

The effects of heating temperatures and time on deformation energy and oil yield of sunflower bulk seeds in compression loading

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Abstract. The deformation energy (J) and percentage oil yield (%) of sunflower bulk seeds under the influence of heat treatment temperatures and heating time were examined in compression test using the universal compression testing machine and vessel diameter of 60 mm with a plunger. The heat treatment temperatures were between 40 and 100 °C and the heating time at specific temperatures of 40 and 100 °C ranged from 15 to 75 minutes. The bulk sunflower seeds were measured at a pressing height of 60 mm and pressed at a maximum force of 100 kN and speed of 5 mm/min. Based on the compression results, the deformation energy and oil yield increased along with increasing heat treatment temperatures. The results were statistically significant ($p < 0.05$). At a 40 °C heat treatment temperature in relation to varying heating time, deformation energy increased while the percentage oil yield decreased. However, at a 100 °C, the deformation energy almost showed no correlation but the oil yield similarly decreased. From the ANOVA statistical analysis, the effect of heating time at 40 and 100 °C heat treatment temperatures on deformation energy and oil yield was not significant ($p > 0.05$).

1. Introduction

The use of vegetable oils as part of renewable energy sources is rapidly growing over the concerns of fossil fuels or climate change [1]. Although renewable energy can provide a clean source of electricity, petroleum fuels still account for the vast majority of the world's energy generation [2]. Sunflower (*Helianthus annuus* L.) produces edible vegetable oil with an annual production of 25.1 million tonnes being one of the potential feedstocks for biodiesel production [3]. The conventional method for sunflower oil extraction involves seed preparation, mechanical extraction and solvent extraction using n-hexane [4, 5]. Mechanical pressing is the most common method for oil extraction from oilseeds especially in the rural areas of developing countries [6]. The main purpose of oilseed post-harvest technology is the recovery of percentage oil yield and quality of oil which is dependent on several factors such as storage, pretreatment and processing [7, 8]. Studies have shown that applied pressure, pressing or heating temperature, heating time, pressing time, pressing speed and seed moisture content thus influence the oil recovery and energy requirement [9, 10, 11, 12]. To obtain a higher percentage oil yield and minimum residual oil in the seed cake, it is very important to control the above-mentioned processing parameters during oil extraction process [13]. The study was aimed to investigate the influence of heat treatment temperatures and heating time on deformation energy and percentage oil yield of sunflower bulk seeds in compression loading and also to describe analytically the dependency between the force and deformation curves as well as the deformation energy.



2. Materials and methods

2.1 Sample and compression test

A sunflower bulk seed of moisture content of 12 w.b. % was used for the compression test. The moisture content was determined using the procedure specified by [14]. The equipment (MEMMERT GmbH + Co. KG, Germany) was used for the samples heat treatment temperatures from 40 to 100 °C and heating time from 15 to 75 minutes at specific heat treatment temperatures of 40 and 100 °C respectively. A universal testing machine of type ZDM 50, Czech Republic together with a pressing vessel of diameter 60 mm with a plunger were used for recording the data points of force (N) and deformation (mm) of sunflower bulk seed of 60 mm measured pressing height [15]. A maximum force of 100 kN and speed of 5 mm/min were applied. The test was repeated twice. The determined amounts namely the deformation energy (J) and oil yield (%) were statistically evaluated using the Statistica software (version 13) [16]. The deformation energy and oil yield were numerically determined based on the equations proposed by the authors [17, 18]. The theoretical relationships between the force and deformation curves as well as the deformation energy were described by the tangent curve mathematical model [19, 20] applicable in Mathcad software (version 14) [21].

3. Results and discussion

The measured amounts of deformation, oil yield and deformation energy in relation to heat treatment temperatures and heating time are presented in Tables 1 to 3 respectively.

Table 1. Measured data (mean±standard deviation) of sunflower bulk seeds at varying temperatures

Temperatures (°C)	Deformation (mm)	Oil yield (%)	Deformation energy (J)	
			*Numerical	**Analytical
*Control	43.400±0.962	19.062±0.431	456.481±3.007	434.481±3.278
40	42.955±0.741	18.092±0.701	485.250±9.159	546.102±0.903
50	44.255±0.813	18.199±0.103	470.057±7.678	526.211±13.062
60	43.425±0.898	19.068±0.087	470.539±13.067	453.991±18.435
70	42.000±0.594	18.431±0.881	489.051±8.034	461.813±5.963
80	42.805±0.559	18.028±0.299	500.084±4.958	514.531±50.973
90	43.905±1.054	20.727±0.053	508.325±7.788	588.006±29.070
100	43.375±0.106	19.120±0.163	510.661±3.155	608.121±13.063

* Based on the area of a trapezoid [17], ** Based on the tangent curve model [19, 20]

Table 2. Measured data (mean±standard deviation) of sunflower bulk seeds at 40 °C

Heating time (min)	Deformation (mm)	Oil yield (%)	Deformation energy (J)	
			*Numerical	**Analytical
*Control	42.955±0.741	18.092±0.701	485.250±9.159	546.102±0.903
15	45.375±0.375	18.979±0.749	485.288±9.509	478.305±9.673
30	44.975±0.686	18.176±0.103	489.252±17.171	500.232±2.137
45	43.990±1.655	16.697±1.641	495.644±9.134	477.881±25.710
60	43.365±3.429	16.831±0.959	506.362±6.164	533.771±1.740
75	43.920±0.467	18.024±0.462	509.229±12.489	554.103±24.579

Based on the ANOVA statistical analysis, the heat treatment temperatures significantly ($p < 0.05$) influenced the amounts of the deformation energy and percentage oil yield (Table 1). This means that the measured amounts mentioned above increased along with increasing heat treatment temperatures with a very high correlation of 0.935 and 0.941 respectively. The influence of heating time at particular heat treatment temperatures of 40 and 100 °C on deformation energy and oil

yield was not statistically significant ($p > 0.05$) in terms of decreasing or increasing trends. However, from the experimental data, the deformation energy increased in relation to the heating time at 40 °C but slightly decreased at 100 °C. The oil yield, on the other hand, decreased at both heat treatment temperatures.

Table 3. Measured data (mean±standard deviation) of sunflower bulk seeds at 100 °C

Heating time (min)	Deformation (mm)	Oil yield (%)	Deformation energy (J)	
			*Numerical	**Analytical
*Control	43.375±0.106	19.120±0.163	510.661±3.155	608.121±13.063
15	41.540±0.651	20.805±0.455	508.488±11.635	550.307±81.070
30	43.205±0.629	20.143±1.248	517.113±1.874	529.770±9.656
45	43.025±0.035	20.141±0.345	509.943±0.103	562.462±12.590
60	42.770±0.509	19.268±0.926	506.657±0.389	553.101±45.837
75	41.910±0.778	19.124±0.108	509.362±0.844	532.237±9.099

Table 4. One-way ANOVA analysis of measured data at varying heat treatment temperatures

Measured data	F _{ratio}	F _{critical}	<i>p</i>	R ²
Deformation energy (J)	8.193	3.866	0.006	0.875
Oil yield (%)	9.115	3.866	0.005	0.887

$p < 0.05$ level of significance or $F_{\text{ratio}} > F_{\text{critical}}$ is significant

Table 5. Factorial or Repeated measures ANOVA analysis of measured data at both 40 and 100 °C in relation to heating time

Measured data	F _{ratio}	F _{critical}	<i>p</i>	R ²
Deformation energy (J)	2.584	3.478	0.078	0.699
Oil yield (%)	5.344	3.478	0.008	0.828

$p > 0.05$ level of significance or $F_{\text{ratio}} < F_{\text{critical}}$ is non-significant

The theoretical description of the experimental dependency between the force and deformation curves of a sunflower bulk seed in relation to heat treatment temperatures is shown in Figure 1 similar to varying heating time at specific temperatures of 40 and 100 °C respectively. The area under the curve is the numerical deformation energy [17] (Tables 1 to 3) which can also be determined analytically using the tangent curve model [19, 20]. The determined coefficients of the tangent curve model using Mathcad 14 software are presented in Tables 6 to 8 respectively. The coefficients were statistically significant with high coefficients of determination (R^2) where the F_{ratio} values were higher than the values of the F_{critical} . In addition, the p values were higher than the significance level of 0.05. The tangent curve mathematical model considers the boundary conditions of the compression process being zero compressive force relate to zero deformation, deformation thus reaches a maximum limit as the force increases to infinity and the integral of the tangent curve function is the energy [19, 20]. The tangent curve mathematical model is described in equation 1 as follows:

$$F(x) = A \cdot (\tan(B \cdot x))^n \quad (1)$$

where F is the pressing force (kN), x is the deformation (mm), A is the force coefficient of mechanical behaviour (kN), B is the deformation coefficient of mechanical behaviour (mm^{-1}), n is the fitting curve function exponent (-).

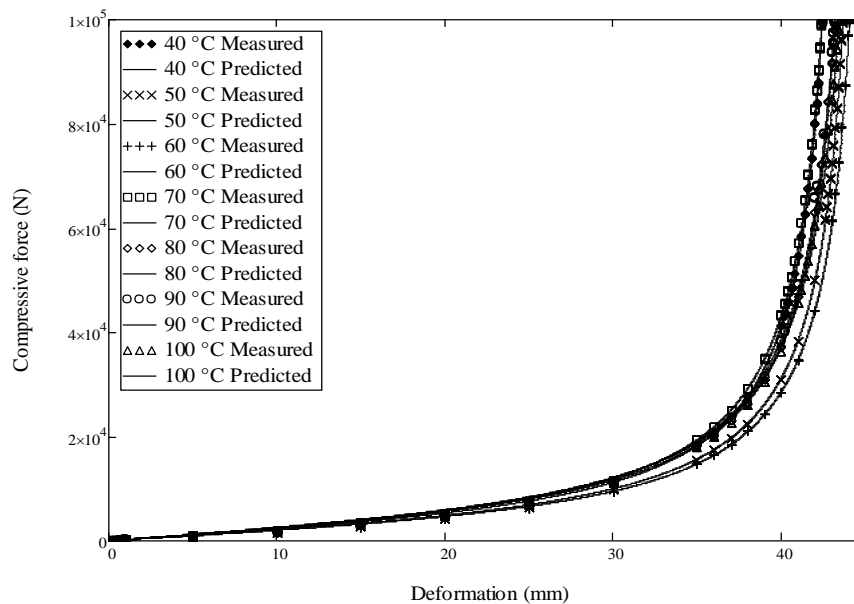


Figure 1. Force and deformation curves of sunflower seeds at heat treatment temperatures.

Table 6. Tangent curve model coefficients and statistical analysis (mean±standard deviation) at varying heat treatment temperatures.

Temperatures (°C)	Tangent curve model coefficients			Statistical analysis			
	A (kN)	B (mm ⁻¹)	n	F _{ratio}	F _{critical}	p	R ²
*Control	5.752	0.035	1	0.0010	3.870	0.975	0.999
	±0.235	±0.001		±0.0002	±0.004	±0.003	±0.001
40	6.298	0.036	1	0.0008	3.867	0.979	0.999
	±0.087	±0.001		±0.0009	±0.004	±0.013	±0.001
50	5.821	0.035	1	0.0009	3.864	0.976	0.999
	±0.127	±0.001		±0.0007	±0.004	±0.009	±0.001
60	5.984	0.035	1	0.0009	3.864	0.977	0.999
	±0.374	±0.001		±0.0004	±0.003	±0.006	±0.001
70	6.485	0.036	1	0.0004	3.865	0.988	0.999
	±0.231	±0.001		±0.0006	±0.004	±0.017	±0.001
80	6.818	0.035	1	0.0020	3.866	0.965	0.999
	±0.027	±0.001		±0.0003	±0.001	±0.002	±0.001
90	7.048	0.035	1	0.0079	3.865	0.929	0.999
	±0.026	±0.001		±0.0029	±0.001	±0.014	±0.001
100	7.227	0.035	1	0.0073	3.863	0.933	0.999
	±0.018	±0.001		±0.0025	±0.001	±0.012	±0.001

* Sunflower bulk seeds at room temperature of 25 °C, $p > 0.05$ level of significance or $F_{critical} > F_{ratio}$ is significant.

Table 7. Tangent curve model coefficients and statistical analysis (mean±standard deviation) at 40 °C in relation to heating time.

Heating time (min)	Tangent curve model coefficients			Statistical analysis			
	A (kN)	B (mm ⁻¹)	n	F _{ratio}	F _{critical}	p	R ²
*Control	5.752 ±0.235	0.035 ±0.001	1	0.0010 ±0.0002	3.870 ±0.004	0.975 ±0.003	0.999 ±0.001
15	6.034 ±0.267	0.033 ±0.001	1	0.0038 ±0.0006	3.863 ±0.001	0.951 ±0.004	0.999 ±0.001
30	6.102 ±0.202	0.034 ±0.001	1	0.0026 ±0.0002	3.864 ±0.001	0.960 ±0.002	0.999 ±0.001
45	6.310 ±0.411	0.034 ±0.001	1	0.0012 ±0.0011	3.865 ±0.002	0.974 ±0.013	0.999 ±0.001
60	6.551 ±0.447	0.035 ±0.003	1	0.0007 ±0.0012	3.866 ±0.002	0.983 ±0.023	0.999 ±0.001
75	6.590 ±0.189	0.035 ±0.001	1	0.0011 ±0.0006	3.865 ±0.002	0.974 ±0.007	0.999 ±0.001

p > 0.05 level of significance or F_{critical} > F_{ratio} is significant.

Table 8. Tangent curve model coefficients and statistical analysis (mean±standard deviation) at 100 °C in relation to heating time.

Heating time (min)	Tangent curve model coefficients			Statistical analysis			
	A (kN)	B (mm ⁻¹)	n	F _{ratio}	F _{critical}	p	R ²
*Control	5.752 ±0.235	0.036 ±0.001	1	0.0010 ±0.0002	3.870 ±0.004	0.975 ±0.003	0.999 ±0.001
15	7.575 ±0.203	0.035 ±0.001	1	0.0054 ±4.6·10 ⁻⁵	3.864 ±0.003	0.941 ±0.001	0.999 ±0.001
30	7.243 ±0.035	0.035 ±0.001	1	0.0087 ±0.0090	3.864 ±0.002	0.933 ±0.041	0.999 ±0.001
45	7.197 ±0.111	0.035 ±0.001	1	0.0081 ±0.0055	3.864 ±0.002	0.931 ±0.026	0.999 ±0.001
60	7.388 ±0.074	0.035 ±0.001	1	0.0113 ±0.0039	3.863 ±0.001	0.916 ±0.015	0.999 ±0.001
75	7.598 ±0.201	0.036 ±0.001	1	0.0077 ±0.0023	3.863 ±0.001	0.931 ±0.011	0.999 ±0.001

p > 0.05 level of significance or F_{critical} > F_{ratio} is significant.

4. Conclusion

Heat treatment temperatures significantly ($p < 0.05$) increased the deformation energy and percentage oil yield of sunflower bulk seeds compressed at a maximum force of 100 kN and speed of 5 mm/min. The interaction effects of heating time and heat treatment temperatures of 40 and 100 °C did not significantly ($p > 0.05$) decrease or increase the deformation energy and percentage oil yield. The analytical deformation energy amounts were within the range of the numerical energy values.

The coefficients of determination of the theoretical description of the experimental relationships between the force and deformation curves in relation to heat treatment temperatures and heating time were 0.999. The theoretical model coefficients were statistically significant ($p > 0.05$). The exponent of the tangent model representing the value of the fitting curve was found to be 1 in all analyses. It is important to mention that the use of the Statistica software [16] interprets the statistical significance when the p value is less than the significance level or the F_{ratio} greater than the F_{critical} (Table 4). This is, however, contrary to the Mathcad statistical package [21] where the p value is greater than the significance level or F_{critical} greater than the F_{ratio} (Tables 6 to 8).

References

- [1] YX Xu, Hanna M A and Josiah S J 2007 Hybrid hazelnut oil characteristics and its potential oleochemical application *Ind. Crop Prod* **26**:69-76.
- [2] Lazkano I, Nostbakken L and Pelli Martino 2017 From fossil fuels to renewables: The role of electricity storage, <https://doi.org/10.1016/j.eurocorev.2017.03.013>.
- [3] Saydut A, Erdogan S, Kafadar A B, Kaya C, Aydin F and Hamamci C 2016. Process optimization for production of biodiesel from hazelnut oil, sunflower oil and their hybrid feedstock *Fuel* **183**:512-517.
- [4] Baumler E R, Carrin M E and Carelli A A 2016 Extraction of sunflower oil using ethanol as solvent *Journal of Food Engineering* **178**:190-197.
- [5] Li Y, Fine F, Fabiano-Tixier A S, Abert-Vian M, Carre P, Pages X and Chemat F 2014 Evaluation of alternative solvents for improvement of oil extraction from rapeseeds *Comptes Rendus Chim* **17**(3):242-251.
- [6] Achten W M J, Mathijs E, Verchot L, Singh V P, Aerts R, Muys B 2007 Jatropha biodiesel fueling sustainability? *Biofuels Bioprod. Biorefining* **1**:283-291
- [7] Nagaraj G 2009 Linseed. In: Oilseeds, Properties, Processing, Products and Procedures, Linseed, New India Publishing Agency, New Delhi, India, pp. 123.
- [8] Kasote D M, Badhe Y S and Hegde M 2013 Effect of mechanical press oil extraction processing on quality of linseed oil *Industrial Crops and Products* **42**:10-13.
- [9] Subroto E, Manurung R, Heeres H J and Broekhuis A A 2015 Mechanical extraction of oil from *Jatropha curcas* L. kernel: Effect of processing parameters *Industrial Crops and Products* **63**:303-310.
- [10] Willems P, Kuipers N J M, de Haan A B 2008 Hydraulic pressing of oilseeds: experimental determination and modeling of yield and pressing rates *J. Food Eng* **89**:8-16.
- [11] Acheheb H, Aliouane R, Ferradji A 2012 Optimization of oil extraction *Pistacia atlantica* Desf. Seeds using hydraulic press *Asian J. Agric. Res.* **6**:73-82.
- [12] Karaj S. Muller J 2011 Optimizing mechanical oil extraction of *Jatropha curcas* L. seeds with respect to press capacity, oil recovery and energy efficiency *Industrial Crops and Products* **34**:1010-1016.
- [13] Bamboye A I and Adejumo O I 2011 Effects of processing parameters of Roselle seed on its oil yield *Int. J Agric & Biol Eng* **4**(1):82-86
- [14] ISI 1996 Indian standard methods for analysis of oilseeds IS:3579 New Delhi Indian Stand. Ins.
- [15] Akangbe O.L and Herak D 2017 Mechanical behaviour of selected bulk oilseeds under compression loading *Agronomy Research* **15**(1), 947–951.
- [16] Statsoft., Inc. Tulsa, OK74104, USA, 2010.
- [17] Herak D, Kabutey A, Sedlacek A and Gurdil G 2012 Mechanical behaviour of several layers of selected plant seeds under compression loading *Res. in Agric. Eng.* **58**(1):24-29
- [18] Deli S, Farah Masturah M, Tajul Aris Y and Wan Nadiyah W A 2011 The effects of physical parameters of the screw press oil expeller on oil yield from *Nigella sativa* L. seeds *Int. Food Res.* **18**:1367–1373.
- [19] Herak D, Kabutey A, Divisova M and Simanjuntak S 2013 Mathematical model of mechanical behaviour of *Jatropha curcas* L. seeds under compression loading *Bio. Eng.* **114**(3):279–288.

- [20] Sigalingging R, Herak D, Kabutey A, Dajbych O, Hrabě P and Mizera C Application of a tangent curve mathematical model for analysis of the mechanical behaviour of sunflower bulk seeds *Int. Agrophys.* **29**(4):517–524.
- [21] Mathsoft Engineering and Education, Inc. 101 Main Street, Cambridge, Ma 02142, USA, 2004.