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Sunflower oil obtained by a new device and extraction system using hydrostatic pressing

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SUMMARY: This study aims to extract sunflower oil using a new hydrostatic pressing system that can operate under different pressures and extraction times. The extraction process was conducted with a press of 50,000 psi (344.74 MPa) capacity. Three different extraction times: 2, 4, and 8 hours, and three different pressures: 10,000, 20,000, and 30,000 psi (68.95, 137.89, 206.84 MPa) were tested. A custom reactor was developed for use with the hydrostatic press. The yield, calculated as the ratio of the mass of the obtained oil to the mass of the grain or seed used, and various properties of the oil obtained through hydrostatic pressing were determined. The results show that the yield of vegetable oil increases with both higher pressure and longer extraction times. The maximum oil yield achieved was 45.17% when using 30,000 psi (206.84 MPa) pressure and an 8-hour extraction time. Under these optimal conditions, the oil properties were as follows: an acid value of 0.8 mg KOH/g, a density of 900.7 kg/m^3, and a kinematic viscosity of 47.4 mm^2/s.

KEYWORDS*: Hydrostatic pressing; Physicochemical characterization; Press reactor; Sunflower oil; Yield.*

RESUMEN: ***Obtención de aceite de girasol mediante un nuevo dispositivo y sistema de extracción usando prensado hidrostático.*** Este trabajo tiene como objetivo obtener aceite de girasol mediante un nuevo sistema de extracción por prensado hidrostático que puede operar bajo diferentes presiones y tiempos de extracción. La extracción se realizó utilizando una prensa con una capacidad de 50.000 psi (344,74 MPa). Se emplearon tres tiempos de extracción: 2, 4 y 8 horas y tres presiones: 10.000, 20.000 y 30.000 psi (68,95, 137,89 y 206,84 MPa). Se desarrolló un reactor específico para su uso en la prensa hidrostática. Se determinaron los rendimientos, calculados como la relación entre la masa del aceite obtenido, y la masa de los granos o semillas utilizados y algunas propiedades de los aceites obtenidos mediante este método. Los resultados muestran que el rendimiento del aceite vegetal aumenta con la presión y el tiempo de extracción. El rendimiento máximo alcanzado fue del 45,17% al utilizar 30.000 psi (206,84 MPa) y un tiempo de extracción de 8 horas. Bajo estas condiciones óptimas, las propiedades del aceite fueron las siguientes: índice de acidez de 0,8 mg KOH/g, densidad de 900,7 kg/m^3 y viscosidad cinemática de 47,4 mm^2/s.

PALABRAS CLAVE*: Aceite de girasol; Caracterización fisicoquímica; Prensado hidrostático; Producción; Reactor de prensa.*

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1. INTRODUCTION

Vegetable oils are extracted from the seeds, fruits, or grains of plants. Used for thousands of years, these oils serve a variety of purposes, including culinary uses, skincare, and hair care, as well as being a raw material for biodiesel production. They are crucial for the body's proper functioning and are an excellent source of essential fatty acids, vitamins, and other nutrients. The market offers a wide range of vegetable oils, each with its own unique properties.

Vegetable oils can be extracted using conventional methods such as cold pressing and solvent extraction. Cold pressing yields a higher-quality oil, though it produces lower quantities. This method allows the oil to be used directly, as there are no contaminants in the pressing process, and it is considered more sustainable.

On the other hand, solvent extraction is generally more cost-effective but can have environmental and health impacts depending on the type of solvent used.

Other methods for extracting vegetable oils include supercritical CO_2 extraction (Mitra *et al*., 2009), aqueous enzymatic processing (Rosenthal *et al*., 1996), microwave extraction (Jiao *et al*., 2014), ultrasound extraction (Long *et al*., 2011), high-pressure extraction (Gros *et al*., 2003), and extrusion (Jung and Mahfuz, 2009).

Processes that improve extractability are pre-treatment or preparatory steps aimed at enhancing the efficiency of the extraction process. Their goal is to modify the raw material to facilitate the extraction of valuable compounds. Examples include mechanical pre-treatments, thermal treatments, enzymatic treatments, and solvent pre-treatment.

Purely extractive processes, on the other hand, focus directly on isolating the desired compounds from the raw material. These processes do not involve any preparatory steps to modify the material but instead aim to extract the target substances as efficiently as possible. Examples include cold pressing or mechanical pressing, solvent extraction, and supercritical fluid extraction.

The sunflower (*Helianthus annuus* L.) seed is rich in highly nutritious oil, making it a significant oilseed (Gupta and Das, 2000). Sunflower oil contains mainly omega-6, and -9 fatty acids, vitamin E, and possesses anti-inflammatory and antioxidant properties. In addition. sunflower oil contains tocopherols and sterols, which are important compounds that contribute significantly to its health benefits (Nakonechna *et al*., 2024). Sunflower oil has been shown to offer cardiovascular benefits. In pharmacy, it is used to treat cholesterol issues and atherosclerosis (Devi *et al*., 2010). For cosmetic purposes, sunflower oil is beneficial for moisturizing the skin, treating acne, and preventing hair loss and thinning. Sunflower oil is widely used in cooking, cosmetics, and other applications (Moigradean *et al*., 2014).

The following methods for obtaining sunflower oil are discussed:

Sunflower crude oil was produced using hot pressing, cold pressing, and solvent extraction. The values of the quality parameters varied depending on the oil processing method. Specifically, the acid value of the crude sunflower oil obtained by cold pressing was lower than that of the oil obtained by hot pressing. Additionally, the saponification value increased from crude sunflower oil obtained by cold pressing to that obtained by extraction. These results suggest that cold pressing is a superior method compared to hot pressing and solvent extraction. (Moigradean *et al*., 2014).

Sunflower oil was extracted using various enzymes, and its quality was compared with that obtained through conventional solvent and pressing methods, focusing on tocopherol and phytosterol contents as well as antioxidant capacity. The use of enzymes in the extraction process results in high-quality oil and represents an environmentally friendly methodology (Ribeiro *et al*., 2016). In enzymatic oil extraction, various enzymes are used to break down the cellular structures of the raw material, allowing for more efficient oil release. These enzymes target complex components such as proteins, fibers, and polysaccharides that make up the cell walls and membranes of plant cells. Some of the key enzymes used in the extraction process include cellulases, pectinases, lipases, and hemicellulases.

A sunflower oil yield of 26.72% was obtained using a vertical press with a piston extraction method. The extraction parameters were a piston speed of 2 mm/min, a maximum force of 100 kN, and temperature of 30 °C. Hydraulic extraction is influenced by several factors, with the most important being the type of oilseed material, pressing time, and temperature (Ionescu *et al*., 2016).

The oil yield is calculated as the ratio of the mass of the obtained oil to the mass of the grain or seed used.

A sunflower oil yield of 21.35% was obtained using hexane as solvent in a bath extractor at a temperature of 50 °C (Pérez *et al*., 2019).

A sunflower oil yield of 41% was achieved using the mechanical pressing extraction method. This result suggests that sunflower seed oil is better suited for consumption as food rather than for industrial applications (Oguche, 2021).

In this research, a new method for extracting vegetable oil using a hydrostatic press was developed. The extraction was performed with a press of 50,000 psi capacity. Three extraction times (2, 4, and 8 hours) and three pressures: 10,000 psi (68.95 MPa), 20,000 psi (137.89 MPa), and 30,000 psi (206.84 MPa) were employed. A specialized reactor for use in the hydrostatic press was also developed. Oils were extracted from various raw materials, with the results for sunflower seeds presented in this article. This new method provides high-quality oil and is environmentally friendly, leaving no toxic solvent residues (dos Santos, 2023; dos Santos *et al*., 2024).

2. MATERIALS AND METHODS

2.1. The extraction system

A device (Figure 1) was developed for extracting vegetable oils using a hydrostatic pressurization system. This device can operate with extraction times similar to those of other presses, but it offers greater forces and pressures, enhancing safety and improving yield.

Given that the device operates under hydrostatic pressure, it was crucial to select a material resistant to both environmental conditions and the fluid used, which is water. The chosen material was 316L stainless steel, which can withstand both the water and the applied pressure of up to 30,000 psi.

The hydrostatic pressing system for extracting vegetable oil, developed in this research, consists of the following components:

- A hydropneumatic pump with a pressurization capacity of up to 50,000 psi (344.74 MPa).
- A stainless steel pressure gauge.
- Needle valves for hydropneumatic pump block and pressure drain.
- A ball valve for pump air block.
- An air regulator for system pressure regulation.
- A pressure transmitter to monitor pressure and extraction time.
- The extraction device, which includes a locking nut, sealing pin, body (28 mm in diameter and 200 mm in length), and extraction cylinder (dos Santos, 2023; dos Santos *et al*., 2024).

The diagram in Figure 1 illustrates the system arrangement. The extraction device (10), where the raw material is stored, is connected to a pressure transmitter (9), a needle valve (5), and a hydropneumatic pump (4).

The pressure transmitter (9) controls both the pressure and extraction time in the extraction device (10), based on the parameters previously defined by the user. Monitoring occurs during system operation, as pressure is applied, with the help of the installed instrumentation. Once the extraction time is completed, the needle valve (5), located at the outlet of the extraction device (10), is opened, allowing the extracted oil to drain into a collection container.

2.2. Extraction of vegetable oil by hydrostatic pressing

The extraction of vegetable oil from sunflower seeds was achieved using a hydrostatic pressing system with a working pressure capacity of 50,000 psi (344.74 MPa). The system includes a hydrostatic test unit and an extraction device made from 316L stainless steel. The device is fully dismountable, which facilitates handling, cleaning, and maintenance of the sealing system after the extraction and removal of the oil (dos Santos, 2023; dos Santos *et al*., 2024).

The sunflower seeds used for vegetable oil extraction were purchased from the local market.

The first step in the hydrostatic pressing extraction experiments was to select and weigh the grain and seed, which were manually shelled and then oven-

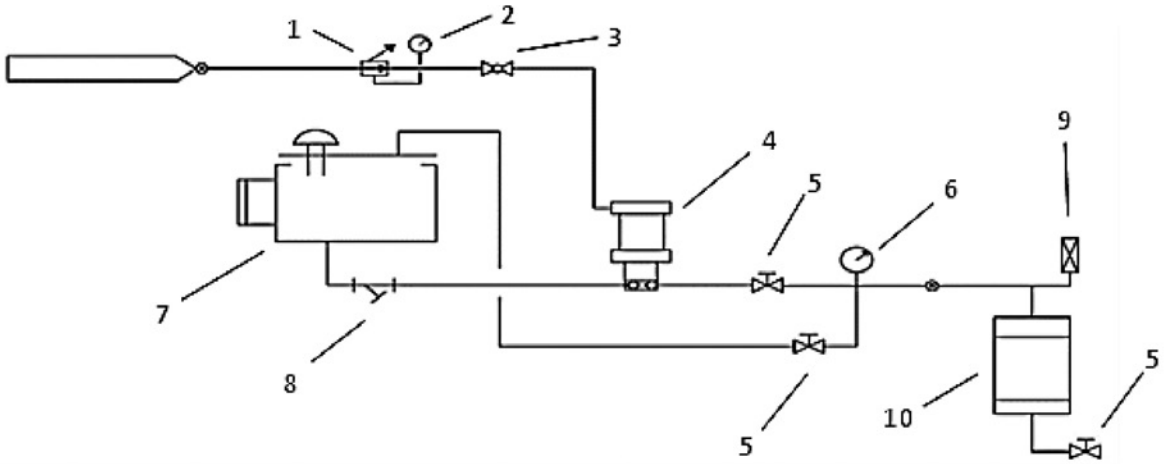

Figure 1. Diagram of the oil extraction system: air regulator (1); pressure gauge (2); ball valve (3); hydropneumatic pump (4); needle valves (5); test pressure gauge (6); reservoir (7); Y-strainer (8); pressure transmitter (9); extraction device (10).

dried at 60 °C. This preparation aimed to facilitate the extraction process by reducing extraction time, minimizing cake residue, and maximizing oil yield.

The sunflower seeds were weighed and placed in a stainless steel reactor, which was then connected to the hydrostatic test unit. A pressure of 10,000 psi was applied for 2 hours. The crude oil collected was weighed and stored in a closed amber bottle at room temperature.

The test was repeated twice using the same amount of raw material, with pressures of 20,000 psi (137.89 MPa) and 30,000 psi (206.84 MPa). The extraction was conducted under the following conditions: pressures of 10,000 psi (68.95 MPa), 20,000 psi (137.89 MPa), and 30,000 psi (206.84 MPa) for durations of 2, 4 and 8 hours. All steps were performed at room temperature to compare the oil yield under these varying conditions.

2.3. Determination of Yield and Oil Characterization

2.3.1. Oil yield

Oil yield refers to the amount of oil extracted from a specific quantity of raw material (such as seed or grain). The purpose is to assess the efficiency of the extraction process, i.e., how much oil can be obtained from the raw material. The mass of the oil is measured immediately after extraction and filtration using a scale. The oil yield is then calculated as the ratio of the mass of the extracted oil to the mass of the raw material used, and is typically expressed as a ratio or percentage.

To determine the oil yield after filtration, the crude oil was filtered using filter paper.

2.3.2. Acid value

The acid value is an important parameter for determining whether oil is suitable for edible or industrial purposes. For edible uses, the acid value should not exceed 4 mg KOH/g (Amoo *et al.*, 2004). High acid values indicate a high content of free fatty acids, which can cause the oil to turn sour (Moigradean *et al*., 2014).

The oil acid value is determined using Equation 1 (ISO 660):

$$AV = \frac{VxCx56.11}{m} \quad (1)$$

Where:
AV is the acid value (mg KOH/g);
V is the volume of KOH used in the sample titration (mL);
C is the molar concentration of KOH solution (mol/L);
m is the mass sample (g).

2.3.3. Density

Density is a crucial property of fluids, used in developing correlation equations and equations of state. Fluid density values are important for the custody transfer of fluids, as well as other applications (dos Santos Junior *et al*., 2022).

The density was determined using a pycnometer (ISO 3507). The pycnometer was initially washed with neutral detergent, then rinsed with petroleum ether, and dried in an oven at 105 ºC for approximately 30 minutes. It was then filled with deionized water and placed in a thermostatic bath until the water temperature reached 20 ºC, as measured by a thermometer. Once the temperature was stabilized, the pycnometer was removed from the bath and its external surface was carefully dried with a paper towel. Finally, the pycnometer was weighed on a digital scale. By knowing the density of water at 20 ºC, the true volume of the pycnometer was determined.

The pycnometer was washed between each sunflower oil analysis in the same manner as during calibration. After washing, it was dried in an oven at 105 ºC for 30 minutes, then cooled to room temperature and weighed on a digital balance to determine its mass. Each sunflower oil was homogenized before being placed in the pycnometer, which was then submerged in a thermostatic bath until the fluid reached a temperature of 20 ºC. The pycnometer was removed from the bath, and its exterior was carefully dried before weighing. The density of each sunflower oil was calculated by dividing the mass of the sample by the volume of the pycnometer, according to Equation (2):

$$\rho = \frac{m_{po} - m_{pe}}{V_p} \quad (2)$$

Where:
ρ - density (kg·m^{-3});
m_{po} - Mass of the pycnometer with sunflower oil (kg);
m_{pe} - Mass of the empty pycnometer (kg);
V_p - Pycnometer volume (m^3).

2.3.4. Viscosity

Viscosity is an important property that describes a fluid's resistance to flow.

The Cup Ford method was used to determine the viscosity of the oils obtained from the vegetable oil extraction system using hydrostatic pressing.

The Cup Ford viscometer, manufactured by Metalúrgica Tech Vision Ltda and compliant with ASTM D1200 standards, was used for the viscosity measurements. This instrument is designed for easy use in determining the kinematic viscosity of paints, varnishes, resins, and other Newtonian liquids at 25 ºC, with efflux times ranging from 20 to 100 seconds. The viscosity is calculated by inserting the measured efflux time into the corresponding equation for the specific Cup Ford model used.

The tests were conducted following these steps: First, the appropriate orifice was selected. At the time of testing, both the viscometer and the material to be tested were ensured to be at a temperature of 25 ± 0.1 ºC. The device was leveled on a laboratory bench. The orifice was closed with a finger, and the sample cup was filled to the top of the device to prevent interference from air bubbles; any excess was removed using a flat glass plate. The finger was then removed from the orifice, and a stopwatch was started simultaneously. The efflux time, noted as the moment when the flow first stops, was measured in seconds. The viscometer was cleaned after each measurement, with special attention given to the drain hole, using an appropriate solvent. Each test was performed in duplicate to ensure accuracy.

The dynamic viscosity of the sunflower oil was obtained by multiplying its kinematic viscosity by its density.

2.4. Analysis of variance (ANOVA)

Analysis of variance (ANOVA) is a statistical method used to compare means among three or more groups to determine if at least one group mean is statistically different from the others.

The steps of ANOVA are as follows: determine the mean of each group; find the mean of all groups combined; measure how much the group means deviate from the overall mean; measure how much individual observations within each group deviate from their group mean; and calculate the F-statistic, which is the ratio of between-group variability to within-group variability. A larger F-value suggests a significant difference among the group means.

The ANOVA p-value determines the significance level (commonly $\alpha = 0.05$). If the p-value is less than α, you reject the null hypothesis, concluding that at least one group mean is different. If significant differences are found, further tests, like Tukey's HSD, can identify which specific groups differ.

More details about the ANOVA can be found in Hardle and Simar (2015) and Heiberger and Holland (2015).

In this study, the ANOVA was conducted to assess the impact of extraction pressures (10,000, 20,000, and 30,000 psi) and extraction times (2, 4, and 8 hours) on sunflower oil yield, acid value, density, and viscosity.

2.5. Tukey test

The Tukey test, specifically Tukey's Honestly Significant Difference (HSD) test, is a post-hoc analysis used after a significant ANOVA result to determine which specific group means are significantly different from each other.

The steps of the Tukey test are as follows: calculate the group means; calculate the overall mean; calculate the mean square error; calculate the Tukey HSD statistic (minimum significant difference); and compare the differences.

If the difference between two group means exceeds the calculated Tukey HSD Statistic value, you reject the null hypothesis for that pair, indicating that the group means are significantly different.

More details about the Tukey test can be found in Heiberger and Holland (2015) and Dean and Voss (1999)

3. RESULTS AND DISCUSSION

3.1. Sunflower oil extraction yield

Table 1 presents the data and yield for sunflower oil extraction.

As shown in Table 1, the sunflower oil yield increased with both higher pressure and longer extraction time. The highest yield, 45.17%, was achieved with a pressure of 206.84 MPa and an extraction time of 8 hours. The yield of the filtered

Table 1. Sunflower oil extraction data.

Exp.	Extraction Pressure (MPa)	Extraction Time (h)	Sunflower mass (g)	Sunflower oil mass (g)	Yield (%)	Sunflower oil mass after filtering (g)	Yield after filtering (%)
1	68.95	2	5.93	1.96	33.05±0.76	1.88	31.70±0.73
2	68.95	4	6.00	2.05	34.17±0.78	1.99	33.17±0.76
3	68.95	8	6.00	2.11	35.17±0.81	2.01	33.50±0.77
4	137.89	2	5.97	2.18	36.52±0.84	2.11	35.34±0.81
5	137.89	4	5.89	2.26	38.37±0.88	2.18	37.01±0.85
6	137.89	8	6.00	2.35	39.17±0.90	2.29	38.17±0.88
7	206.84	2	6.01	2.48	41.26±0.95	2.42	40.27±0.93
8	206.84	4	5.99	2.57	42.90±0.99	2.51	41.90±0.96
9	206.84	8	6.00	2.71	45.17±1.04	2.64	44.00±1.01

Each result represents the average of three tests

sunflower oil was very close to that of the crude oil. The average yield of sunflower oil across all experiments was 38.42% (standard deviation = 4.11). Each result presented in Table 1 represents the average of three tests.

Table 2 compares the maximum sunflower oil extraction yield from this study with yields reported in the literature.

As shown in Table 2, the sunflower oil yield obtained using the hydrostatic pressing method was the highest compared to other methods, except for the yield reported by Ribeiro *et al*. (2016) using a solvent extraction method.

3.1.1. Analysis of variance (ANOVA) - the influence of extraction pressure on sunflower oil yield

ANOVA was employed to determine whether significant differences exist in yield based on extraction pressure (psi). The data were organized into three groups (68.95, 137.89 and 206.84 MPa), with each group containing three yield values corresponding to the extraction times of 2, 4, and 8 hours.

Table 2. Sunflower oil extraction yield: present and published results.

Work	Extraction method	Maximum sunflower oil yield (%)
Present	Hydrostatic pressing	45.2
Ribeiro *et al*., 2016	Enzymatic	36.6
Ribeiro *et al*., 2016	Pressing	36.8
Ribeiro et al., 2016	Solvent	55.1
Ionescu *et al*., 2016	Hydraulic pressing	26.7
Oguche, 2021	Mechanical pressing	41.0

Applying ANOVA to the data in Table 1, we obtained an F-statistic of 26.7336 and a p-value of 0.001027. The F-critical value at a significance level of 0.05 was 5.1433. Since the F-statistic was greater than the F-critical value and the p-value was less than 0.05, there were significant differences in the group means for the different extraction pressures. This indicates that extraction pressure significantly influenced the yield of sunflower oil.

Applying the Tukey test, we obtained a Tukey HSD statistic of 3.7793.

The differences between all combinations of group means were as follows: 3.89 for the 68.95 vs. 137.89 MPa groups, 8.98 for the 68.95 vs. 206.84 MPa groups, and 5.09 for the 137.89 vs. 206.84 MPa groups.

Since the differences in group means were greater than the Tukey HSD statistic value, it was concluded that all pairs of groups had significant differences in their yield means, indicating that extraction pressure had a significant effect on yield and that yields differed between the pressure levels of 68.95, 137.89 and 206.84 MPa.

3.1.2. Analysis of variance (ANOVA) – the influence of extraction times on sunflower oil yield

ANOVA was employed to determine whether there were significant differences in yield based on extraction times (h). The data were organized into three groups (2, 4, and 8 hours), with each group containing three yield values corresponding to the three extraction pressures (68.95, 137.89 and 206.84 MPa).

Upon applying ANOVA to the data presented in Table 1, we obtained an F-statistic of 0.3073 and

a p-value of 0.7464. The F- critical value at a 0.05 significance level was 5.1433. Since the F-statistic was less than the F-critical value and the p-value exceeded 0.05, there were no significant differences in group means across the different extraction times. Thus, extraction times did not significantly influence the yield of sunflower oil.

As the F-statistic was less than the F-critical value, there were no significant differences among the group means, and therefore, the Tukey test was not applied.

3.2. Sunflower oil acid value

Table 3 shows the acid value of sunflower oil.

As shown in Table 3, the minimum acid value of sunflower oil (0.6 mg KOH/g) was achieved with a pressure of 137.89 MPa and an extraction time of 4 hours. The average acid value for sunflower oil across all experiments was 1.1 mg KOH/g (standard deviation = 0.5). Each result presented in Table 3 represents the average of three tests.

Table 4 compares the sunflower oil acid value (0.8 mg KOH/g) obtained under the maximum yield conditions (206.84 MPa pressure and 8 hours extraction time) with values reported in other published studies.

Based on the acid value obtained, the sunflower oil produced through hydrostatic pressing is suitable for edible uses.

If the vegetable oil refining is compulsory, higher acidity values could be corrected during refining.

Pressure can have some influence on the acid value of vegetable oil during the extraction process, although this effect is generally minimal under typical extraction conditions.

Table 3. Sunflower oil acid value.

Exp.	Extraction Pressure (MPa)	Extraction Time (h)	Sunflower oil acid value (mg KOH/g)
1	68.95	2	0.8±0.1
2	68.95	4	2.0±0.2
3	68.95	8	1.8±0.2
4	137.89	2	0.8±0.1
5	137.89	4	0.6±0.1
6	137.89	8	0.8±0.1
7	206.84	2	1.0±0.1
8	206.84	4	0.9±0.1
9	206.84	8	0.8±0.1

Each result represents the average of three tests

Table 4. Sunflower oil acid value: present and published results.

Work	Extraction method	Sunflower oil acid value (mg KOH/g)
Present	Hydrostatic pressing	0.8
Jamal and Kareem, 2022	Solvent (hexane)	0.9
Jamal and Kareem, 2022	Ultrasound 5s and hexane	0.8
Jamal and Kareem, 2022	Ultrasound 15s and hexane	0.6
Oguche, 2021	Mechanical pressing	0.4
Moigradean *et al.,* 2014	Hydraulic pressing	0.1
Moigradean *et al*., 2014	Hot pressing	0.4
Moigradean *et al*., 2014	Solvent (petroleum ether)	3.0

3.2.1. Analysis of variance (ANOVA) - the influence of extraction pressure on sunflower oil acid value

ANOVA was used to assess whether there were significant differences in acid value based on extraction pressure (psi). The data were organized into three groups (68.95, 137.89 and 206.84 MPa), with each group containing three acid values corresponding to the three extraction times (2, 4, and 8 hours).

Applying ANOVA to the data in Table 3, we obtained an F-statistic of 3.6718 and a p-value of 0.09092. The F-critical value at a 0.05 significance level was 5.1433. Since the F-statistic was less than the F-critical value and the p-value exceeded 0.05, there were no significant differences in group means across different extraction pressures. Therefore, extraction pressure did not significantly influence the acid value of sunflower oil.

As the F-statistic was less than the F-critical value, there were no significant differences among the group means, and the Tukey test was not applied.

3.2.2. Analysis of variance (ANOVA) - the influence of extraction times on sunflower oil acid value

ANOVA was employed to determine whether there were significant differences in acid value based on extraction times (h). The data were organized into three groups (2, 4, and 8 hours), with each group containing three acid values corresponding to the three extraction pressures (68.95, 137.89 and 206.84 MPa).

Applying ANOVA to the data in Table 3, we obtained an F-statistic of 0.2734 and a p-value of 0.7698. The F-critical value at a 0.05 significance level was 5.1433. Since the F-statistic was less than the F-critical value and the p-value exceeded 0.05, there were no significant differences in group means across different extraction times. Thus, extraction times did not significantly influence the acid value of sunflower oil.

As the F-statistic was less than the F-critical value, there were no significant differences among the group means, and therefore, the Tukey test was not applied.

3.3. Sunflower oil density

Table 5 shows the density of sunflower oil at 20 ºC.

The highest density of sunflower oil at 20 ºC (900.8 kg/m^3) was obtained with a pressure of 206.84 MPa and an extraction time of 2 hours. The average density of sunflower oil across all experiments was 880.2 kg/m^3 (standard deviation = 27.2). Each result presented in Table 5 represents the average of three tests.

Table 6 compares the sunflower oil density (900.7 kg/m^3) under maximum yield conditions (206.84 MPa pressure and 8 hours extraction time) with values reported in other published studies.

The density of sunflower oil produced through hydrostatic pressing was comparable to that obtained using other extraction methods.

Changes in pressure will cause a small change in density, but the effect is typically minor under standard conditions used for oil extraction.

Table 5. Sunflower oil density at 20 ºC.

Exp.	Extraction Pressure (MPa)	Extraction Time (h)	Sunflower oil density (Kg·m^{-3})
1	68.95	2	848.3±4.2
2	68.95	4	850.4±4.2
3	68.95	8	925.7±4.6
4	137.89	2	856.3±4.3
5	137.89	4	866.6±4.3
6	137.89	8	875.0±4.4
7	206.84	2	900.8±4.5
8	206.84	4	898.3±4.5
9	206.84	8	900.7±4.5

Each result represents the average of three tests

Table 6. Sunflower oil density: present and published results.

Work	Extraction method	Sunflower oil density (Kg·m^{-3})
Present	Hydrostatic pressing	900.7 (at 20 ºC)
Jamal and Kareem 2022	Solvent (hexane)	918.0 (at 25 ºC)
Jamal and Kareem 2022	Ultrasound 5s and hexane	921.0 (at 25 ºC)
Jamal and Kareem 2022	Ultrasound 15s and hexane	926.0 (at 25 ºC)
Davies 2016	n.a*	910.0 (at 20 ºC)
Esteban et al. 2012	n.a*	916.9 (at 20 ºC)

n.a – not available
* - oil purchased from local market

3.3.1. Analysis of variance (ANOVA) - the influence of extraction pressure on sunflower oil density

ANOVA was used to determine whether there were significant differences in density based on extraction pressure (psi). The data were organized into three groups (68.95, 137.89 and 206.84 MPa), with each group containing three density values corresponding to the three extraction times (2, 4, and 8 hours).

Applying ANOVA to the data in Table 5, we obtained an F-statistic of 1.3743 and a p-value of 0.3226. The F-critical value at a 0.05 significance level was 5.1433. Since the F-statistic was less than the F-critical value and the p-value exceeded 0.05, there were no significant differences in group means across the different extraction pressures. Therefore, extraction pressure did not significantly influence the density of sunflower oil.

As the F-statistic was less than the F-critical value, there were no significant differences among the group means, and consequently, the Tukey test was not applied

3.3.2. Analysis of variance (ANOVA) - the influence of extraction times on sunflower oil density

ANOVA was used to determine whether there were significant differences in density based on extraction times (h). The data were organized into three groups (2, 4, and 8 hours), with each group containing three density values corresponding to the three extraction pressures (68.95, 137.89 and 206.84 MPa).

Applying ANOVA to the data in Table 5, we obtained an F-statistic of 1.3690 and a p-value of 0.3237. The F-critical value at a 0.05 significance

level was 5.1433. Since the F-statistic was less than the F-critical value and the p-value exceeded 0.05, there were no significant differences in group means across the different extraction times. Thus, extraction times did not significantly influence the density of sunflower oil.

As the F-statistic was less than the F-critical value, there were no significant differences among the group means, and therefore, the Tukey test was not applied.

3.4. Viscosity of sunflower oil

Table 7 shows the kinematic viscosity of sunflower oil at 25 ºC. As shown in Table 7, the viscosity values were similar across all experiments. The highest kinematic viscosity of sunflower oil at 25 ºC (47.4 mm^2/s) was achieved with a pressure of 206.84 MPa and an extraction time of 8 hours. The average kinematic viscosity of sunflower oil across all experiments was 45.0 mm^2/s (standard deviation = 1.1). Each result presented in Table 7 represents the average of three tests.

Table 8 compares the sunflower oil viscosity (47.4 mm^2/s) under maximum yield conditions (206.84 MPa pressure and 8 hours extraction time) with values reported in other published studies. The dynamic viscosity of sunflower oil was calculated by multiplying the kinematic viscosity by the density, resulting in a value of 42.6 mPa·s.

The viscosity of sunflower oil produced through hydrostatic pressing is comparable to that obtained using other extraction methods.

Pressure can influence the viscosity of vegetable oils during extraction, although the effect is generally more noticeable at extreme pressures or when dealing with high-temperature processes

Table 7. Sunflower oil kinematic viscosity at 25 ºC.

Exp.	Extraction Pressure (MPa)	Extraction Time (h)	Sunflower oil kinematic viscosity ($mm^2 \cdot s^{-1}$)
1	68.95	2	43.3±0.4
2	68.95	4	44.8±0.4
3	68.95	8	44.1±0.4
4	137.89	2	45.2±0.5
5	137.89	4	45.2±0.5
6	137.89	8	45.0±0.5
7	206.84	2	44.8±0.4
8	206.84	4	45.2±0.5
9	206.84	8	47.4±0.5

Each result represents the average of three tests

3.4.1. Analysis of variance (ANOVA) – the influence of extraction pressure on sunflower oil viscosity

ANOVA was used to determine whether there were significant differences in viscosity based on extraction pressure (psi). The data were organized into three groups (68.95, 137.89 and 206.84 MPa), with each group containing three viscosity values corresponding to the three extraction times (2, 4, and 8 hours).

Applying ANOVA to the data in Table 7, we obtained an F-statistic of 2.7122 and a p-value of 0.1449. The F-critical value at a 0.05 significance level was 5.1433. Since the F-statistic was less than the F-critical value and the p-value exceeded 0.05, there were no significant differences in group means

Table 8. Sunflower oil viscosity: present and published results.

Work	Extraction method	Sunflower oil kinematic viscosity ($mm^2 \cdot s^{-1}$)	Sunflower oil dynamic viscosity (mPa.s)
Present	Hydrostatic pressing	47.4 (at 25 ºC)	42.6 (at 25 ºC)
Jamal and Kareem, 2022	Solvent (hexane)		57.5 (at 25 ºC)
Jamal and Kareem, 2022	Ultrasound 5s and hexane		60.5 (at 25 ºC)
Jamal and Kareem, 2022	Ultrasound 15s and hexane		65.0 (at 25 ºC)
Abramovic and Klofutar, 1998	n.a	–	49.1 (at 25 ºC)
Davies, 2016	n.a*	–	26.0 (at 30 ºC)
Diamante and Lan, 2014	n.a*	–	48.8 (at 30 ºC)
Esteban *et al.,* 2012	n.a*	48.6 (at 30 ºC)	

n.a – not available
* - oil purchased from local market

across the different extraction pressures. Therefore, extraction pressure did not significantly influence the viscosity of sunflower oil.

As the F-statistic was less than the F-critical value, there were no significant differences among the group means, and consequently, the Tukey test was not applied.

3.4.2. Analysis of variance (ANOVA) - the influence of extraction times on sunflower oil viscosity

ANOVA was used to determine whether there were significant differences in viscosity based on extraction times (h). The data were organized into three groups (2, 4, and 8 hours), with each group containing three viscosity values corresponding to the three extraction pressures (68.95, 137.89 and 206.84 MPa).

Applying ANOVA to the data in Table 7, we obtained an F-statistic of 0.6529 and a p-value of 0.5539. The F-critical value at a 0.05 significance level was 5.1433. Since the F-statistic was less than the F-critical value and the p-value exceeds 0.05, there were no significant differences in group means across the different extraction times. Therefore, extraction times did not significantly influence the viscosity of sunflower oil.

As the F-statistic was less than the F-critical value, there were no significant differences among the group means, and consequently, the Tukey test was not applied.

4. CONCLUSIONS

The newly developed vegetable oil extraction system using hydrostatic pressing produces high-quality oil and is an environmentally friendly method, free from toxic solvent residues.

The maximum sunflower oil yield of 45.17%, achieved under the conditions of maximum extraction pressure and maximum extraction time (206.84 MPa and 8 hours), is comparable to yields obtained through other pressing processes.

The extraction pressure significantly influenced the yield of sunflower oil, as demonstrated by the ANOVA results.

Regarding the physical and chemical aspects analyzed, the sunflower oil obtained in this study using hydrostatic pressing exhibits properties comparable to those of vegetable oils produced by other pressing methods.

Concerning the economic analysis of the new device and extraction system using hydrostatic pressing, it is important to emphasize that this system utilizes conventional, low-cost equipment. As for its potential industrialization, the technical and economic feasibility will be explored in future work.

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DECLARATION OF COMPETING INTEREST

The authors declare that there are no conflicts of interest.

AUTHORSHIP CONTRIBUTION STATEMENT

C. dos Santos: Conceptualization, Investigation, Methodology

R. Pereira: Formal analysis, Methodology, Writing–original draft, Writing–review & editing

REFERENCES

Abramovic H, Klofutar C. 1998, The temperature dependence of dynamic viscosity for some vegetable oils. *Acta Chim. Slov.* **45** (1), 69-77.

Amoo I, Eleyinmi A, Ilelaboye N, Akoja, S. 2004. Characterization of oil extracted from gourd (Cucurbita maxima) seed. *J. Food Agric. Environ.* **2** (2), 38-39.

ASTM 1200:2023, Standard Test Method for Viscosity by Ford Viscosity Cup.

Davies RM. 2016. Effect of the temperature on dynamic viscosity, density and flow rate of some vegetable oils. *J. Sci. Res. Eng. Technol.* **1** (1), 14-24.

Dean A, Voss D. 1999. Design and Analysis of Experiments. Springer.

Devi NKD, Madhavi BR, Mrudula BS, Babu RN. 2010. The importance of biodegradable bio-oil – SUNFLOWER, *Int. J. Pharm. Tech. Res*. **2** (3), 1913-1915.

Diamante LM., Lan T. 2014. Absolute Viscosities of Vegetable Oils at Different Temperatures and Shear Rate Range of 64.5 to 4835 s^{-1}. *J. Food Process.* **2014**, ID 234583. http://dx.doi.org/10.1155/2014/234583.

dos Santos CMA. 2023. Development of a System for Extracting Vegetable Oil Using Hydrostatic Pressing, M.Sc, dissertation, Fluminense Federal University.

dos Santos CMA, Pereira RG., Pereira CR. 2024. Device and System for Extracting Vegetable Oil with Hydrostatic Pressing. Invention Patent. Depositor: Fluminense Federal University. BR 10 2024 017537 9. Deposit: Aug. 26, 2024.

dos Santos Junior JJP, Pereira RG, de Mendonça AJSM, do Espirito Santo Filho DM, Rosendahl-Avelino M, Gouveia JM. 2022. Determination of Density, Isobaric Thermal Expansivity Coefficient and Isothermal Compressibility Coefficient Correlations for n-Dodecane and n-Nonane, as a Function of Temperature and Pressure, *Int. J. Thermophys.* **43**,107. https://doi.org/10.1007/s10765-022-03024-x.

Esteban B, Riba JR, Baquero G, Rius A, Puig R. 2012. Temperature dependence of density and viscosity of vegetable oils. *Biomass Bioenerg.* **42**, 164-171. https://doi.org/10.1016/j.biombioe.2012.03.007.

Gros C, Lanoisellé J, Vorobiev E. 2003. Towards an alternative extraction process for linseed oil. *Chem Eng Res Des.* **81** (9), 1059-1065. https://doi.org/10.1205/026387603770866182

Gupta RK, Das SK. 2000. Fracture resistance of sunflower seed and kernel to compressive Loading, *J. Food Eng.* **46**, 1-8.

Hardle WK, Simar, L. 2015. Applied Multivariate Statistical Analysis, Fourth Edition, Springer. https://doi.org/10.1007/978-3-662-45171-7.

Heiberger RM, Holland B. 2015. Statistical Analysis and Data Display. An Intermediate Course with Examples in R. Second Edition. Springer. https://doi.org/10.1007/978-1-4939-2122-5.

Ionescu M, Voicu GH, Biriş SST, Vlăduţ V, Ungureanu N, Ştefan EM, Dincă M, Matache M. 2016. Oil extraction using a vertical press with piston. 44. Symposium "Actual Tasks on Agricultural Engineering", Opatija, Croatia.

ISO 660:2020, Animal and Vegetable Fats and Oils. Determination of Acid Value and Acidity.

ISO 3507:1999, Laboratory glassware - Pyknometers.

Jamal AR, Kareem AA. 2022, Use of Ultrasound Treatment to Improve Oil Extraction From Sunflower. IOP Conference Series: Earth and Environmental Science, 1060 012081. doi:10.1088/1755-1315/1060/1/012081.

Jiao J, Li Z-G, Gai Q-Y, Li X-J, Wei FY, Fu YJ, Ma W. 2014. Microwave-assisted aqueous enzymatic extraction of oil from pumpkin seeds and evaluation of its physicochemical properties, fatty acid compositions and antioxidant activities. *Food Chem*. **147**, 17-24. https://doi.org/10.1016/j.foodchem.2013.09.079.

Jung S, Mahfuz A. 2009. Low temperature dry extrusion and high-pressure processing prior to enzyme-assisted aqueous extraction of full fat soybean flakes. *Food Chem.* **114** (3), 947-954. https://doi.org/10.1016/j.foodchem.2008.10.044.

Long J-j, Fu Y-j, Zu Y-g, Li J, Wang W, Gu C-b, Luo M. 2011. Ultrasound-assisted extraction of flaxseed oil using immobilized enzymes. *Bioresour Technol.* **102** (21), 9991-9996. https://doi.org/10.1016/j.biortech.2011.07.104.

Mitra P, Hosahalli S, Kyu R, Chang S. 2009. Pumpkin (Cucurbita maxima) seed oil extraction using supercritical carbon dioxide and physicochemical properties of the oil. *J Food Eng*. **95** (1), 208-213. https://doi.org/10.1016/j.jfoodeng.2009.04.033.

Moigradean D, Cula V, Poiana MA. 2014. Quality indices of crude sunflower oil obtained by diferente Methods, *J. Agroaliment. Processes Technol*. **20** (4), 404-407.

Nakonechna K, Ilko V, Bercíková M, Vietoris V, Panovská Z, Doležal M. 2024. Nutritional, Utility, and Sensory Quality and Safety of Sunflower Oil on the Central European Market. *Agriculture* **14**, 536. https://doi.org/10.3390/agriculture14040536.

Oguche SO. 2021. Extraction and Physicochemical Characterization of Sunflower Seed Oil. *Int. J. Sci. Res. Chem. Sci.* **8** (5), 01-03.

Pérez EP, Baümler ER, Crapiste GH, Carelli AA. 2019. Effect of Sunflower Collets Moisture on Extraction Yield and Oil Quality, *Eur. J. Lipid Sci. Technol.* **121** (2), 1800234. https://doi.org/10.1002/ejlt.201800234.

Ribeiro SAO, Nicacio AE, Zanqui AB, Biondo PBF, de Abreu-Filho BA, Visentainer JV, Gomes STM, Matsushita M. 2016. Application of Enzymes in

Sunflower Oil Extraction: Antioxidant Capacity and Lipophilic Bioactive Composition. *J. Braz. Chem. Soc.* **27** (5), 834-840. http://doi.org/10.5935/0103-5053.20150335.

Rosenthal A, Pyle D, Niranjan K. 1996. Aqueous and enzymatic processes for edible oil extraction. *Enzyme Microb. Technol*. **19** (6), 402-420. https://doi.org/10.1016/S0141-0229(96)80004-F.