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Effect of mechanical oil pressing parameters on rapeseed oil efficiency ratios

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Abstract: *Effect of mechanical oil pressing parameters on rapeseed oil efficiency ratios.* The objective of this study was to determine the relation between operational parameters of the screw press during the mechanical pressing process of rapeseed oil and the ratios describing this process. Four rotational speeds of the screw press were applied (20, 30, 40, 50 rpm), and three nozzle diameters (6, 8, 10 mm). The ratios: oil yield, oil flow rate, capacity and energy efficiency were analyzed. Mechanical oil pressing parameters: screw speeds and the nozzle diameter, as well as their interaction, were found to affect significantly the mechanical oil pressing ratios. Screw rotation speed and diameter of the nozzle had an impact on efficiency ratios, but the effect of rotational speed was greater than the nozzle diameter.

Key words: oil yield, oil flow rate, capacity, energy efficiency

INTRODUCTION

The efficiency of mechanical liquid pressing (oil) and energy consumption in this process depends on numerous factors related to the raw material and technology, including the appropriate adjustment of process parameters to the type of raw material to be pressed [Zdanowska et al. 2013]. Mechanical oil pressing ratios are a good tool for evaluating the technology. Wojdalski and Dróżdż [2012] and Dróżdż [2013] have taken up the topic of energy efficiency in agro-food industry. In the works of Dróżdż [1998, 2010] the characteristics of energy consumption in the oil industry were presented.

Oil yield, oil flow rate, capacity and energy consumption ratios are determined according to the reference scale, as of an aggregate, technological, production and factory nature [Wojdalski et al. 1998, Wojdalski and Dróżdż 2006]. An analysis of the problem has shown that there is no information concerning the relation between operational parameters of the rapeseed oil screw press and the (aggregate) ratios describing this process. It was found that former research results regarding operational aspects of the rapeseed oil pressing process are merely fragmentary. Evaluation of energy consumption and efficiency of processes in agro-food processing, including oil yield in the oil industry, is an issue of extreme importance. It provides data on issues of sustainable energy policy, reduction of harmful energy impact on the environment, as well as business economic issues. Hence, the purpose of the work is to identify the relation between the operational parameters of the oil pressing process and ratios describing the process, and consequently to gain knowledge as to appropriate oil pressing conditions.

MATERIAL AND METHODS

The experiments were carried out at the Department of Production Management and Engineering, Faculty of Production Engineering, Warsaw University of Life Sciences – SGGW. The test stand (Fig. 1) consisted of a Farmet-Uno single-screw press equipped with a Varispeed F7 frequency inverter from Omron to control the frequency of the power supply, and as a consequence of the motor speed and the screw. Four rotational speeds of the screw press were applied (20, 30, 40, 50 rpm), and three nozzle diameters (6, 8, 10 mm). There were 12 combinations of press parameters. Using LabView software, oil and rapeseed cake weight data were collected and processed by the National Instruments SCXI-1000 measuring instrument from W1 and W2 weighing scales. The scales were working in a continuous data transmission mode to the computer. Thermocouples (T) controlled the temperature of the oil pressing process, which was in the range of 54–63°C.

For this study, rapeseeds from the Masovian Voivodship cultivation were used. Using PN-EN ISO 665:2004 standard for oilseed, moisture content of the rapeseed was found to be 5.0 ±0.2%.

The mechanical oil pressing process was characterized by the following ratios:

- oil yield

$$W_u = \frac{M_o}{M_{rz}}$$

$$M_{rz} = M_o + M_w$$

- oil flow rate

$$W_o = \frac{M_o}{t}$$

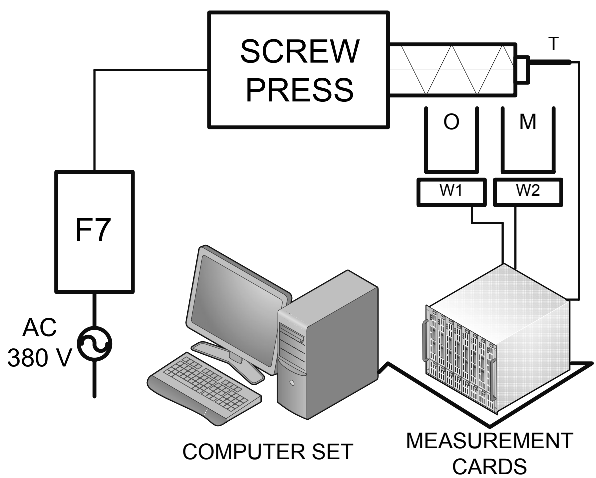

FIGURE 1. Test stand for mechanical oil pressing process with screw press

• capacity

$$W_p = \frac{M_{rz}}{t}$$

• energy efficiency

$$EE_o = \frac{M_o}{A_e}$$

where:

W_u – oil yield [kg of oil·kg of rapesed^{-1}];
W_o – oil flow rate [kg of oil·h^{-1}];
W_p – capacity [kg of rapeseed·h^{-1}];
EE_o – energy efficiency [kg of oil·kWh^{-1}];
M_o – oil mass [kg];
M_w – rapeseed cake mass [kg];
M_{rz} – rapeseed mass [kg];
t – time [h];
A_e – electrical energy consumption [kWh].

A Statistica 13.1 software was used to generate statistical analyses. Statistical inference was performed based on parametric tests, despite slight deviations from variance homogeneity. These exceptions was allowed by test F, especially when random samples were equinumerous. The F Welch test enables analysis of variance when the assumption of variance homogeneity is violated. In addition, parametric tests constitute higher-power tests [Stanisz 2007, Meissner 2010, Bedynska and Cypryanska 2013].

RESULTS AND DISCUSSION

Tables 1–3 show results of a statistical analysis of oil yield depending on parameters of the oil pressing process: the outlet nozzle diameter and the screw speed. Figure 2 presents a graphical interpretation of statistical analysis.

Results of a two-way analysis of variance (Tables 1–3) allow a presumption on a statistically significant influence on the variation in oil yield values of the nozzle diameter, the rotational screw speed, and the interaction of both factors. The Fisher–Snedecor test values were $F_{v1=2, v2=84} = 151.4$, with $p < 0.0001$; $F_{v1=3, v2=84} = 930.6$, with $p < 0.0001$; $F_{v1=6, v2=84} = 3.2$, with $p = 0.0068$. The test F value was higher for rotational speed than for nozzle diameter, indicating a stronger influence of the rotational speed change than the nozzle diameter on a change in oil yield. Statistically significant interaction of factors points to a synergy of interaction and enhancement of the effect both of factors together to oil yield with simultaneous change in the rotational screw speed and the nozzle diameter.

Tukey's HSD test results have shown that each of the rotational speeds and nozzles formed a separate homogeneous group (Table 3). The highest oil yields of 0.36–0.37 kg of oil per 1 kg of rapeseed (Table 2) were recorded at the setting of the operating parameters of 6/20 and

TABLE 1. Variance analysis for oil yield depending on oil pressing parameters

Source	SS	*Df*	*MS*	*F*-ratio	*p*
Nozzle diameter: A	0.012582	2	0.006291	151.4	< 0.0001
Rotational speed: B	0.116003	3	0.038668	930.6	< 0.0001
Interaction: A × B	0.000802	6	0.000134	3.2	0.0068
Error	0.003490	84	0.000042	–	–

TABLE 2. Average values of oil yield (W_u) according to oil pressing parameters, 95% confidence intervals and standard deviations from mean

Nozzle diameter [mm]	Rotational speed [rpm]	Average W_u [kg of oil·kg of rapeseed^{-1}]	–95% [kg of oil·kg of rapeseed^{-1}]	95% [kg of oil·kg of rapeseed^{-1}]	*SD* [kg of oil·kg of rapeseed^{-1}]
10	50	0.260[a]	0.256	0.265	0.005
10	40	0.287[b]	0.278	0.295	0.010
10	30	0.317[c]	0.312	0.323	0.007
10	20	0.353[d,e]	0.350	0.357	0.004
8	50	0.262[a]	0.252	0.272	0.012
8	40	0.293[b]	0.292	0.294	0.001
8	30	0.329	0.327	0.332	0.003
8	20	0.364[e,f]	0.359	0.368	0.005
6	50	0.290[b]	0.284	0.296	0.007
6	40	0.316[c]	0.310	0.322	0.007
6	30	0.347[d]	0.344	0.349	0.003
6	20	0.374[f]	0.370	0.378	0.005

[a,b,c,d,e,f] Mean values with identical letters do not differ statistically significantly at $p < 0.05$.

TABLE 3. Tukey HSD test of variance analysis for oil yield (W_u) depending on oil pressing parameters

Property	Average W_u [kg of oil·kg of rapeseed^{-1}]	Homogenous group			
		1	2	3	4
Nozzle diameter [mm]					
10	0.304	X			
8	0.312		X		
6	0.332			X	
Rotational speed [rpm]					
50	0.271	X			
40	0.298		X		
30	0.331			X	
20	0.364				X

8/20 (nozzle diameter/rotational speed). These values were within one homogeneous group. The lowest oil yield was 0.26 kg of oil per 1 kg of rapeseed at 10/50 and 8/50 oil pressing parameters. As the oil yield decreased, the screw speed increased (Fig. 2), which has also been reported by Sriti et al. [2012] and Rabadán et al. [2017]. However, values of the oil yield ratio have varied in a non-homogenous way for the different nozzle diameters. For the smallest nozzle diameter, the highest oil yields were recorded and the smallest changes were made according to the rotational speed. Similar conclusions reached Karaj and Müller [2011] pressing oil from the seeds of jatropha.

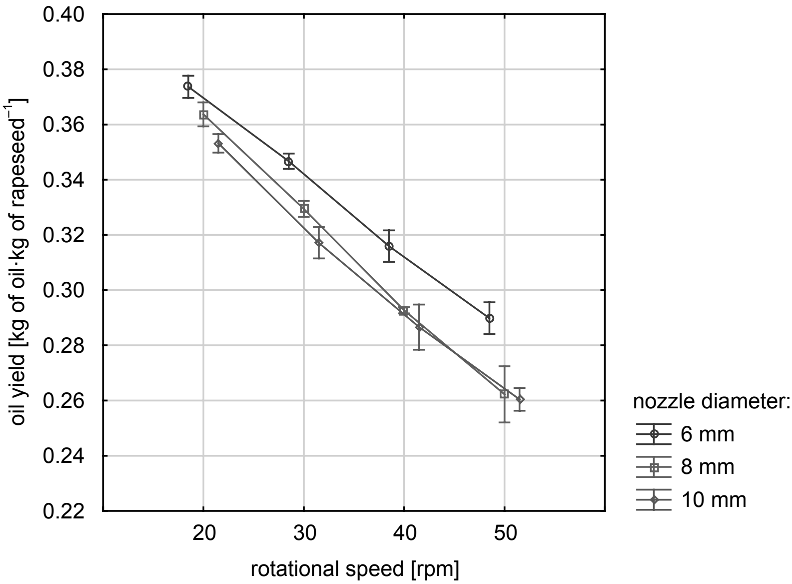

FIGURE 2. Average oil yield according to oil pressing parameters

Tables 4–6 and Figure 3 present results of statistical analysis for the oil flow rate according to the process parameters. Based on the analysis of variance (Table 4) it was found that the rotational speed of the screw, the nozzle diameter and the interaction of both factors significantly affect the oil flow rate performance. The Fisher–Snedecor test values were $F_{v1=2,\ v2=84} = 17.3$, with $p < 0.0001$; $F_{v1=3,\ v2=84} = 2632.4$, with $p < 0.0001$; $F_{v1=6,\ v2=84} = 8.7$, with $p < 0.0001$. The response of the oil flow rate to the change in rotational speed differed depending on nozzle diameter. The interaction between the nozzle diameter and the rotational speed is shown in Figure 3. The value of the F test is significantly higher for the rotational speed than for the nozzle diameter, and therefore the first factor differentiates the value of the oil flow rate.

Tukey's HSD test results for rotational speed showed that there were four homogeneous groups, and two homogeneous groups were formed for the nozzle (Table 6). Differences in the oil flow rate performance between the nozzle diame-

TABLE 4. Variance analysis for oil flow rate depending on oil pressing parameters

Source	*SS*	*Df*	MS	*F*-ratio	*p*
Nozzle diameter: A	0.448	2	0.224	17.3	< 0.0001
Rotational speed: B	102.034	3	34.011	2632.4	< 0.0001
Interaction: A × B	0.673	6	0.112	8.7	< 0.0001
Error	1.085	84	0.013	–	–

TABLE 5. Average values of oil flow rate (W_o) according to oil pressing parameters, 95% confidence intervals and standard deviations from mean

Nozzle diameter [mm]	Rotational speed [rpm]	Average W_o [kg of oil·h^{-1}]	–95% [kg of oil·h^{-1}]	95%, [kg of oil·h^{-1}]	*SD* [kg of oil·h^{-1}]
10	50	5.50^{d}	5.34	5.66	0.19
10	40	4.90^{c}	4.75	5.05	0.18
10	30	4.03^{b}	3.92	4.14	0.13
10	20	2.95^{a}	2.93	2.97	0.03
8	50	5.59^{d}	5.40	5.78	0.23
8	40	4.95^{c}	4.93	4.96	0.02
8	30	4.12^{b}	4.09	4.15	0.03
8	20	2.95^{a}	2.92	2.97	0.03
6	50	5.92	5.84	6.00	0.09
6	40	5.15	5.12	5.18	0.04
6	30	4.08^{b}	4.05	4.12	0.04
6	20	2.88^{a}	2.86	2.91	0.03

^{a,b,c,d} Mean values with identical letters do not differ statistically significantly at $p < 0.05$.

TABLE 6. Tukey HSD test of variance analysis for oil flow rate value (W_o) depending on oil pressing parameters

Property	Average W_o [kg of oil·h^{-1}]	Homogenous group			
		1	2	3	4
Nozzle diameter [mm]					
10	4.34	X			
8	4.40	X			
6	4.51		X		
Rotational speed [rpm]					
20	2.93	X			
30	4.08		X		
40	5.00			X	
50	5.67				X

ters of 8 and 10 mm were not statistically significant at the assumed significance level of α = 0.05. Tukey's post-hoc test results show that the highest oil flow rate (5.92 kg of oil·h^{-1}) at 6/50 varied significantly (at the assumed significance level α = 0.05) from other press operations. A lower oil flow rate was achieved at the same rotational speed for 8 and 10 mm diameter nozzles. The smallest oil flow rate (2.88–2.95 kg of oil·h^{-1}) was recorded at a rotational speed of 20 rpm for all nozzle diameters and was twice lower than the maximum value

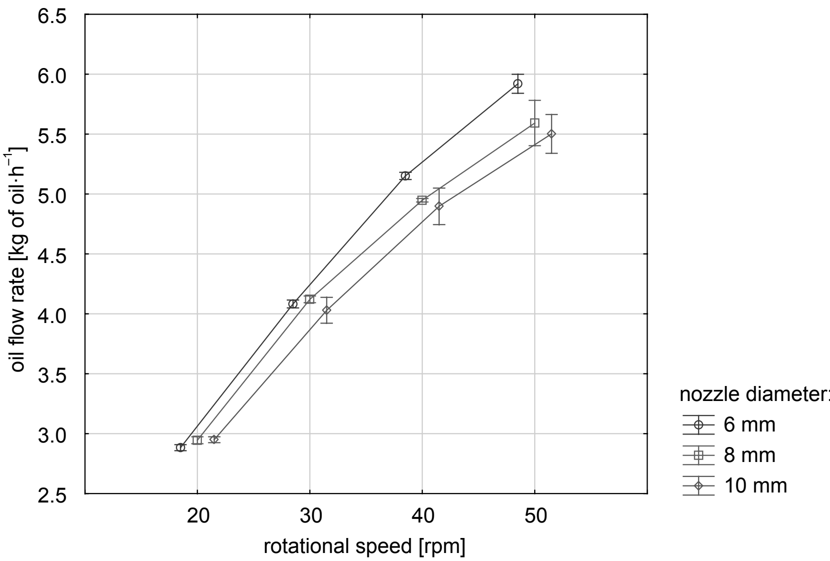

FIGURE 3. Average oil flow rate according to the oil pressing parameters

of this ratio. The oil flow rate increased exponentially with increasing rotational screw speed and was inversely dependent on the diameter of the nozzle. The decrease in performance relative to the nozzle diameter was uneven compared to the rotational speed difference and was higher at higher rotational speeds of the screw (Fig. 3).

Tables 7–9 and Figure 4 show results of a statistical analysis of the capacity (rapeseed flow rate) according to the parameters of the oil pressing process. The two-factor analysis of variance (Table 7) showed that both operational parameters (rotational speed, nozzle diameter) had a different effect on the capacity, with a critical significance level of $p < 0.0001$. The interaction of these factors is not significantly affected. It can be said that the increase in rotational speed increases the capacity, regardless of the outlet nozzle used. However, the value of $p = 0.0556$ slightly exceeded the assumed significance level of $\alpha = 0.05$. Consequently the combined effect of both parameters on the value of the ratio is not clear and further studies are warranted for unambiguous reasoning.

The minimum capacity (7.72–8.1 kg of rapeseed·h^{-1}) occurred at operational

TABLE 7. Variance analysis for capacity based on oil pressing parameters

Source	*SS*	*Df*	*MS*	*F*-ratio	*p*
Nozzle diameter: A	10.80	2	5.40	80.5	<0.0001
Rotational speed: B	2 235.32	3	745.11	11 106.7	<0.0001
Interaction: A × B	0.87	6	0.14	2.2	0.0556
Error	5.64	84	0.07	–	–

parameters 6/20 and 8/20 (Table 8). The maximum value of the ratio (21 kg of rapeseed·h^{-1}), almost three times higher, was achieved during the press operation at 50 rpm and the use of nozzles with a diameter of 8 and 10 mm.

Similarly to the oil flow rate, the rapeseed flow rate generates four separate homogeneous groups for rotational speed, while for the nozzle diameter two groups (Table 9). However, the average capacity was lower for 6 mm

TABLE 8. Average values of capacity (W_p) according to oil pressing parameters, 95% confidence intervals and standard deviations from mean

Nozzle diameter [mm]	Rotational speed [rpm]	Average W_p [kg r.·h^{-1}]	–95% [kg of rapeseed·h^{-1}]	95% [kg of rapeseed·h^{-1}]	SD [kg of rapeseed·h^{-1}]
10	50	21.13[e]	20.65	21.60	0.57
10	40	17.09[d]	16.85	17.33	0.29
10	30	12.70[c]	12.53	12.88	0.21
10	20	8.353[b]	8.249	8.456	0.12
8	50	21.33[e]	21.17	21.50	0.20
8	40	16.91[d]	16.84	16.97	0.08
8	30	12.51[c]	12.36	12.66	0.18
8	20	8.099[a,b]	8.007	8.191	0.11
6	50	20.43	20.18	20.69	0.30
6	40	16.31	16.00	16.62	0.37
6	30	11.78	11.71	11.84	0.07
6	20	7.72[a]	7.605	7.828	0.13

[a,b,c,d,e] Mean values with identical letters do not differ statistically significantly at $p < 0.05$.

TABLE 9. Tukey HSD test of variance analysis for capacity value (W_p) based on oil pressing parameters

Property	Average W_p [kg of rapeseed·h^{-1}]	Homogenous group			
		1	2	3	4
Nozzle diameter [mm]					
6	14.06		X		
8	14.71	X			
10	14.82	X			
Rotational speed [rpm]					
20	8.06	X			
30	12.33		X		
40	16.77			X	
50	20.96				X

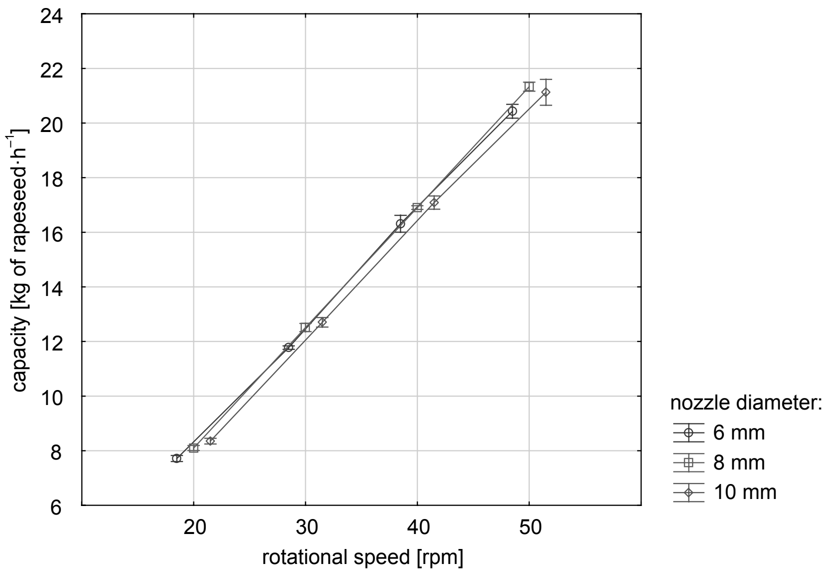

FIGURE 4. Average capacity according to the oil pressing parameters

than for 8 and 10 mm, as opposed to the oil flow rate.

Tables 10–12 show results of a statistical analysis of energy efficiency depending on operational parameters: the outlet nozzle and the rotational speed of the screw. Figure 5 presents a plot of the average values of this ratio and the interaction of the resulting effects. The increase in rotational speed contributed to an increase in the energy efficiency of pressing, however, with the use of an 8-mm nozzle and a change of speed from 40 to 50 rpm, an decrease was observed. The nozzle diameter affected the value of the ratio under the impact of changing speed. Greater energy efficiency and hence a lower energy consumption were attained for the largest diameter nozzle, 10 mm. Żelaziński [2014] studied the process of extrusion in a single-screw extruder have the same conclusions. Those facts among others point to potential similarities in both processes.

The results of two-way variance analysis (Table 10) showed a highly statistically significant effect of the nozzle diameter and rotational speed of the screw on the differentiation of energy efficiency values. Similarly, the combined effect of those parameters significantly influences the analyzed ratio.

TABLE 10. Variance analysis for energy efficiency based on oil pressing parameters

Source	*SS*	*Df*	*MS*	*F*-ratio	*p*
Nozzle diameter: A	6.123	2	3.062	85.2	<0.0001
Rotational speed: B	71.747	3	23.916	665.6	<0.0001
Interaction: A × B	4.459	6	0.743	20.7	<0.0001
Error	3.018	84	0.036	–	–

The Tukey's HSD test results (Table 11) suggest the presence of multicomponent homogeneous groups for the energy efficiency ratio, which is also confirmed in Figure 5. The highest energy efficiency was achieved by pressing at operational parameters of 10/50, 6/50, 8/40, 10/40. This energy efficiency value was 8.16–8.46 kg of oil·kWh^{-1}. The minimum rotational speed and the minimum nozzle diameter (Table 12), in particular pressing parameters 6/20 and

TABLE 11. Average values of energy efficiency (EE_o) based on oil pressing parameters, 95% confidence intervals and standard deviations from mean

Nozzle diameter [mm]	Rotational speed [rpm]	Average EE_o [kg of oil·kWh^{-1}]	–95% [kg of oil·kWh^{-1}]	95% [kg of oil·kWh^{-1}]	*SD* [kg of oil·kWh^{-1}]
10	50	8.46^{d}	8.21	8.71	0.30
10	40	8.16^{a,b,c,d}	7.91	8.42	0.30
10	30	8.06^{a,b,c}	7.84	8.28	0.26
10	20	6.56^{f}	6.50	6.61	0.07
8	50	7.99^{a,b}	7.72	8.26	0.32
8	40	8.25^{b,c,d}	8.22	8.27	0.03
8	30	7.49	7.44	7.54	0.06
8	20	5.89^{e}	5.83	5.95	0.07
6	50	8.32^{c,d}	8.12	8.51	0.23
6	40	7.93^{a}	7.88	7.97	0.06
6	30	6.81^{f}	6.75	6.86	0.07
6	20	5.77^{e}	5.72	5.82	0.06

^{a,b,c,d,e,f}Mean values with identical letters do not differ statistically significantly at $p < 0.05$.

TABLE 12. Tukey HSD test of variance analysis for energy efficiency value (EE_o) based on oil pressing parameters

Property	Average EE_o [kg of oil·kWh^{-1}]	Homogenous group			
		1	2	3	4
Nozzle diameter [mm]					
6	7.20	X			
8	7.41		X		
10	7.81			X	
Rotational speed [rpm]					
20	6.07	X			
30	7.45		X		
40	8.11			X	
50	8.26				X

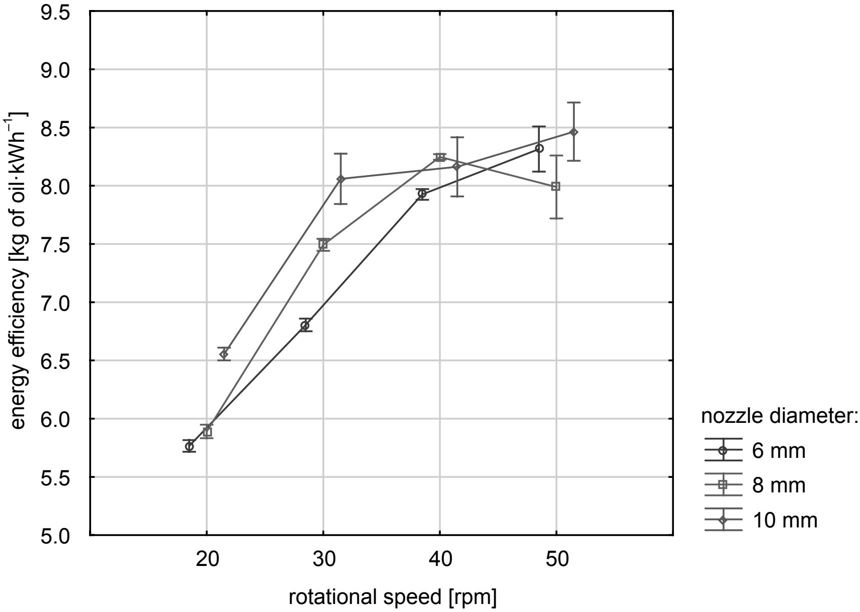

FIGURE 5. Average energy efficiency according to oil pressing parameters

8/20, have been proven to be the least advantageous. These are the parameters at which the highest oil yield has been achieved.

CONCLUSIONS

Parameters of the oil pressing process have a significant influence on the ratios of this process, the rotational screw speed having a much greater effect than the nozzle diameter. When selecting pressing parameters, attention should be paid to simultaneous changes in both rotational speed and outlet nozzle diameter to enhance the expected effect, as a result of the interaction of these factors, as shown by the statistical analyzes. The presented results do not exhaust the scientific problem. There is also a need to investigate the variability of oil pressing ratios when changing operational parameters under other factors, such as the type of pre-treatment or the physico-chemical characteristics of the raw material.

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Streszczenie: *Wpływ parametrów procesu wytłaczania na wskaźniki efektywności pozyskiwania oleju rzepakowego*. Celem pracy jest wyznaczenie relacji między parametrami prasy ślimakowej podczas wytłaczania oleju rzepakowego a wskaźnikami opisującymi ten proces. Zastosowano cztery prędkości obrotowe ślimaka (20, 30, 40, 50 obr.$\cdot$min^{-1}) i trzy średnice otworu dyszy wylotowej wytłoków (6, 8, 10 mm). Analizowano wskaźniki: uzysku i wydajności otrzymywania oleju, wydajności prasy oraz efektywności energetycznej. Parametry procesu wytłaczania (prędkość obrotowa ślimaka oraz średnica dyszy wylotowej), a także ich interakcja istotnie wpływają na wskaźniki procesu wytłaczania. W badanym zakresie przeważa efekt różnicującego działania prędkości obrotowej nad wpływem średnicy dyszy na wartości omawianych wskaźników efektywności pozyskiwania oleju.

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