Analysis of output oil yield and energy utilization of bulk pumpkin seeds under constant loading

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Abstract. The present study examined a repeated pressing of bulk pumpkin seeds heated at temperatures of 40, 60 and 80 ºC for 1 hour and compressed under an axial loading at a maximum load of 200 kN and speed of 5 mm/min. The sample temperature of 23 ºC served as the control. The pressing vessel of diameter 60 mm with a plunger was used with the initial pressing height of the sample measured at 70 mm (87.38 g). Each sample was repeatedly pressed four times to recover the maximum oil output from the bulk seeds and the residual oil in the seedcake. The force-deformation curves were obtained where the area under the curve represents the energy based on the trapezoidal rule. Oil yield (%) and oil expression efficiency (%) were also calculated. The correlation results were not significant ($P > 0.05$) indicating that the calculated parameters were not affected by the heating temperatures with or without the control temperature. However, the maximum mass of oil of 23.62±1.52 g with the corresponding oil yield of 29.64±2.29%, oil expression efficiency of 88.40±6.82% and energy of 2475.79±20.90 J was obtained at the heating the temperature of 40 ºC and the time of 60 min.

Keywords: *bulk pumpkin seeds, heating temperatures, repeated pressings, maximum oil output, energy requirement.*

1 INTRODUCTION

Obtaining the maximum output oil from bulk oilseeds and seedcake under the uniaxial compression loading (Munson-Mcgee, 2014; Divišova et al. 2014) provides the foundation for understanding the complex mechanisms involved in the mechanical screw pressing operation and improving its performance for large-scale oil production for both domestic and industrial applications (Karaj and Muller, 2011; Bogaert et al.2018). In our previously published study on pumpkin seeds under compression

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loading (Kabutey et al. 2021), the optimum operating factors for high percentage oil yield, oil expression efficiency and minimum energy were the force of 200 kN, speed of either 4 or 5 mm/min and heating temperature of 80 °C. The compression tests of the bulk oilseed samples were done at a first/single pressing leaving considerable residual oil in the seedcake. It has been reported that the residual oil content in the seedcake or meal ranges from 0.5 to 20 % with the mechanical pressing system (Kartika, Pontalier and Rigal, 2010; Voges, Eggers and Pietsch, 2008). The present study is a continuation of the previous work aimed at recovering the maximum oil in the bulk oilseeds and seedcake at constant load, speed and volume of material.

2 MATERIALS AND METHODS

In this study, the remaining pumpkin seeds purchased from Středni, Prague 6, Czech Republic were used. The moisture content and oil content were determined to be 6.37±0.24% and 33.53±1.16% as reported in our previously published study (Kabutey et al. 2021). For the compression tests, the samples of pumpkin seeds were heated at temperatures between 40 and 80 °C with a 20 °C interval for 1 hour using the oven (MEMMERTGmbH+Co.KG, Schwabach, Germany). The samples' masses were measured using an electronic balance (Kern 440-35, Kern & Sohn GmbH, Balingen, Germany). The compression test for each preheated sample was done using the universal compression machine (TEMPOS spol. s.r.o., Opava, Czech Republic (Machine Service); ZDM 50, VEB Werkstoffprüfmaschinen Leipzig, Germany) and the pressing vessel of diameter 60 mm with a plunger as shown in Figure 1a.

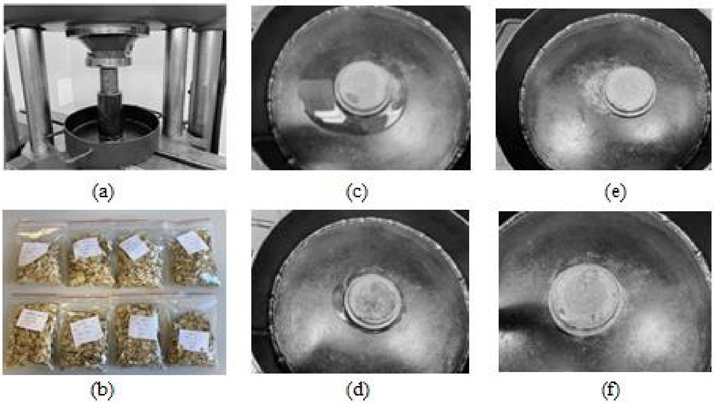

Fig. 1. (a) A setup of the compression test, (b) samples of pumpkin seeds at 23, 40, 60 and 80 °C, (c) 1st sample pressing, (d) 2nd repeated pressing, (e) 3rd repeated pressing and (f) and 4th repeated pressing.

The initial pressing height of the samples was measured at 70 mm corresponding to a mass of 87.38 g. The compression test for each sample was constantly pressed four times to recover the maximum and the residual oil that remained in the seedcake after the first pressing (Figure 1c-f). From the force-deformation curves of the samples at a maximum force of 200 kN and speed of 5 mm/min; the mass of oil, oil yield, oil expression efficiency and energy were calculated according to the equations stated in the work by Demirel et al. (2021). The tests were replicated twice, and averaged values were used in all calculations and analyses. The area under the force deformation curve as shown in Figure 2 represents the energy for obtaining the oil (Gupta and Das, 2000; Lysiak, 2007). The data were put through a single factor ANOVA and correlation analyses at a 5% significance level using the Statistica software (Statsoft, 2013) and Microsoft Excel.

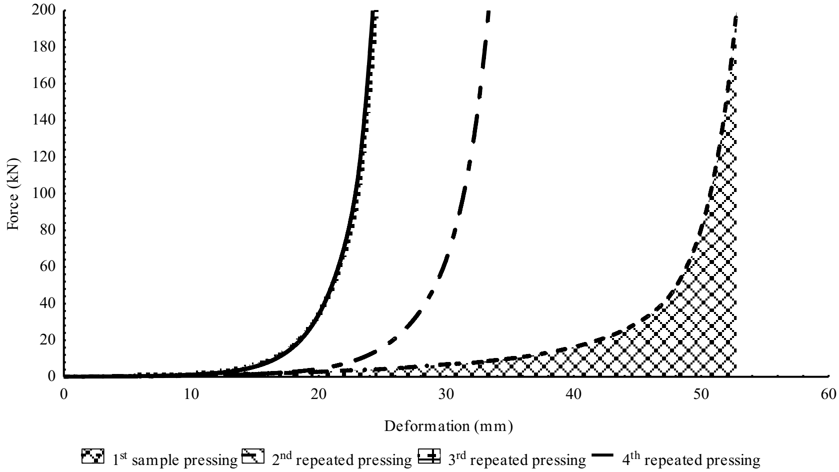

Fig. 2. Force-deformation curves of a sample at 40 °C like other samples tested.

3 RESULTS AND DISCUSSION

The results are given in Tables 1 to 6. The calculated parameters were mass of oil (g), oil yield (%), oil expression efficiency (%) and energy (J). Based on the results of the control temperature of 23 °C (Table 1), the calculated amounts at the first pressing increased with an increase in heating temperatures from 40 to 80 °C (Tables 2 to 4). However, samples repeatedly pressed at each temperature did not linearly increase the calculated amounts. The data showed both increasing and decreasing trends along with the heating temperatures. The heating temperature of 40 °C showed the highest cumulative amounts which were the mass of oil of 23.62±1.52 (g), oil yield of 29.64±2.29 (%), oil expression efficiency of 88.40±6.82 (%) and energy of 2475.79±20.90 (J). The energy values increased from the control temperature of 23 °C until the heating temperature of 60 °C and then decreased at 80 °C. This indicates that above the heating temperature of 60 °C, the seeds thus soften hence minimum energy is required to recover the oil (Table 5). Based on the single factor ANOVA analysis (data not presented herein), the amounts of mass of oil and energy were significant ($P < 0.05$) whereas the oil yield and oil expression efficiency were non-significant ($P > 0.05$). On the other hand, all the amounts correlated negatively with the heating temperatures with or without the control temperature (Table 6). However, the results were not significant (P > 0.05). Both analyses show that the repeated pressing of the samples to recover the maximum/residual oil in the bulk seeds/seedcake can be achieved at the control or laboratory temperature of the samples without necessarily subjecting them to heating pretreatment. In comparison with the previously published work (Kabutey et al. 2021); a yield of 11.47±0.37%, oil expression efficiency of 34.11±1.10% and energy of 721.57±24.15 J for the control temperature of 22 °C at a maximum force of 200 kN and speed of 5 mm/min were reported. Again, for the heating temperature of 80 °C at a maximum force of 200 kN and speed of 5 mm/min; the oil yield of 20.48 %, oil expression efficiency of 60.90% and energy of 848.04 J were also disclosed. These values were obtained at the first pressing. The present study revealed that a substantial residual oil content remains in the seedcake after the first pressing which needs to be recovered utilizing a constant loading/pressure approach.

Table 1. Determined parameters at a control temperature of 23 °C.

P_h (mm)	M_b	M_a	M_o (g)	O_y (%)	O_{ee} (%)	E_n (J)
70*[1a]	87.38	75.38	12.00	13.73	40.96	841.09
70*[1b]	87.38	76.28	11.10	12.70	37.89	834.54
50[2a]	75.38	68.66	6.72	8.91	26.59	576.12
50[2b]	76.28	68.17	8.11	10.63	31.71	628.93
40[3a]	68.66	66.30	2.36	3.44	10.25	480.42
40[3b]	68.17	66.03	2.14	3.14	9.36	510.75
40[4a]	66.30	65.18	1.12	1.69	5.04	446.13
40[4b]	66.03	64.84	1.19	1.80	5.37	442.27
Sum			22.20[a]	27.77[a]	82.83[a]	2343.77[a]
			22.54[b]	28.28[b]	84.33[b]	2416.50[b]
Mean			**22.37**	**28.03**	**83.58**	**2380.13**
± SD			± 0.24	± 0.35	± 1.06	± 51.43

* Initial pressing height; [1]: First pressing; [2]: Second repeated pressing; [3]: Third repeated pressing; [4]: Fourth repeated pressing; [a]: Test 1; [b]: Test 2; SD: Standard Deviation; M_b: Initial mass of sample; M_a: pressed seedcake; P_h: Pressing height; M_o: Mass of oil; O_y: Oil yield; O_{ee}: Oil expression efficiency and E_n: Energy.

Table 2. Determined parameters at a heating temperature of 40 °C.

P_h (mm)	M_b	M_a	M_o (g)	O_y (%)	O_{ee} (%)	E_n (J)
70*[1a]	87.38	73.29	14.09	16.12	48.09	880.86
70*[1b]	87.38	73.09	14.29	16.35	48.77	895.16
50[2a]	73.29	67.59	5.70	7.78	23.20	627.81
50[2b]	73.09	68.26	4.83	6.61	19.71	624.81
40[3a]	67.59	63.96	3.63	5.37	16.02	495.24
40[3b]	68.26	65.76	2.50	3.66	10.92	517.50
40[4a]	63.96	62.69	1.27	1.99	5.92	457.10
40[4b]	65.76	64.84	0.92	1.40	4.17	453.10
Sum			24.69[a]	31.26[a]	93.23[a]	2461.01[a]
			22.54[b]	28.02[b]	83.58[b]	2490.57[b]

Mean ± SD			**23.62** ± 1.52	**29.64** ± 2.29	**88.40** ± 6.82	**2475.79** ± 20.90

Table 3. Determined parameters at a heating temperature of 60 °C.

P_h (mm)	M_b	M_a	M_o (g)	O_y (%)	O_{ee} (%)	E_n (J)
70*[1a]	87.38	71.49	15.89	18.18	54.23	926.29
70*[1b]	87.38	70.24	17.14	19.62	58.50	938.94
50[2a]	71.49	67.62	3.87	5.41	16.14	590.52
50[2b]	70.24	66.33	3.91	5.57	16.60	600.79
40[3a]	67.62	65.76	1.86	2.75	8.20	504.10
40[3b]	66.33	64.69	1.64	2.47	7.37	511.04
40[4a]	65.76	64.96	0.80	1.22	3.63	450.51
40[4b]	64.69	63.98	0.71	1.10	3.27	455.03
Sum			22.42[a]	27.57[a]	82.21[a]	2471.42[a]
			23.40[b]	28.75[b]	85.75[b]	2505.81[b]
Mean ± SD			**22.91** ± 0.69	**28.16** ± 0.84	**83.98** ± 2.50	**2488.61** ± 24.32

Table 4. Determined parameters at a heating temperature of 80 °C.

P_h (mm)	M_b	M_a	M_o (g)	O_y (%)	O_{ee} (%)	E_n (J)
70*[1a]	87.38	68.53	18.85	21.57	64.34	952.96
70*[1b]	87.38	69.48	17.90	20.49	61.10	916.76
50[2a]	68.53	65.98	2.55	3.72	11.10	563.78
50[2b]	69.48	65.85	3.63	5.22	15.58	583.64
40[3a]	65.98	64.36	1.62	2.46	7.32	482.77
40[3b]	65.85	64.69	1.16	1.76	5.25	472.60
40[4a]	64.36	63.86	0.50	0.78	2.32	424.35
40[4b]	64.69	64.19	0.50	0.77	2.31	418.31
Sum			23.52[a]	28.53[a]	85.07[a]	2423.85[a]
			23.19[b]	28.24[b]	84.24[b]	2391.31[b]
Mean ± SD			**23.36** ± 0.23	**28.39** ± 0.20	**84.66** ± 0.60	**2407.58** ± 23.01

Table 5. The difference in amounts of heating temperatures with the control.

Heating temperatures (°C)	M_o (g)	O_y (%)	O_{ee} (%)	E_n (J)
40	1.25	1.62	4.82	95.65
60	0.54	0.13	0.40	108.48
80	0.99	0.36	1.08	27.45

Table 6. Correlation results from the effect of heating temperatures.

Heating temperatures (°C)	M_o (g)*	O_y (%)*	O_{ee} (%)*	E_n (J)*
R	-0.36	-0.79	-0.79	-0.78
P-value	> 0.05	> 0.05	> 0.05	> 0.05

R: Correlation; P-value > 0.05 denotes non-significant; *: Repeatedly pressed sample at each heating temperature; M_o: Mass of oil; O_y: Oil yield; O_{ee}: Oil expression efficiency and E_n: Energy.

4 CONCLUSION

The sample heated at 40 °C for 60 min produced the highest cumulative oil yield of 29.64±2.29%, oil expression efficiency of 88.40±6.82% and energy of 2475.79±20.90 J. Compared with the control temperature of 23 °C, the differences were 1.62 %, 4.82 % and 95.65 J. The maximum residual oil in the pumpkin seedcake was obtained at the second repeated pressing. The third and fourth repeated pressings were not energy efficient concerning the negligible residual oil output. A similar study should be conducted for other bulk oilseeds to obtain adequate information on the uniaxial process to develop an economical and universal mechanical oil pressing system.

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