

**ACCEPTED ARTICLE:**

**Influence of variety and seed moisture content on chemical and physical properties of oilseed rape**

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**ABSTRACT**

By studying the physical properties of oilseed rape, obtained data have a practical application when constructing machines for sowing, harvesting, transporting, warehouse design, and seed processing. During oilseed rape harvest, seed moisture can be different, and it's imperative to understand the physical properties of the seeds to correctly adjust the equipment. Depending on the climate conditions, oilseed rape can have different seed moisture content. This investigation included three winter varieties of oilseed rape widely grown in European countries. The influence of different degrees of seed moisture 6, 11, 16 and 21% on the physical properties of oilseed rape seed was investigated by using standard methods. The results presented are averages from three growing seasons (2015/17). When moisture content in the kernels increased, **1000-grain weight**, seed volume and porosity, static and dynamic angles of repose also increased in tested varieties. Increased seed moisture reduced the true density and bulk density of the three tested varieties. The highest coefficient of friction was found on plywood and the lowest on stainless steel sheet. Oil and protein contents of tested varieties ranged between 39.38 and 43.90%, and 17.65 and 23.12%, respectively. Oleic, linoleic,  $\alpha$ -linolenic, and palmitic acids were the most representative fatty acids. Knowing the physical and chemical properties of oilseed rape seeds it will be possible to significantly contribute to the breeding process in order to identify high-quality genotypes.

**Keywords:** oilseed rape, quality, weight, volume, porosity, friction coefficient.

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## INTRODUCTION

Oilseed rape (genus *Brassica*, family *Brassicaceae*) is an important oil crop with several advantages over alternative oilseeds. It gives very high yields per unit area and its seeds contain 40-48% oil and 18-25% protein (Balalić *et al.*, 2017). Oilseed rape oil has a low content of saturated fatty acids (5-7%), and a high content of unsaturated fatty acids, *i.e.* oleic acid 50-65%, linoleic acid 17-21% and  $\alpha$ -linolenic 7-10% (El-Beltagi and Mohamed, 2010). The oilseed rape oil is a very healthy cooking oil, as described by Baux *et al.* (2008).

On the other hand, the high oxidative and thermal stability of oilseed rape oil relates to the high content of monounsaturated (oleic) acid (Farsak, 2009; Islam *et al.*, 2022). Additionally, being an essential fatty acid, linoleic acid is regarded as highly important, and its share in oilseed rape oil is significant. This fatty acid plays important role in the human body – it is an energy source, a building block of phospholipids and structural elements of cellular membranes, a precursor to important hormonal compounds (prostaglandins, leukotrienes, thromboxanes) (Akoh *et al.*, 1999) and it lowers cholesterol and triglyceride levels in the blood (Tan, 2009; Shen *et al.*, 2023). Furthermore, oilseed rape seeds are a good source of crude protein, and fiber (Acikgoz, 2014; Rajković *et al.*, 2022). Nevertheless, it's worth mentioning that oilseed rape oil is not only suitable as human food but also for biodiesel production. Oilseed rape oil is an important bioenergy feedstock representing 10 to 15% share in the global biodiesel production (Haile *et al.*, 2014). Press cakes from oilseed rape, produced after oil extraction, which commonly used in animal feed (Baltrukoniene *et al.*, 2015), can also be used for making pellets or biogas (methane) in digesters (Krička *et al.*, 2015). Finally, oilseed rape straw is used for producing briquettes for energy production.

Understanding the seed physical properties of oilseed rape is crucial for designing machinery for sowing, harvest and transport, as well as for constructing equipment for seed processing and storage. The results of physical and chemical analyses from this study can be used in oilseed rape breeding as a criterion for genotypes with modified seed quality (Fu *et al.*, 2016; Iniyana *et al.*, 2020; Cao *et al.*, 2021). In addition, the results of the research will be used in precision agriculture for early prediction of oilseed rape quality using artificial neural networks. Based on the results obtained, it will also be possible to create an application for determining grain sizes using image processing. Additionally, the application was also created to determine the natural grain loss due to shaking during harvesting. The results obtained will be used to determine when to start harvesting rapeseed.

72 Although numerous studies on the physical properties of oilseed rape varieties have been  
73 conducted worldwide, none of them included the varieties mentioned in this paper, which is  
74 important for the further selection process and the expansion of acreage of this important oilseed  
75 crop in the Western Balkans region. The tribometer T1 was used for the first time to measure  
76 the coefficient of friction of biomaterials (in this case rapeseed) on different surfaces. The  
77 results obtained are compared with the research results of other authors who have used other  
78 instruments to measure the coefficient of friction, and in this way its reliability and accuracy  
79 are determined, which is used to further improve the existing device.

80 The aim of this study was to determine the effects of different levels of seed moisture content  
81 (seed maturity) on the changes in the basic physical properties of oilseed rape seed, to use them  
82 practically for designing machinery and equipment, and their adjustments during operation. The  
83 secondary aim was to determine the differences in contents of protein, oil, and fatty acids in  
84 seeds of three oilseed rape cultivars.

## 85 86 **EXPERIMENTAL**

### 87 **Plant material**

88 In this research, three varieties of winter oilseed rape were examined. All three varieties are  
89 'double low' varieties (low erucic acid, less than 2% of measured fatty acid, and low  
90 glucosinolates, less than 20  $\mu$ mole glucosinolates per gram of meal). Three candidate varieties  
91 are grown at the Institute of Field and Vegetable Crops Novi Sad. These varieties are the most  
92 commonly grown in European countries and typically have oil content of 43-44%. The first  
93 variety (X) has a vegetation length of about 288 days. The 1000-grain weight is 4.1 g. It has a  
94 high genetic potential for seed yield – over 5 t ha<sup>-1</sup>. The oil content of the seed is about 45%,  
95 and the protein content is 20%. The second variety (Y) has a vegetation length of 280 days. The  
96 1000-grain weight is 3.4 g. It has a high genetic potential for seed yield – over 5 t ha<sup>-1</sup>. The oil  
97 content of the seed is about 41% and the protein content is 20%. The third variety (Z) has a  
98 vegetation length of about 284 days. The 1000-grain weight is 4.2 g. It has a high genetic  
99 potential for seed yield – over 4.5 t ha<sup>-1</sup>. The oil content of the seed is about 46%, and the protein  
100 content is 23%. The harvest of oilseed rape was carried out at the stage of full technological  
101 maturity. The initial moisture content in the grains ranged from 10.56-14.0% (ISO 665:2020).

102 The oilseed rape cultivars X, Y and Z were assessed for seed physical and chemical  
103 properties. Firstly, the grain was cleaned from impurities after harvesting, then it was divided  
104 into two parts. In order to obtain the initial lowest moisture content (6%), the first part of the  
105 grain in which the physical properties were determined was dried at 105°C, and the second part

106 of the grain that was used for chemical analysis was dried at 50°C. Secondly, the increasing  
107 grain moisture contents for all samples grain (11, 16 and 21%) were assured by adding pre-set  
108 amounts of distilled water to the previously mentioned grain (with a moisture content of 6%)  
109 according to the method used by Calisir *et al.* 2005; Razavi *et al.* 2009; Izli *et al.* 2009;  
110 Sangamithra, 2016. After that, the grains were stored in a refrigerator (petri dishes) for a week  
111 at a temperature of 5°C, in order to obtain a uniform sample with the same moisture content in  
112 the grain.

113 A highly sensitive automatic device Elmor S3 (1/1000 measurement precision, Marty  
114 elektromechanik antriebstechnik Brunen) was used to count 1000 grain, and the mass of one  
115 thousand grains was measured on an analytical balance (Kern EW 150-3 M, accuracy 0.001 g,  
116 Kern GmbH Großmaischeid, Deutschland). The volume and porosity of a certain number of  
117 grains were determined by the method of pouring liquid (distilled water). Bulk mass (hectoliter  
118 mass) was determined by pouring grain into a container of a certain volume and measuring its  
119 mass together with the space between the grains (Calisir *et al.*, 2005; Razavi *et al.*, 2009; Izli *et*  
120 *al.*, 2009; Koprivica, 2018). The angle of repose (static and dynamic) is the angle that the  
121 sloping surface of a heap of loose material poured on a horizontal surface makes with the  
122 horizontal surface. That is the angle at the base of a cone of material formed with the vertical  
123 axis, as the material is allowed to fall onto a horizontal base plate under specified conditions  
124 (Razavi *et al.*, 2009; Izli *et al.*, 2009; Koprivica, 2018). To measure the height of the cone, an  
125 electronic measuring device with a Fowler-Pro-maxSylvyc system display was used with an  
126 accuracy of 0.01 mm (Fowler high precision Canton USA).

127 The coefficient of friction was tested on different types of friction surfaces, excluding the  
128 surface roughness of the friction surfaces. It was measured using a mechanical device — a  
129 tribometer that works on the principle of a steep plane, on the scale of which the values of the  
130 coefficient of friction are read. For the purposes of testing friction on the surfaces of friction  
131 surfaces made of different materials, a tribometer was constructed at the Faculty of Engineering  
132 Sciences in Kragujevac. The experience gained in the application of the tribometer and the  
133 research results will be used to further improve the existing device by installing sensors and  
134 connecting it to a computer. Based on the results of measuring the coefficient of friction, friction  
135 surfaces can be selected for the construction of tanks, seed boxes, mineral fertilizer spreaders,  
136 combine bunkers, as well as for the construction of silos, grain elevators, etc.

137 In addition to grain diameter, the 1000-grain weight is also used as a measure of coarseness.  
138 In 2020 research, the authors have created an application for rapid measurement of a large  
139 number of grain samples by software image analysis and its transmission with the application

140 of IoT [Internet of Things]. We can consider this as an indirect contribution to science, as the  
141 idea was created during the research and obtaining the results presented in this paper (Marković  
142 *et al.*, 2020). According to the results, the mean value of seed diameter for variety X is 2.30  
143 mm, Y is 2.22 mm and Z is 2.11 mm. Based on the obtained results, it is possible to adjust the  
144 sieve openings of the harvester during harvesting and seed calibration during seed processing.  
145 In addition, using an image analysis application and based on the 1000-grain weight and the  
146 surface area of the container into which the grains fell, it is possible to determine the natural  
147 loss of spilled grains in the field and determine the start of harvesting of canola, soybeans, etc.  
148 (Marković *et al.*, 2022).

### 149 **Chemical analysis**

151 The total oil content was determined following the NMR (Nuclear Magnetic Resonance)  
152 method by Granlund and Zimmerman (1975) on whole seed dried at 50°C. The Kjeldahl method  
153 was used for determining protein content in oilseed rape as described by analytical method 46–  
154 16.01 (AACC, 1999). The factor 6.25 was applied for converting nitrogen content to crude  
155 protein.

156 Fatty acid (FA) composition was determined on Konik HRGC 4000 gas chromatograph  
157 (GC) coupled with a flame ionisation detector. Samples for GC analysis were processed in a  
158 hydraulic press (Sirio, Mikodental 10–tons strength, cc 40 000 kPa). In order to chemically  
159 convert FA to volatile methylesters (FAME), 10 µL of oils were exposed to transesterification  
160 using 190 µL methanolic trimethylsulfonium hydroxide solution (0.2 mol dm<sup>-3</sup>) as described  
161 by AOCS official method Ce 2–66 (AOCS, 1992). A fused silica capillary column Omegawax®  
162 250 (30 m length, 0.25 mm ID, film thickness 0.25 µm) with poly (ethylene glycol) stationary  
163 phase was used. This process was operated at an oven temperature of 150°C, which was then  
164 raised to 250°C at a rate of 12°C min<sup>-1</sup> and then kept at 250°C for 8 min. The injector and  
165 detector temperatures were 250°C. The carrier gas was helium with constant flow rate of 1 ml  
166 min<sup>-1</sup> and split was 1:70. Identification of the individual fatty acids was performed by  
167 comparing relative retention times with those of the pure commercial standard mixture of  
168 FAME. Reference multi standard from Supelco (Cat. No. 07756–1AMP, Bellefonte, PA, USA)  
169 was used, containing the methyl esters of 11 fatty acids (myristic C14:0, palmitic C16:0, stearic  
170 C18:0, oleic C18:1, linoleic C18:2, α-linolenic C18:3, arachidic C20:0, eicosenoic C20:1,  
171 behenic C22:0, erucic C22:1, and lignoceric C24:0). The results were processed by the Data  
172 Apex software (version 7.4.1.88).

173

## 174 Data analysis

175 All measurements were performed in three replicates. The data are shown as a mean value  
176  $\pm$  standard deviation (SD). The obtained data on the physical properties of oilseed rape were  
177 processed using the method of analysis of variance (ANOVA) of a two-factorial and three-  
178 factorial experiment according to the "completely random block system" plan. Testing the  
179 significance of the differences between the mean values of the tested properties (factors) was  
180 determined using the LSD test, for a significance level of 5% and 1% in relation to the standard.  
181 The Pearson correlation coefficient was used to show the strength and direction of the  
182 connection between the variables in the paper. The values of the correlation coefficient range  
183 from  $-1$  to  $+1$ . Statistical analysis of chemical composition was performed by one-way analysis  
184 of variance (ANOVA), while the means of values were compared with Tukey's HSD test. All  
185 significance level was set at less than 0.05. The results were statistically processed in the  
186 program STATISTICA 6.0 (StatSoft Inc., 1995).

187

## 188 RESULTS AND DISCUSSION

### 189 Physical properties

190 Seed moisture content drops as the crop mature, so the of harvest date, combine harvester  
191 operation regime, and parameters for seed drying, storing and should be optimized based on  
192 this.

193 The highest 1000-grain weight (4.66 g) was found in Y (Table 1), whereas  
194 X (4.41 g) and Z (4.35 g) showed somewhat higher weight than, in other studies (Vujaković *et*  
195 *al.*, 2010; Jovičić *et al.*, 2011) which could most probably be a result of different climatic and  
196 edaphic conditions, as well as the applied cultivation practices. The studied cultivars showed  
197 an increase in the 1000-grain weight and seed volume as seed moisture content increased. At  
198 all tested seed moisture contents, Y showed higher volume (4.59 mm<sup>3</sup>) as a result of its larger  
199 seeds which absorbed more water, than the other two cultivars (X and Z).

200

**Table 1.** Effect of cultivars and moisture content on seed physical traits.

	1000-grain weight, g	Seed volume, mm <sup>3</sup>	Bulk density, kg m <sup>-3</sup>	Seed porosity, %	True density, kg m <sup>-3</sup>
<b>Cultivar (A)</b>					
X (1)	4.41 $\pm$ 0.06 <sup>b</sup>	4.36 $\pm$ 0.07 <sup>b</sup>	597.73 $\pm$ 3.80	40.65 $\pm$ 0.18	1007.01 $\pm$ 4.62
Y (2)	4.66 $\pm$ 0.06 <sup>a</sup>	4.59 $\pm$ 0.08 <sup>a</sup>	595.16 $\pm$ 6.28	41.20 $\pm$ 0.39	1011.93 $\pm$ 4.75
Z (3)	4.35 $\pm$ 0.07 <sup>c</sup>	4.33 $\pm$ 0.08 <sup>b</sup>	590.61 $\pm$ 5.11	41.13 $\pm$ 0.34	1003.20 $\pm$ 6.40
<b>Moisture content, % (B)</b>					
6 (1)	4.20 $\pm$ 0.05 <sup>d</sup>	4.07 $\pm$ 0.04 <sup>d</sup>	620.45 $\pm$ 4.14 <sup>a</sup>	39.65 $\pm$ 0.20 <sup>c</sup>	1028.05 $\pm$ 5.33 <sup>a</sup>
11 (2)	4.31 $\pm$ 0.05 <sup>c</sup>	4.25 $\pm$ 0.04 <sup>c</sup>	598.81 $\pm$ 2.48 <sup>b</sup>	40.78 $\pm$ 0.22 <sup>b</sup>	1011.21 $\pm$ 2.10 <sup>b</sup>
16 (3)	4.58 $\pm$ 0.04 <sup>b</sup>	4.55 $\pm$ 0.03 <sup>b</sup>	586.91 $\pm$ 2.02 <sup>c</sup>	41.39 $\pm$ 0.24 <sup>b</sup>	1001.53 $\pm$ 2.96 <sup>b</sup> <sup>c</sup>
21 (4)	4.80 $\pm$ 0.04 <sup>a</sup>	4.84 $\pm$ 0.05 <sup>a</sup>	571.82 $\pm$ 2.51 <sup>d</sup>	42.15 $\pm$ 0.33 <sup>a</sup>	988.73 $\pm$ 6.52 <sup>c</sup>
<b>Cultivar <math>\times</math> moisture (A<math>\times</math>B)</b>					

Cultivar	Moisture content, %					
X (1)	6	4.16±0.04 <sup>a</sup>	4.00±0.02 <sup>a</sup>	617.87±5.07 <sup>a</sup>	39.97±0.18 <sup>a</sup>	1029.32±10.70 <sup>a</sup>
	11	4.24±0.01 <sup>a</sup>	4.17±0.01 <sup>a</sup>	600.26±0.84 <sup>a</sup>	40.58±0.09 <sup>a</sup>	1010.18±0.57 <sup>a</sup>
	16	4.51±0.02 <sup>a</sup>	4.48±0.02 <sup>a</sup>	592.15±4.14 <sup>a</sup>	40.71±0.52 <sup>a</sup>	998.90±3.04 <sup>a</sup>
	21	4.73±0.02 <sup>a</sup>	4.76±0.01 <sup>a</sup>	580.63±0.57 <sup>a</sup>	41.32±0.23 <sup>a</sup>	989.65±3.43 <sup>a</sup>
Y (2)	6	4.38±0.04 <sup>a</sup>	4.24±0.00 <sup>a</sup>	629.10±4.26 <sup>a</sup>	39.10±0.21 <sup>a</sup>	1033.14±9.72 <sup>a</sup>
	11	4.52±0.04 <sup>a</sup>	4.43±0.04 <sup>a</sup>	602.59±3.08 <sup>a</sup>	40.76±0.30 <sup>a</sup>	1017.39±4.78 <sup>a</sup>
	16	4.77±0.03 <sup>a</sup>	4.69±0.04 <sup>a</sup>	584.42±2.01 <sup>a</sup>	41.97±0.23 <sup>a</sup>	1007.07±1.56 <sup>a</sup>
	21	4.98±0.04 <sup>a</sup>	5.02±0.03 <sup>a</sup>	564.52±1.56 <sup>a</sup>	42.98±0.08 <sup>a</sup>	990.12±2.11 <sup>a</sup>
Z (3)	6	4.06±0.04 <sup>a</sup>	3.97±0.01 <sup>a</sup>	614.38±10.28 <sup>a</sup>	39.88±0.47 <sup>a</sup>	1021.69±8.96 <sup>a</sup>
	11	4.16±0.05 <sup>a</sup>	4.13±0.04 <sup>a</sup>	593.57±6.53 <sup>a</sup>	41.00±0.65 <sup>a</sup>	1006.05±1.88 <sup>a</sup>
	16	4.48±0.03 <sup>a</sup>	4.47±0.02 <sup>a</sup>	584.15±3.15 <sup>a</sup>	41.50±0.25 <sup>a</sup>	998.63±8.33 <sup>a</sup>
	21	4.68±0.04 <sup>a</sup>	4.73±0.09 <sup>a</sup>	570.32±4.74 <sup>a</sup>	42.13±0.81 <sup>a</sup>	986.43±21.18 <sup>a</sup>
<b>ANOVA</b>						
A		**	**	ns	ns	ns
B		**	**	**	**	**
A × B		ns	ns	ns	ns	ns

201 Mean values in columns marked by the same letters are not different ( $P > 0.05$ ) according to LSD test  
202 F-test: ns=  $P > 0.05$ ; \* $P \leq 0.05$ ; \*\* $P \leq 0.01$ ; \*\*\* $P \leq 0.001$ ;  
203 Letters A and B indicate different influencing factors (cultivar and moisture content);  
204 Numbers 1,2,3,(4) indicate different levels of same factor (cultivar X, Y, Z and moisture content 6, 11, 16 or  
205 21%);  
206 Value  $\pm$  SD, SD – standard deviation  
207

208 Seed volume ( $V$ ) and 1000-grain weight ( $W_{1000}$ ) were positively correlated, can be  
209 represented using regression equation (Eq. 1):

$$210 V = 0.80 + 0.83W_{1000} (R^2 = 0.92) \quad (\text{Eq. 1})$$

211 The results of this study on the effect of increased seed moisture content in on the rise of 1000-  
212 grain weight and seed volume are in line with those reported by Calisir *et al.* (2005), Razavi *et*  
213 *al.* (2006) and Izli *et al.* (2009). Small differences in the values of these properties are probably  
214 related to the different cultivars and agroecological conditions of oilseed rape cultivation.

215 Bulk density and true density values did not differ significantly among the cultivars, which  
216 is in accordance with Izli *et al.* (2009). Seed moisture content is inversely proportional to seed  
217 weight, therefore bulk density and true density of all cultivars decreased as moisture content  
218 grew. Bulk density and true density values ranged from the highest (620.45 kg m<sup>-3</sup>, 1028 kg m<sup>-3</sup>)  
219 at the lowest seed moisture content, to the lowest (571.82 kg m<sup>-3</sup>, 988 kg m<sup>-3</sup>) at the highest  
220 moisture content, respectively.

221 Bulk density declined linearly with the rise of moisture content, as a result of accumulated water  
222 content and simultaneously reduced dry matter content in the total seed volume. The equation  
223 (Eq. 2) shows the negative correlation between seed volume ( $V$ ) and bulk density ( $\rho_B$ ):

$$224 V = 803.64 - 47.25 \rho_B, (R^2 = 0.58) \quad (\text{Eq. 2})$$

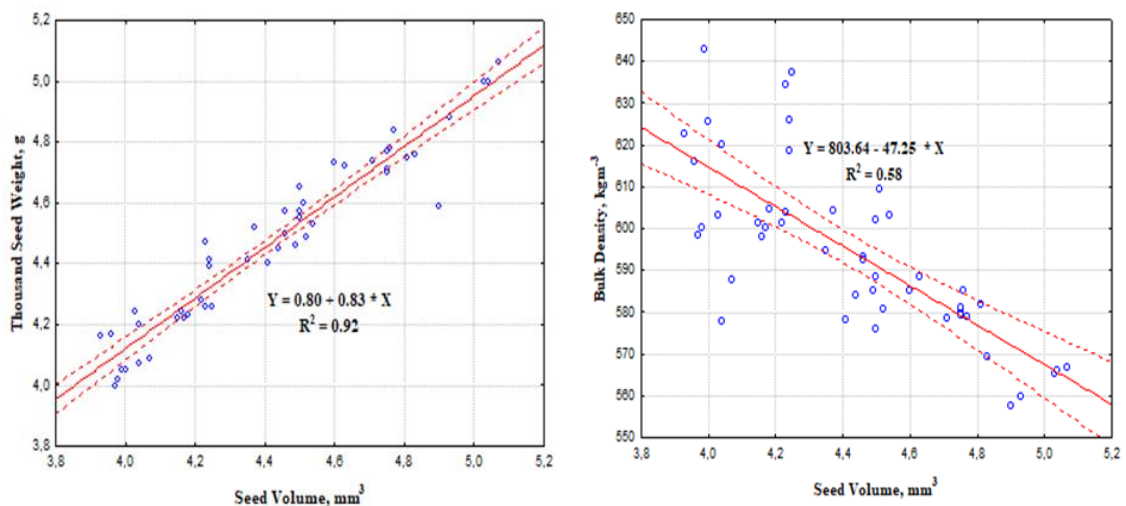
225 The relationship between true density ( $\rho_T$ ) and bulk density ( $\rho_B$ ) were positively correlated can  
226 be expressed by the following equation (Eq. 3):

227  $\rho_B = -191.2 + 0.78 \rho_T$ , ( $R^2 = 0.66$ ) (Eq. 3)

228 Seed moisture content significantly affected bulk density and true density ( $P \leq 0.01$ ), which is  
 229 in agreement with Calisir *et al.* (2005); Szot (2008); Duc *et al.* (2008); Razavi *et al.* (2009); Izli  
 230 *et al.* (2009). The relative decrease of true density with increased moisture content is explained  
 231 by smaller rise in seed weight than in its volume, owing to higher water content and lower dry  
 232 matter content in the seed.

233 A decrease in the value of the 1000-grain weight is associated with an increase in the value of  
 234 grain density. As variety Y had the highest 1000-grain weight, as expected the grain density of  
 235 this variety was lower than the other two, which is in agreement with the results of Izli *et al.*  
 236 (2009), Hazbavi *et al.* (2009) and Razavi *et al.* (2006). It is known that the porosity of the bulk  
 237 mass depends on the characteristics of the variety: shape, surface, size and 1000-grain weight.  
 238 Also, variety Y, due to larger grains, with a smooth and flat surface of the grain coat, had higher  
 239 porosity than the other two varieties. The highest measured dynamic angle of filling in variety  
 240 Z is most likely due to the small grain. In addition, the grain had good flowability, less  
 241 sphericity, so when it was poured and fell on the pile, it did not roll down the steep sides, but  
 242 remained close to them due to the effect of cohesive forces and friction.

243 All cultivars showed increases in seed weight porosity from 39.65 to 42.15% as water content  
 244 in seed grew from 6 to 21%, confirming the results of Calisir *et al.* (2005); Szot (2008); Razavi  
 245 *et al.* (2009); Izli *et al.* (2009). Seed porosity and bulk density were negatively correlated, as  
 246 shown in Fig. 1.



**Figure 1.** Interdependence of seed volume and thousand seed weight, seed volume and bulk density, porosity and bulk density.

247 All studied cultivars showed an increasing trend in static angle of repose as moisture content in  
 248 seed gradually increased (Table 2). The lowest static angle of repose ( $24.97^\circ$ ) in all cultivars



249 was found at the lowest moisture content (6%). As seed moisture content accumulated, static  
 250 angle of repose grew gradually, only to reach its highest value (29.01°) at the highest moisture  
 251 content (21%). However, increase in static angle of repose in X and Y was found only at the  
 252 extreme moisture contents, the lowest and the highest (interaction between cultivar and seed  
 253 moisture content). Values found for static angle of repose follow those reported for the cultivar  
 254 Jet Neuf (Izli *et al.*, 2009).

255 The studied cultivars differed significantly in the values of static angle (filling) of repose for all  
 256 moisture contents. However, Y and Z differed from X in the values of static angle of repose  
 257 only at lower moisture contents (6 and 11%). Similar findings were reported by Razavi, *et al.*  
 258 (2006) for the cultivar Hyola and by Izli *et al.* (2009) for cultivars Capitol and Samurai. The  
 259 lowest static angle of repose was found in X (24.97°), and the highest in Z (28.59°). Average  
 260 values of static angle of repose for the studied cultivars are similar to those reported for cultivars  
 261 Margo and Jura (Szot, 2008).”

262  
 263  
 264

**Table 2.** Static and dynamic angles of repose (filling) of oilseed rape cultivars depending on seed moisture content.

		Static angle of repose, °	Dynamic angle of repose, °
<b>Cultivar (A)</b>			
X (1)		24.97±0.36 <sup>c</sup>	20.96±0.45 <sup>c</sup>
Y (2)		27.25±0.35 <sup>b</sup>	23.59±0.53 <sup>b</sup>
Z (3)		28.59±0.59 <sup>a</sup>	24.41±0.44 <sup>a</sup>
<b>Moisture (B)</b>			
6 (1)		24.97±0.43 <sup>d</sup>	20.51±0.52 <sup>d</sup>
11 (2)		26.14±0.41 <sup>c</sup>	22.41±0.34 <sup>c</sup>
16 (3)		27.63±0.57 <sup>b</sup>	23.93±0.57 <sup>b</sup>
21 (4)		29.01±0.63 <sup>a</sup>	25.09±0.51 <sup>a</sup>
<b>Cultivar × moisture (A × B)</b>			
X (1)	6.85%	23.22±0.12 <sup>h</sup>	18.36±0.20 <sup>g</sup>
	10.87%	24.45±0.23 <sup>g</sup>	21.20±0.48 <sup>ef</sup>
	15.54%	25.39±0.35 <sup>fg</sup>	21.45±0.27 <sup>ef</sup>
	20.38%	26.83±0.30 <sup>de</sup>	22.83±0.45 <sup>cd</sup>
Y (2)	6.57%	25.90±0.60 <sup>ef</sup>	21.07±0.53 <sup>f</sup>
	11.02%	26.75±0.49 <sup>de</sup>	22.49±0.29 <sup>d</sup>
	16.48%	27.67±0.30 <sup>cd</sup>	24.67±0.41 <sup>b</sup>
	20.98%	28.68±0.60 <sup>c</sup>	26.14±0.15 <sup>a</sup>
Z (3)	6.56%	25.79±0.38 <sup>ef</sup>	22.11±0.33 <sup>de</sup>
	11.60%	27.23±0.20 <sup>d</sup>	23.55±0.11 <sup>c</sup>
	16.86%	29.83±0.18 <sup>b</sup>	25.68±0.21 <sup>a</sup>
	20.60%	31.52±0.36 <sup>a</sup>	26.31±0.14 <sup>a</sup>
<b>ANOVA</b>			
A		**	**
B		**	**
A × B		**	*

265 Mean values in columns marked by the same letters are not different (P>0.05) according to LSD test

266 F-test: ns = P > 0.05; \* P < 0.05; \*\* P < 0.01; \*\*\* P < 0.001

267 Letters A and B indicate different influencing factors (cultivar and moisture content);

268 Numbers 1,2,3,(4) indicate different levels of same factor (cultivar X, Y, Z and moisture content 6, 11, 16 or  
269 21%); Value  $\pm$  SD, SD – standard deviation.

270  
271 The dynamic angle of repose (filling) in all cultivars increased as seed moisture content  
272 accumulated progressively (6, 11, 16 and 21%). However, dynamic angle of repose did not  
273 grow significantly at moisture content of 11 and 16% in X, and 16 and 21% in Z (interaction  
274 between cultivar and moisture content in seed). The increase of the dynamic angle of repose in  
275 line with the rise of moisture content was probably because of enhanced adhesion forces and  
276 seed friction. Additionally, seeds with higher moisture content become sticky and compact,  
277 which enhances the pileup and dynamic angle of repose. The enhanced angle of repose with  
278 increased moisture content was also reported by Szot *et al.* (2007) and Szot (2008) and Hong  
279 *et al.* (2008).

280 The mean values of dynamic angle of repose for all moisture contents significantly differed  
281 among the cultivars (X 20.96°, Y 23.59°, and Z 24.41°), except at the highest moisture content  
282 between Y and Z (interaction between cultivar and seed moisture content) (Table 2). The  
283 highest static and dynamic angles of repose found in Z were probably the result of its smaller  
284 seeds, which increase cohesion between the seeds and provide closer pile up.

285 The differences among these values were probably due to different seed properties of the  
286 studied cultivars and different growing conditions. The positive correlation between dynamic  
287 ( $\alpha_D$ ) and static ( $\alpha_S$ ) angles of repose is shown in equation (Eq. 5).

$$288 \alpha_S = 7.31 + 0.85 \alpha_D \quad (R^2 = 0.77) \quad (\text{Eq. 5})$$

289 On the other hand, dynamic angle of repose was negatively correlated with bulk density, and  
290 positively with seed porosity in equation (Eq. 6) and (Eq. 7).

$$291 \rho_B = 740.24 - 6.34 \alpha_D, (R^2 = 0.74) \quad (\text{Eq. 6})$$

$$292 P = 32.29 + 0.38 \alpha_D, (R^2 = 0.72) \quad (\text{Eq. 7}),$$

293 where  $P = \frac{V_V}{V_T}$ ,  $V_V$  – volume of void–space between seeds,  $V_T$  – total volume of seeds.

294 The values of dynamic angle of repose presented in this study are slightly lower than those  
295 reported by Szot *et al.* (2007) and Szot (2008) for the cultivars Star, Margo, and Jura, and by  
296 Baran *et al.* (2016) for the cultivar Elvis.

297 The coefficient of friction varied significantly under the influence of investigated three factors  
298 – type of friction surfaces, grade and grain moisture (Table 3). It can be seen from Table 3 that  
299 the lowest grain friction coefficient was measured for grade X (0.288) and was significantly  
300 different from grades Y (0.322) and Z (0.321). Izli *et al.* (2009) studied Samurai, Jet Neuf, and  
301 Capitol cultivars and Razavi *et al.* (2009) studied Orient and SLM cultivars and proved that

302 there is a difference in the coefficient of friction between cultivars regardless of friction surface  
 303 and water content in the grain, which is inconsistent with the studies in our study.  
 304 Increasing the moisture content in the grain significantly increases the grain friction coefficient  
 305 of the tested grades on investigated friction surfaces. The lowest coefficient of friction of 0.264  
 306 was measured at the lowest grain water content of 6%. With a gradual increase in grain water  
 307 content, the coefficient of friction also increases, reaching its highest value of 0.354 at the  
 308 highest grain water content of 21%. The increase in water content makes the grains sticky, so  
 309 that the cohesive forces between the grains and the contact surface increase, leading to an  
 310 increase in the coefficient of friction.

311 **Table 3.** Coefficient of friction depending on the type of surface, variety and moisture in the  
 312 grain

<i>Type of surface (A)</i>	n	mean±SD
Galvanized sheet	48	0.302±0.004 <sup>d</sup>
Steel sheet	48	0.308±0.006 <sup>cd</sup>
Stainless steel sheet	48	0.271±0.005 <sup>e</sup>
Aluminium sheet	48	0.313±0.006 <sup>c</sup>
Plastic slab	48	0.331±0.007 <sup>b</sup>
Plywood slab	48	0.338±0.007 <sup>a</sup>
<i>Variety (B)</i>		
X	96	0.288±0.004 <sup>b</sup>
Y	96	0.322±0.004 <sup>a</sup>
Z	96	0.321±0.005 <sup>a</sup>
<i>Moisture, % (C)</i>		
6	72	0.264±0.003 <sup>d</sup>
11	72	0.298±0.003 <sup>c</sup>
16	72	0.325±0.004 <sup>b</sup>
21	72	0.354±0.005 <sup>a</sup>
<i>ANOVA</i>	<i>df</i>	
A	5	**
B	2	**
C	3	**

313 Mean values per columns marked with the same letters do not differ ( $P > 0.05$ ) based on the LSD test. \*\* F-test  
 314 significant at  $P < 0.01$ ; Letters A, B, C indicate different influencing factors (type of surface, variety, moisture).  
 315

316 Studies by other authors (Calisir *et al.*, 2005; Razavi *et al.*, 2009; Izli *et al.*, 2009; Hong *et al.*,  
 317 2008) have confirmed that the coefficient of friction of the grains increases with increasing  
 318 moisture content in the grain of the tested varieties on investigated friction surfaces. Regardless  
 319 of the grade and grain moisture content, the highest coefficient of friction on the plywood  
 320 surface was 0.338 (Table 3). On the rough and uneven surfaces of the plywood, the grains did  
 321 not slide as easily, so the highest coefficients of friction were measured on them. The lowest  
 322 grain friction coefficients of the tested grades were measured on the surface of the stainless  
 323 steel sheet (0.271), which is consistent with the studies of Hazbavi and Minaei (2009), Baran  
 324 *et al.*, (2016). The smooth and flat polished surface of the stainless steel sheet allowed the seed  
 325 to slide over it without any resistance.

326 The results of the research and other authors Calisir *et al.* (2005), Hong *et al.* (2008) Razavi *et*  
327 *al.* (2009), Izli *et al.* (2009) and Cao *et al.* (2021) confirm that the value of the coefficient of  
328 friction depends on the surface of the friction surfaces.

329

### 330 **Chemical properties**

331 High seed oil content is one of the main goals in oilseed rape breeding. Oil quality and  
332 composition are determined by genetic factors and are under the influence of the environment  
333 and cultivation practices. The study determined that there were no significant differences in oil  
334 content for the analyzed oilseed rape cultivars ( $P>0.05$ ). Since the analyzed seed samples came  
335 from the same locality and from the same growing season, the differences between the cultivars  
336 can only come from genetic variability, which was presumably restrained since all the cultivars  
337 originate from the same breeding program (Marjanović–Jeromela *et al.*, 2019). Seed oil content  
338 in oilseed rape ranged between 39.38 and 43.90%, depending on the genotype, with the highest  
339 mean value in Y (42.05%) and lowest in Z (40.09%), as shown in Table 4. The present results  
340 for seed oil content are in accordance with other studies which reported average oil content in  
341 oilseed rape of 35.2-38.0% (Kurmi and Kalita 1992), 27.71-40.77% (Basalma, 1997), 34.7-  
342 39.3% (Caliskan, *et al.*, 1998), 12.31-46.47% (Tan, 2009) and 36.9-40.52% (Beyzi, *et al.*,  
343 2019). Small differences in all the listed seed oil content results may be caused by different  
344 growing conditions and genetic potential of the analyzed oilseed rape cultivars.

345

### 346 **Protein content**

347 Protein content in oilseed rape depends on genetic and agroecological factors, as well as  
348 their interaction. Apart from genetic factors, variability of protein content is also reported to be  
349 under the influence of the environment (Piljuk, 2006; Kulikovskij and Srokov, 2006;  
350 Marinković *et al.*, 2010) and sowing date (Kapilovič and Srokov, 2006). Protein content in  
351 oilseed rape seed is negatively correlated to oil content, and both parameters are highly under  
352 the effect of agroecological growing conditions and genetic control. Therefore, the parameters  
353 that increase protein content in oilseed rape also decrease its oil content (Šidlauskas and Rife,  
354 2000). Significant differences were not found between protein content in the studied oilseed  
355 rape cultivars ( $P >0.05$ ). Similarly, to oil content differences in protein contents were not  
356 significant in this study, since all the cultivars originated from the same breeding program  
357 (Balalic *et al.*, 2017). Oilseed rape protein content ranged from 17.65 to 23.12%, with the  
358 highest value detected in Z (20.86%) and the lowest in Y (19.49%), as shown in Table 4. These  
359 results agree with Marinković *et al.* (2010) who reported protein content of 19.26-25.93%

360 depending on the environment, as well as Vujaković *et al.* (2014) who found it to be 18.06–  
 361 20.00% and Balalic *et al.* (2017) who reported protein content of 17.13-23.32% depending on  
 362 the year.

363

### 364 **Fatty acid composition**

365 Table 4. shows the results of fatty acid composition in the analysed oilseed rape cultivars  
 366 and the results of total content of saturated, monounsaturated and polyunsaturated fatty acids.  
 367 The analyses confirmed the presence of 10 fatty acids in the studied oilseed rape oil. Taking  
 368 into account the composition of fatty acids in the studied oilseed rape oil, the differences  
 369 between C16:0, C18:0, C18:1 n9c, C18:2 n6c, and C18:3 n3 components and saturated fatty  
 370 acids (SFA), monounsaturated fatty acids (MUFA), and polyunsaturated fatty acids (PUFA)  
 371 were found to be significant ( $P \leq 0.05$ ), unlike the differences between C20:0, C20:1, C22:0,  
 372 C22:1, and C24:0 fatty acids which were not significant.

373 **Table 4. Content of oil and protein in the seed and fatty acid composition in oilseed rape oil**

Parameter	Content, %		
	X	Y	Z
	mean±SD	mean±SD	mean±SD
OC	41.35±1.42 <sup>a</sup>	42.05±1.75 <sup>a</sup>	40.09±0.71 <sup>a</sup>
PC	20.52±1.45 <sup>a</sup>	19.49±3.14 <sup>a</sup>	20.86±0.90 <sup>a</sup>
C16:0	4.56±0.03 <sup>a,b</sup>	4.67±0.07 <sup>a</sup>	4.45±0.02 <sup>b</sup>
C18:0	1.49±0.03 <sup>b</sup>	1.72±0.02 <sup>a</sup>	1.47±0.10 <sup>b</sup>
C18:1 n9c	57.58±0.29 <sup>c</sup>	60.36±0.27 <sup>a</sup>	59.34±0.50 <sup>b</sup>
C18:2 n6c	22.48±0.19 <sup>a</sup>	22.20±0.38 <sup>a</sup>	21.24±0.28 <sup>b</sup>
C18:3 n3	11.54±0.24 <sup>a</sup>	9.40±0.26 <sup>b</sup>	11.28±0.36 <sup>a</sup>
C20:0	0.53±0.02 <sup>a</sup>	0.56±0.01 <sup>a</sup>	0.51±0.03 <sup>a</sup>
C20:1	1.21±0.05 <sup>a</sup>	1.13±0.06 <sup>a</sup>	1.22±0.01 <sup>a</sup>
C22:0	0.32±0.02 <sup>a</sup>	0.31±0.01 <sup>a</sup>	0.31±0.03 <sup>a</sup>
C22:1	0.11±0.01 <sup>a</sup>	0.08±0.02 <sup>a</sup>	0.07±0.03 <sup>a</sup>
C24:0	0.19±0.01 <sup>a</sup>	0.16±0.05 <sup>a,b</sup>	0.10±0.03 <sup>b</sup>
SFA	7.08±0.08 <sup>b</sup>	7.41±0.08 <sup>a</sup>	6.84±0.16 <sup>b</sup>
MUFA	58.89±0.34 <sup>c</sup>	61.57±0.25 <sup>a</sup>	60.64±0.47 <sup>b</sup>
PUFA	34.02±0.41 <sup>a</sup>	31.60±0.64 <sup>b</sup>	32.53±0.63 <sup>b</sup>

374 OC: oil content; PC: protein content; SD: standard deviation; SFA: sum of saturated fatty acids; MUFA: sum of  
 375 monounsaturated fatty acids; PUFA: sum of polyunsaturated fatty acids. Different Latin letters in the same row  
 376 refer to significant differences between cultivars (X,Y and Z) according to Tukey's HSD test ( $P \leq 0.05$ ).

377 Among the fatty acids, oleic acid (C18:1 n9c) was the main component, followed by linoleic  
 378 acid (C18:2 n6c), **α-linolenic** acid (C18:3 n3) and palmitic acid (C16:0). The content of oleic  
 379 acid (C18:1 n9c) ranged from **57.25%** to 60.67% with the highest found in Y (60.36%) and the  
 380 lowest in X (57.58%). The content of linoleic acid (C18:2 n6c) ranged from 21.01 to 22.65%,  
 381 content of **α-linolenic** fatty acid (C18:3 n3) ranged from 9.22 to 11.82%, and palmitic acid  
 382 (C16:0) from 4.44 to 4.75%. The content of total unsaturated fatty acids was significantly higher  
 383 than the content of saturated fatty acids namely 93.17% in Y and 92.92% in X. The highest  
 384 contribution of the total monounsaturated fatty acids was found in Y (61.57%), followed by X

385 (58.89%) and Z (60.64%), while the total contribution of polyunsaturated fatty acids was found  
386 in X (34.02%), followed by Y (31.60%) and Z (32.52%). According to Beyzi *et al.* (2019)  
387 average values were as follows: oleic acid 53.95-60.98%, linoleic 20.42-25.02%, and linolenic  
388 8.74-9.56% and other authors reported similar these values: oleic 56.31-58.67%, linoleic 10.52-  
389 13.74%, and linolenic 8.83-10.32% (El-Beltagi and Mohamed, 2010). These small differences  
390 probably were related to genetic variability and different environmental growing conditions.  
391 The influence of the variety and physical properties on the chemical composition of the grain  
392 was not studied, but Rajković *et al.* (2022) reported that the oil content was positively correlated  
393 with grain yield, 1000-grain weight, and oil and protein yield.

## 394 CONCLUSION

395 The influence of different degrees of seed moisture 6, 11, 16 and 21% on the physical properties  
396 of oilseed rape seed was investigated by using standard methods. When moisture content in the  
397 kernels increased, 1000-grain weight, seed volume and porosity, static and dynamic angles of  
398 repose also increased in tested varieties. Increased seed moisture reduced the true density and  
399 bulk density of the three tested varieties. The highest coefficient of friction was found on  
400 plywood and the lowest on stainless steel sheet. Oil contents of tested varieties ranged between  
401 39.38 and 43.90%, while protein content ranged between 17.65 and 23.12%. The dominant fatty  
402 acids in oil of tested varieties were oleic, linoleic,  $\alpha$ -linolenic, and palmitic acids. It is possible  
403 to significantly contribute to the oilseed rape breeding process in order to identify high-quality  
404 genotypes if its physical and chemical properties are known. The research results enabled the  
405 improvement of existing and the development of new applications and devices for testing the  
406 physical properties of materials, especially for determining the dimensions of grain using image  
407 processing, as well as for determining the amount of grain loss due to grain shattering and  
408 determining the start of harvesting. The research results will be used in precision agriculture  
409 for early prediction of oilseed rape quality in terms of oil content, protein, grain yield, and 1000-  
410 grain weight based on genotype and year of production using neural networks.

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