# UNIAXIAL COMPRESSION TEST OF BULK SOYBEANS UNDER DIFFERENT PRE-TREATMENT TEMPERATURES

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**Abstract.** The study aimed at exploring the effects of different pre-treatment temperatures on bulk soybeans under uniaxial compression test. The initial pressing height of the samples was measured at 40 mm using a pressing vessel of diameter 60 mm with a plunger. The samples were pre-treated at temperatures from 45 to -36 ºC, all at a constant time of 30 minutes. Sample laboratory temperature of 25 ºC served as the control. The dependencies between the force and deformation curves were recorded at a maximum force of 160 kN and a speed of 5 mm min-1. Parameters calculated were mass of oil (g), oil yield (%), volume oil (l), oil expression efficiency (%), energy (J) and volume oil energy ($kJ \cdot l^{-1}$). The ANOVA results showed that deformation was not significant (*P*-value > 0.05) with temperature. Energy, oil expression efficiency and volume oil energy were significant (*P*-value < 0.05) with high coefficients of determination (R2) between 95 and 97 %. The study observed the optimum volume oil energy of 96.21 ± 10.78 $kJ \cdot l^{-1}$ at 75 °C compared to 25 ºC of 128.65 ± 6.42 $kJ \cdot l^{-1}$ and -2 ºC of 195.54 ± 18.35 $kJ \cdot l^{-1}$.

**Keywords:** soybeans, pretreatment, pressing, oil, energy.

## Introduction

In the global oilseed production 2019/2020, soybeans accounted for 337.5 million metric tons compared to copra, cottonseed, palm kernel, peanuts, apeseed and sunflower seed, although the leading vegetable oil worldwide is palm oil [1]. Soybean oil is one of the most widely used industrial bio-based materials [2; 3]. Brazil is currently the world's largest exporter of soybeans, while China is the largest importer, accounting for over 60 % of the world's total exports [4-7], as well as the highest consumption of soybean oil worldwide [6]. Soybean is also a major protein source of animal feed [8]. Both the direct and indirect demands on soybeans thus contribute to the enormous consumption all over the world [5; 8]. Oil extraction involves various preliminary operations, such as grinding, drying and cleaning. However, the total amount of extracted oil thus depends greatly on pressure, temperature, pressing time, moisture content and particle size of the oil-bearing material [9; 10]. Mechanical expression of oil in both linear (uniaxial compression) and non-linear (hydraulic and screw presses) requires the application of pressure with the corresponding speed to force the oil out of the oil-bearing material [11; 12]. Uniaxial and screw press are commonly used methods for oil expression in a small-medium scale production [11; 13-15] compared to large scale production, where advanced techniques and green solvents, such as microwave-assisted and pressurized liquid extractions are used [16; 17].

The present study considered the uniaxial approach, where the material to be pressed is loaded into a pressing chamber with holes at the bottom that allow the oil to escape while the seedcake is retained. Here, the piston applies the desired compressive pressure. In this process, the mechanical properties such as force, deformation and toughness are important for designing oil expression equipment with maximum efficiency in the small-medium scale production, and to achieve this purpose, the oil processing factors need to be understood fully under the uniaxial compression process [18-20].

The study, therefore, evaluated the effects of heating and freezing pre-treatment temperatures on deformation, oil yield, oil expression efficiency, energy and volume oil energy of bulk soybeans under uniaxial compression loading.

## Materials and methods

Bulk soybeans were purchased from the Supermarket in Prague, Czech Republic. The oil content of 11.36 % was determined using a Soxhlet extraction method [21; 22]. The samples were measured at a pressing height of 40 mm using the vessel diameter of 60 mm and a plunger [23], and thereafter pre-treated at temperatures between 45 ºC to -36 ºC. The pre-treated samples were compressed at a

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maximum force of 160 kN and speed of 5 mm·min$^{-1}$ using the universal compression-testing machine (Tempos, ZDM 50, Czech Republic) [24]. The force-deformation curve (Figure 1) data were further processed for the calculation of the energy, which is characterized by the area under the curve [20; 25]. Compression parameters, namely, mass of oil (g), oil yield (%), volume oil (L), oil expression efficiency (%), energy (J) and volume oil energy (kJ·l$^{-1}$) were calculated [14; 26] and statistically analysed using the Statistica software [27] by employing One-Way ANOVA and Correlation techniques.

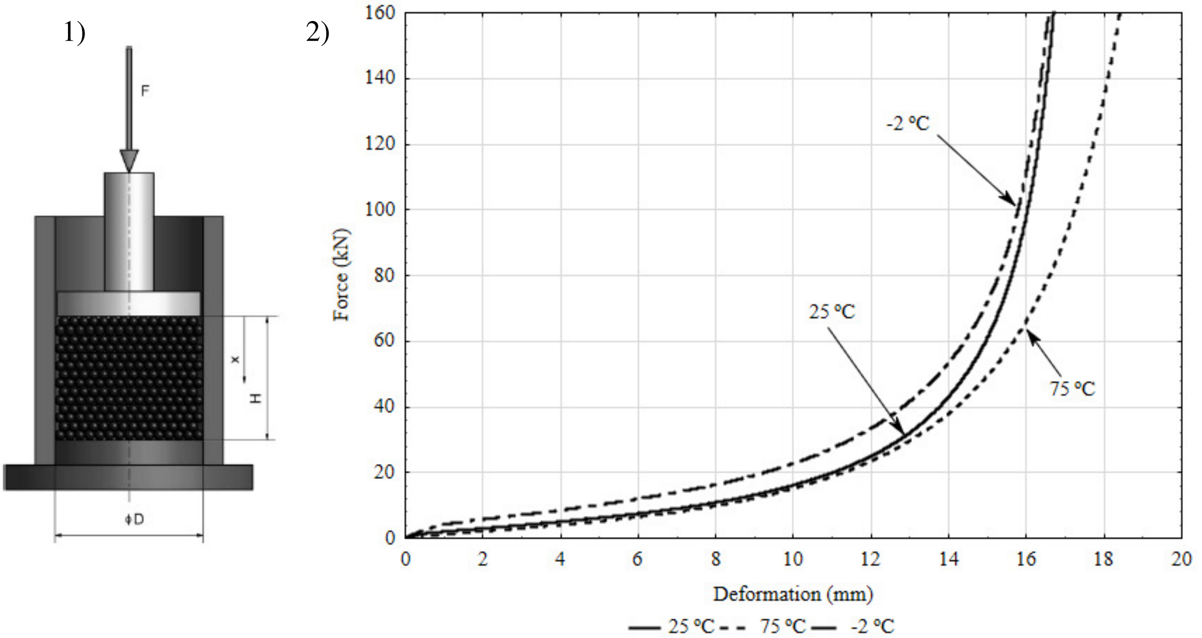


Fig. 1. **Compression test of bulk soybeans:** 1 – vessel diameter of 60 mm with a plunger (*F* – Force, kN; x – deformation, mm; H – pressing height, mm; [23]); 2 – force-deformation curves at different temperatures (-22, -36, 45 and 60 ºC followed similar trends)

## Results and discussion

The results of the provisional study are given in Tables 1 to 4 and Figures 1 to 4. The mass of oil (g), oil yield (%) and the volume oil (l) decreased from -36 ºC to -2 ºC and then increased from 25 ºC until 75 ºC (Table 1). In other words, a decrease in the freezing temperatures from -2 ºC to -36 ºC and an increase in the heating temperatures from 45 ºC to 75 ºC significantly ($P$-value < 0.05) increased the mass of oil, oil yield and the volume oil with high coefficients of determination ($R^2$) of approximately 97 % based on the ANOVA results. The control (25 ºC) showed almost similar values to that of 45 ºC heating temperature.

Table 1

**Mass of oil, oil yield and volume oil of bulk soybeans**

| **Temperature, ºC** | ****Mass of oil, g** | **Oil yield, %** | ****Volume oil, x 10$^{-3}$ l** |
|---|---|---|---|
| *25 | 2.94 ± 0.07 | 3.63 ± 0.09 | 3.21 ± 0.08 |
| 45 | 3.00 ± 0.16 | 3.65 ± 0.19 | 3.27 ± 0.17 |
| 60 | 4.46 ± 0.26 | 5.41 ± 0.32 | 4.86 ± 0.29 |
| 75 | 4.94 ± 0.45 | 6.01 ± 0.55 | 5.39 ± 0.49 |
| -2 | 2.31 ± 0.11 | 2.86 ± 0.13 | 2.52 ± 0.12 |
| -22 | 2.38 ± 0.31 | 2.94 ± 0.39 | 2.60 ± 0.34 |
| -36 | 2.65 ± 0.08 | 3.28 ± 0.11 | 2.89 ± 0.09 |

* Control (Laboratory temperature);
** Density of oil: 917 g·l$^{-1}$

Deformation (mm), oil expression efficiency (%), energy (J) and energy volume oil (kJ·l$^{-1}$) of soybeans are presented in Table 2. The deformation values showed both decreasing and increasing trends. Oil expression efficiency increased at decreasing temperatures from -2 ºC to -36 ºC, as well as heating temperatures from 45 ºC to 75 ºC. Whereas energy increased at decreasing temperatures, it decreased at heating temperatures. This meant that soybeans harden at freezing temperatures, but soften at heating temperatures, hence, higher output oil. Energy volume oil was noticed to be higher at -22 ºC followed by -36 ºC and the lowest at -2 ºC. However, -2 ºC showed much higher value than the control of 25 ºC, indicating that it is not economically sustainable to freeze soybeans before oil extraction.

On the other hand, increased heating temperatures decreased the energy volume oil suggesting an economically sound way for obtaining maximum oil recovery. The results were statistically significant ($P$-value < 0.05), except deformation, which indicated non-significant ($P$-value < 0.05) (Table 3). Generally, deformation and energy did not correlate ($P$-value < 0.05) with temperature, whereas oil expression efficiency and energy volume oil correlated with temperature ($P$-value < 0.05) (Table 4).

The effect of temperature on energy, volume oil energy and oil expression efficiency is graphically shown in Fig. 2 and 3. The normal probability plot of energy volume oil, for instance, is presented in Fig. 4, for assessing the normal distribution of the data.

Table 2

**Deformation, oil expression efficiency, energy and energy volume oil of bulk soybeans**

| Temperature, ºC | Deformation, mm | Oil expression efficiency, % | Energy, J | Energy volume oil, kJ·l$^{-1}$ |
|---|---|---|---|---|
| *25 | 17.49 ± 1.12 | 31.99 ± 0.77 | 412.70 ± 30.50 | 128.65 ± 6.42 |
| 45 | 18.32 ± 0.18 | 32.11 ± 1.68 | 614.57 ± 9.50 | 188.03 ± 6.85 |
| 60 | 19.42 ± 0.27 | 47.67 ± 2.81 | 561.43 ± 7.14 | 115.81 ± 8.27 |
| 75 | 17.84 ± 0.81 | 52.92 ± 4.81 | 516.20 ± 11.41 | 96.21 ± 10.78 |
| -2 | 18.83 ± 3.21 | 25.19 ± 1.14 | 492.58 ± 23.70 | 195.54 ± 18.35 |
| -22 | 17.51 ± 0.28 | 25.90 ± 3.41 | 529.06 ± 3.24 | 205.52 ± 25.62 |
| -36 | 18.01 ± 0.36 | 28.84 ± 0.94 | 583.61 ± 10.85 | 202.11 ± 10.23 |

* Control, laboratory temperature

Table 3

**ANOVA test of sum of squares whole model**

| Dependent variables | $R^2$ | $F$ value | $P$-value |
|---|---|---|---|
| Deformation, mm | 0.329 | 0.572 | 0.743 |
| Oil expression efficiency, % | 0.967 | 34.652 | 0.000 |
| Energy, J | 0.965 | 32.520 | 0.000 |
| Energy volume oil, kJ·l$^{-1}$ | 0.949 | 21.932 | 0.000 |

$R^2$: coefficient of determination;
$F$ value: compares a pair of models;

Table 4

**Correlation results of bulk soybean compression parameters**

| Variable | Deformation, mm | Oil expression efficiency, % | Energy, J | Energy volume oil, kJ·l$^{-1}$ |
|---|---|---|---|---|
| Temperature, ºC | 0.173 | 0.836 | -0.007 | -0.815 |
| $P$-value | 0.555 | 0.000 | 0.982 | 0.000 |

$P$ value < 0.05: Significant;
$P$ value > 0.05: Non-significant

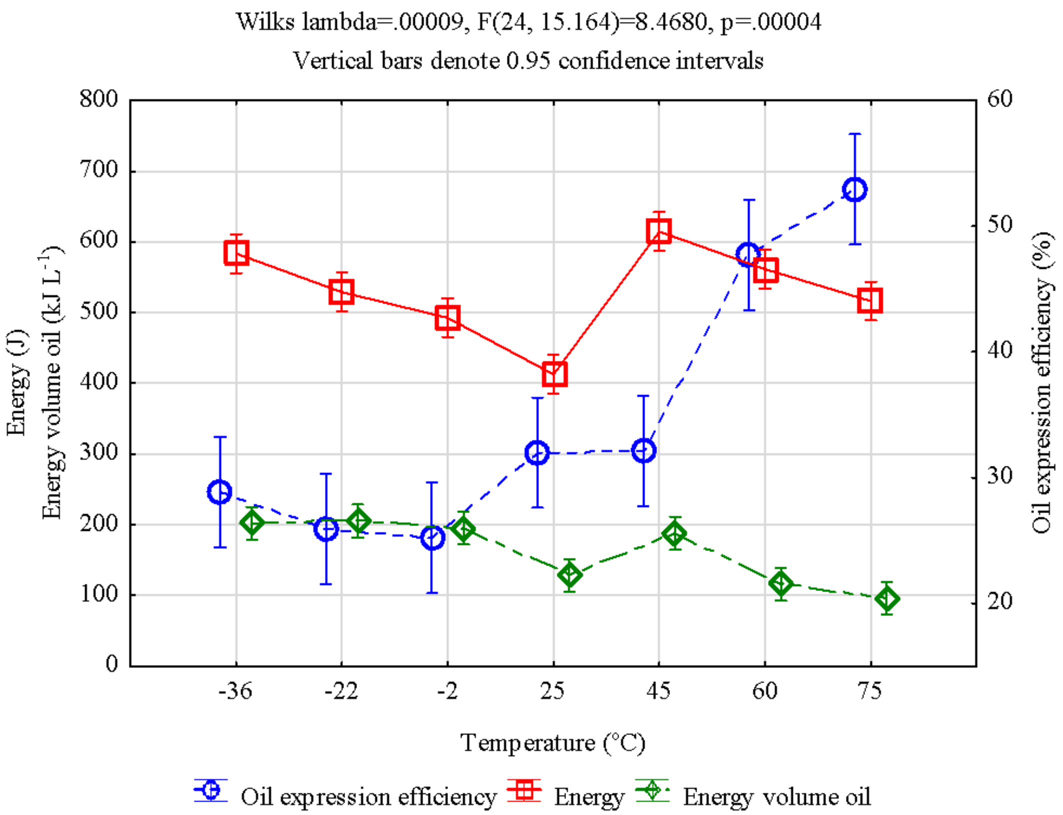


Fig. 2. **Effect of temperature on energy, energy volume oil and oil expression efficiency**

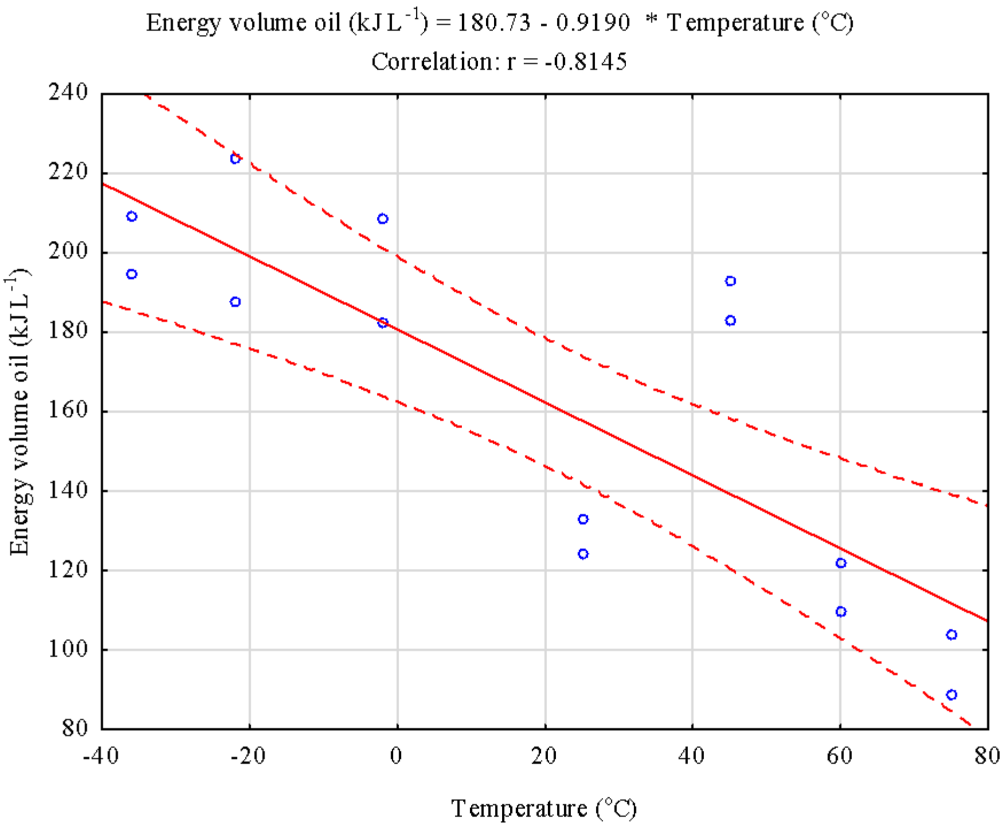


Fig. 3. **Scatterplot of energy volume oil against temperature**

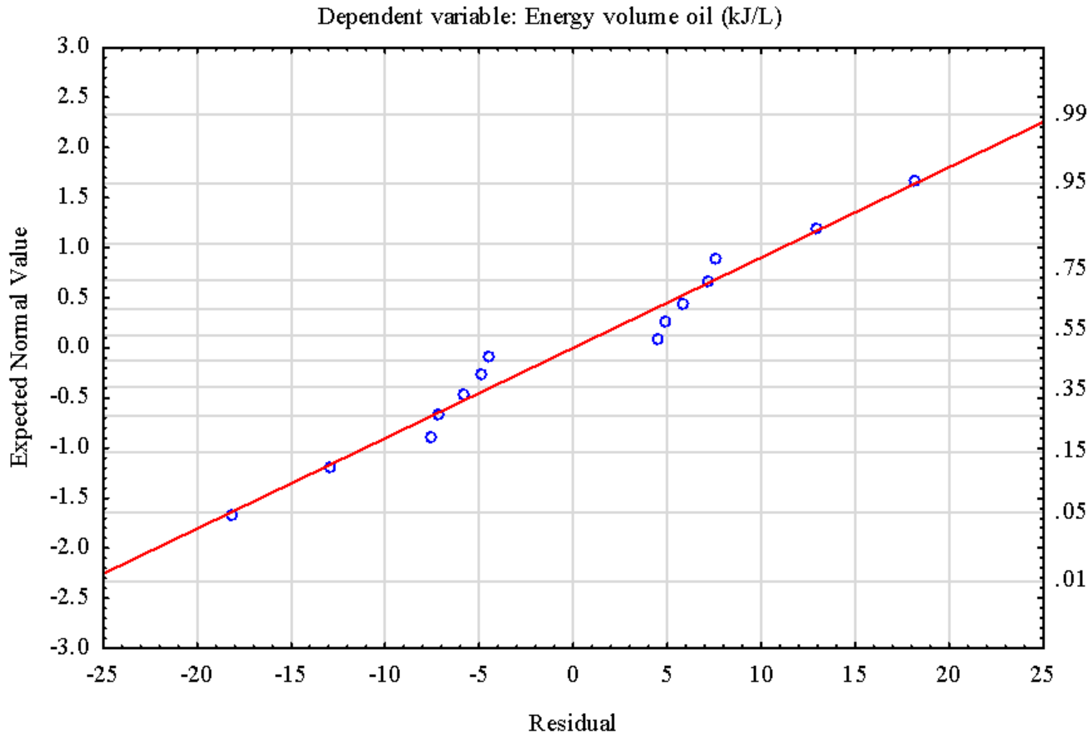


Fig. 4. **Normal probability plot; raw residuals of energy volume oil (kJ·l$^{-1}$)**

## Conclusions

A provisional study result of soybean uniaxial compression test is presented.

1. Oil expression efficiency (%) increased at the pre-treatment temperatures from -2 ºC to -36 ºC and 45 ºC to 75 ºC. However, higher efficiency was achieved at 75 ºC.
2. Energy (J) increased at the pre-treatment temperatures from -2 ºC to -36 ºC, but decreased at 45 ºC to 75 ºC. This suggests that freezing hardens, while heating softens the beans.
3. Optimum volume oil energy of 96.21 ± 10.78 kJ·l$^{-1}$ was observed at the heating temperature of 75 ºC compared to the control (25 ºC) and the freezing temperature (-2 ºC) values of 128.65 ± 6.42 kJ·l$^{-1}$ and 195.54 ± 18.35 kJ·l$^{-1}$ respectively.
4. This study will continue further by considering the chemical analysis of the oil for quality assessment after pre-treatment temperatures [21], as well as the application of a higher compression force, higher pressing height (volume of material) and bigger pressing vessels.

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