0.92
ε_n (-)	3	0.72	2.16	0.69	0.75	0.03	3.72	0.02
σ_s (MPa)	3	66.78	200.33	63.76	70.17	3.22	4.82	1.86
Residual oil output								
Parameters	N	Mean	Sum	Minimum	Maximum	± SD	% CV	SE
F_r (kN)	2	195.39	390.78	173.93	216.85	30.36	15.54	21.46
D_f (mm)	2	48.01	96.01	47.63	48.38	0.53	1.10	0.38
H_d (kN/mm)	2	4.07	8.13	3.65	4.48	0.59	14.44	4.15
ε_n (-)	2	0.69	1.37	0.68	0.69	0.01	1.10	0.01
σ_s (MPa)	2	69.10	138.21	61.51	76.70	10.74	15.54	7.59

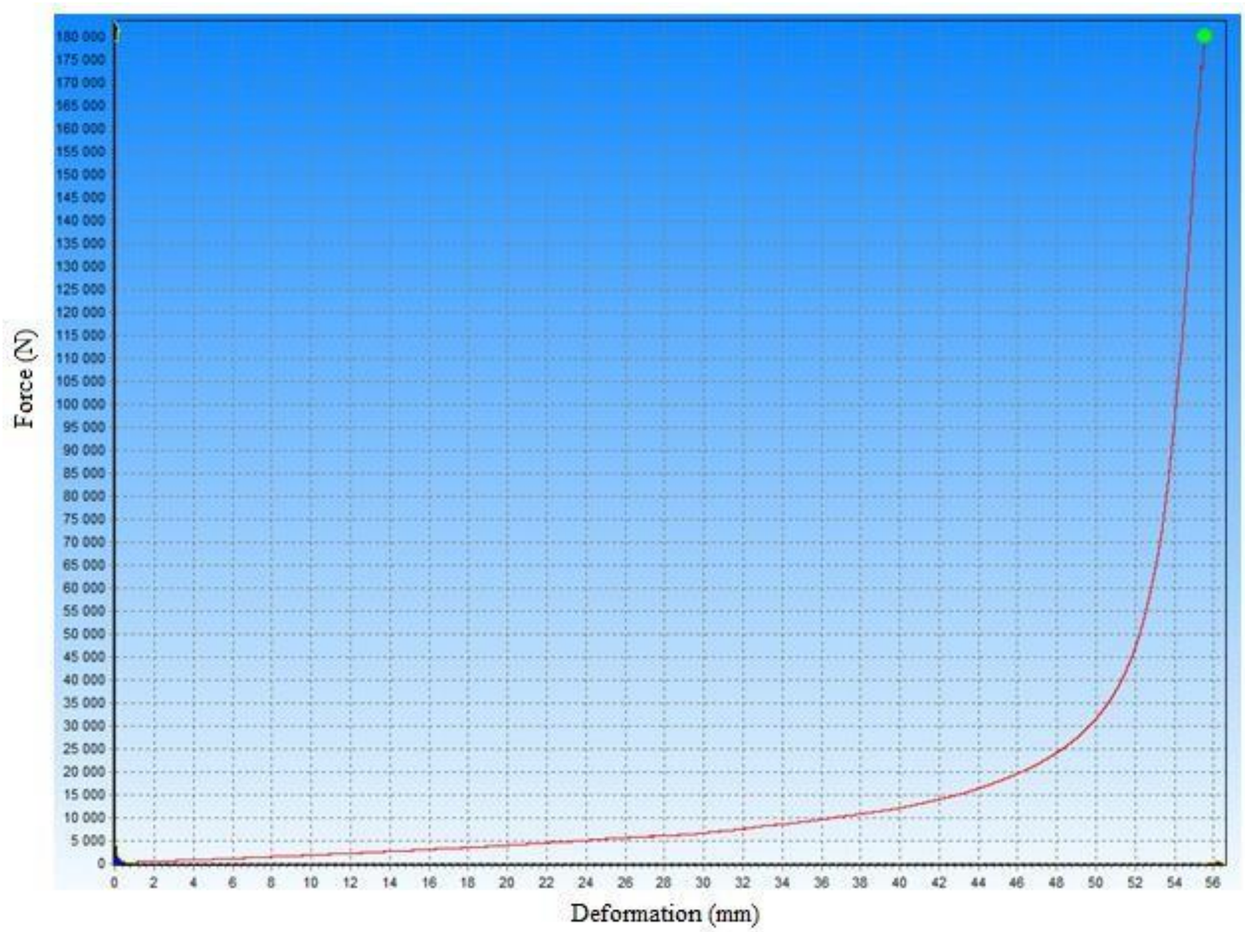
N: Number of samples; N: Number of samples; N: Number of samples; F_r: Maximum force; D_f: Deformation; H_d: Hardness; ε_n: Strain; σ_s: Stress; SD: Standard Deviation; CV: Coefficient of Variation and SE: Standard Error.



Appendix 7. Experimental force-deformation curve of hemp bulk oilseeds sample for the first test like the other tests conducted.



Appendix 8. Experimental force-deformation curve of pumpkin bulk oilseeds sample for the first test like the other tests conducted.



Appendix 9. Experimental force-deformation curve of sunflower bulk oilseeds sample for the first test like the other tests conducted.