J. Agric. Sci. Technol. (2024) Vol. 26 (6): 1317-1331

Effect 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, the 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 is 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 effect of different degrees of seed moisture (6, 11, 16, and 21%) on the physical properties of oilseed rape, seeds were investigated by using standard methods in 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 the 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 the tested varieties ranged between 39.38 and 43.90%, and 17.65 and 23.12%, respectively. Oleic, linoleic, α-linolenic, and palmitic acids were the most representative fatty acids. Knowing the physical and chemical properties of oilseed rape seeds, it would be possible to significantly contribute to the breeding process in order to identify high-quality genotypes.

Keywords: Family *brassicaceae*, Friction coefficient, Kernel porosity, Oilseed rape quality.

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 α-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,

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[DOI: 10.22034/JAST.26.6.1317]

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 fibre (Acikgoz, 2014; Rajković *et al.,* 2022). Nevertheless, it is 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 10-15% share in the global biodiesel production (Haile *et al*., 2014). Press cakes from oilseed rape, produced after oil extraction, which is 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; Iniyan *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 (Marković *et al*. 2022). The results obtained will be used to determine when to start harvesting rapeseed.

Although numerous studies on the physical properties of oilseed rape varieties have been conducted worldwide, none of them included the varieties mentioned in the present paper, which is important for further selection process and the expansion of acreage of this important oilseed crop in the Western Balkans region. The tribometer T1 was used for the first time to measure the coefficient of friction of biomaterials (in this case rapeseed) on different surfaces. The results obtained are compared with the research results of other authors who have used other instruments to measure the coefficient of friction and, in this way, its reliability and accuracy are determined, which is used to further improve the existing device. (Hong *et al*., (2008), Razavi *et al*. (2009), Izli et al. (2009), Hazbavi and Minaei (2009) and Baran *et al*., (2016). and Cao *et al*., (2021).

The aim of this study was to determine the effects of different levels of seed moisture content (seed maturity) on the changes in the basic physical properties of oilseed rape seed, to use them practically for designing machinery and equipment, and their adjustments during operation. The secondary aim was to determine the differences in contents of protein, oil, and fatty acids in seeds of three oilseed rape cultivars. (Hong *et al*., (2008), Razavi *et al*. (2009), Izli et al. (2009), Hazbavi and Minaei (2009) and Baran *et al*., (2016). and Cao *et al*., (2021).

MATERIALS AND METHODS

Plant Material

In this research, three varieties of winter oilseed rape were examined. All three varieties were 'double low' varieties (low erucic acid, less than 2% of measured fatty acid, and low glucosinolates, less than 20 μmole glucosinolates per gram of meal). The three candidate varieties are grown at the Institute of Field and Vegetable Crops Novi Sad, Serbia. These varieties are the most commonly grown in European countries and typically have oil content of 43-44%. The first variety (X) has a vegetation length (the period from sowing to harvest) of about 288 days. The 1,000-grain weight is 4.1 g. It has a high genetic potential for seed yield – over 5 t ha^{-1}. The oil content of the seed is about 45%, and the protein content is 20%. The second variety (Y) has a vegetation length of 280 days. The 1000-grain weight is 3.4 g. It has a high genetic potential for seed yield – over 5 t ha^{-1}. The oil content of

[DOI: 10.22034/JAST.26.6.1317]

the seed is about 41% and the protein content is 20%. The third variety (Z) has a vegetation length of about 284 days. The 1000-grain weight is 4.2 g. It has a high genetic potential for seed yield – over 4.5 t ha^{-1}. The oil content of the seed is about 46%, and the protein content is 23%. The harvest of oilseed rape was carried out at the stage of full technological maturity. The initial moisture content in the grains ranged from 10.56-14.0% (ISO 665, 2020).

The oilseed rape cultivars X, Y, and Z were assessed for seed physical and chemical properties. Firstly, the grain was cleaned from impurities after harvesting and was divided into two parts. In order to obtain the initial lowest moisture content (6%), the first part of the grain in which the physical properties were determined was dried at 105°C, and the second part of the grain that was used for chemical analysis was dried at 50°C. Secondly, the increasing grain moisture contents for all samples grain (11, 16, and 21%) were assured by adding pre-set amounts of distilled water to the previously mentioned grain (with a moisture content of 6%) according to the method used by some researchers (Calısır *et al*., 2005; Razavi *et al*. 2009; Izli *et al*. 2009; Sangamithra, 2016). After that, the grains were stored in a refrigerator (Petri dishes) for a week at 5°C, in order to obtain a uniform sample with the same moisture content in the grain.

A highly sensitive automatic device Elmor S3 (1/1000 measurement precision, Marty elektromechanik antriebstechnik Brunen) was used to count 1,000 grain, and the mass of one thousand grains was measured on an analytical balance (Kern EW 150-3 M, accuracy 0.001 g, Kern GmBH Großmaischeid, Deutschland). The volume and porosity of a certain number of grains were determined by the method of pouring liquid (distilled water). Bulk mass (hectoliter mass) was determined by pouring grain into a container of a certain volume and measuring its mass together with the space between the grains (Calisir *et al*., 2005; Razavi *et al*., 2009; Izli *et al*., 2009; Koprivica, 2018). The angle of repose (static and dynamic) is the angle that the sloping surface of a heap of loose material poured on a horizontal surface makes with the horizontal surface. That is the angle at the base of a cone of material formed with the vertical axis, as the material is allowed to fall onto a horizontal base plate under specified conditions (Razavi *et al.,* 2009; Izli *et al*., 2009; Koprivica, 2018). To measure the height of the cone, an electronic measuring device with a Fowler-Pro-maxSylvyc system display was used with an accuracy of 0.01 mm (Fowler high precision Canton USA).

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

In addition to grain diameter, the 1,000-grain weight is also used as a measure of coarseness. In 2020 research, the authors developed an application for rapid measurement of a large number of grain samples by software image analysis and its transmission with the application of IoT (Internet of Things). We can consider this as an indirect contribution to science, as the idea was created during the research and obtaining the results presented in this paper (Marković *et al*., 2020). According to the results, the mean value of seed diameter for variety X= 2.30 mm, Y= 2.22 mm, and Z=

[DOI: 10.22034/JAST.26.6.1317]

2.11 mm. Based on the obtained results, it is possible to adjust the sieve openings of the harvester during harvesting and seed calibration during seed processing. In addition, using an image analysis application and based on the 1000-grain weight and the surface area of the container into which the grains fell, it is possible to determine the natural loss of spilled grains in the field and determine the start of harvesting of canola, soybeans, etc. (Marković *et al*., 2022).

Chemical Analysis

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

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

Data Analysis

All measurements were performed in three replicates. The data are shown as a mean value±Standard Deviation (SD). The obtained data on the physical properties of oilseed rape were processed using the method of Analysis Of Variance (ANOVA) of a two–factorial and three–factorial experiment according to the "completely random block system" plan. Testing the significance of the differences between the mean values of the tested properties (factors) was determined using the LSD test, for a significance level of 5 and 1% in relation to the standard. The Pearson correlation coefficient was used to show the strength and direction of the connection between the variables in the paper. The values of the correlation coefficient ranged from –1 to +1. Statistical analysis of chemical composition was performed by one–way Analysis Of Variance (ANOVA), while the means of values were compared with Tukey's HSD test. All significance level was set at less than 0.05.The results were statistically processed in the program STATISTICA 6.0 (StatSoftInc., 1995).

RESULTS AND DISCUSSION

Physical Properties

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

The highest 1,000-grain weight (4.66 g) was found in Y (Table 1), whereas X (4.41 g) and Z (4.35 g) showed somewhat

[DOI: 10.22034/JAST.26.6.1317]

Table 1. Effect of cultivars and moisture content on seed physical traits.^{a}

Parametr		1000-Grain weight (g)	Seed volume (mm^{3})	Bulk density (kg m^{-3})	Seed porosity (%)	True density (kg m^{-3})
Cultivar (A)						
X (1)		4.41±0.06^{b}	4.36±0.07^{b}	597.73±3.80	40.65±0.18	1007.01±4.62
Y (2)		4.66±0.06^{a}	4.59±0.08^{a}	595.16±6.28	41.20±0.39	1011.93±4.75
Z (3)		4.35±0.07^{c}	4.33±0.08^{b}	590.61±5.11	41.13±0.34	1003.20±6.40
Moisture content (%, B)						
6 (1)		4.20±0.05^{d}	4.07±0.04^{d}	620.45±4.14^{a}	39.65±0.20^{c}	1028.05±5.33^{a}
11 (2)		4.31±0.05^{c}	4.25±0.04^{c}	598.81±2.48^{b}	40.78±0.22^{b}	1011.21±2.10^{b}
16 (3)		4.58±0.04^{b}	4.55±0.03^{b}	586.91±2.02^{c}	41.39±0.24^{b}	1001.53±2.96b^{c}
21 (4)		4.80±0.04^{a}	4.84±0.05^{a}	571.82±2.51^{d}	42.15±0.33^{a}	988.73±6.52^{c}
Cultivar×Moisture (*A*×*B*)						
Cultivar	Moisture content (%)					
X (1)	6	4.16±0.04^{a}	4.00±0.02^{a}	617.87±5.07^{a}	39.97±0.18^{a}	1029.32±10.70^{a}
	11	4.24±0.01^{a}	4.17±0.01^{a}	600.26±0.84^{a}	40.58±0.09^{a}	1010.18±0.57^{a}
	16	4.51±0.02^{a}	4.48±0.02^{a}	592.15±4.14^{a}	40.71±0.52^{a}	998.90±3.04^{a}
	21	4.73±0.02^{a}	4.76±0.01^{a}	580.63±0.57^{a}	41.32±0.23^{a}	989.65±3.43^{a}
Y (2)	6	4.38±0.04^{a}	4.24±0.00^{a}	629.10±4.26^{a}	39.10±0.21^{a}	1033.14±9.72^{a}
	11	4.52±0.04^{a}	4.43±0.04^{a}	602.59±3.08^{a}	40.76±0.30^{a}	1017.39±4.78^{a}
	16	4.77±0.03^{a}	4.69±0.04^{a}	584.42±2.01^{a}	41.97±0.23^{a}	1007.07±1.56^{a}
	21	4.98±0.04^{a}	5.02±0.03^{a}	564.52±1.56^{a}	42.98±0.08^{a}	990.12±2.11^{a}
Z (3)	6	4.06±0.04^{a}	3.97±0.01^{a}	614.38±10.28^{a}	39.88±0.47^{a}	1021.69±8.96^{a}
	11	4.16±0.05^{a}	4.13±0.04^{a}	593.57±6.53^{a}	41.00±0.65^{a}	1006.05±1.88^{a}
	16	4.48±0.03^{a}	4.47±0.02^{a}	584.15±3.15^{a}	41.50±0.25^{a}	998.63±8.33^{a}
	21	4.68±0.04^{a}	4.73±0.09^{a}	570.32±4.74^{a}	42.13±0.81^{a}	986.43±21.18^{a}
ANOVA						
A		**	**	ns	ns	ns
B		**	**	**	**	**
A × B		ns	ns	ns	ns	ns

^{a} Letters A and B indicate different influencing factors (cultivar and moisture content). Numbers (1), (2), (3), (4) indicate different levels of same factor (cultivar X, Y, Z and moisture content 6, 11, 16 or 21%).

a-d: Mean values in columns marked by the same letters are not different (P> 0.05) according to LSD test. F–test: ns= P > 0.05; * P≤ 0.05; ** P≤0.01; *** P≤ 0.001. Value±SD (Standard Deviation)

higher weight than in other studies (Vujaković *et al*., 2010; Jovičić *et al*., 2011), which, most probably, could be a result of different climatic and edaphic conditions, as well as the applied cultivation practices. The studied cultivars showed an increase in the 1,000-grain weight and seed volume as seed moisture content increased. At all tested seed moisture contents, Y showed higher volume (4.59 mm^{3}) as a result of its larger seeds, which absorbed more water than the other two cultivars (X and Z).

Seed Volume (V) and 1,000-grain Weight (W_{1000}) were positively correlated and can be represented using Equation (1):

$$V= 0.80+0.83W_{1000}\,,\ (R^2 = 0.92) \qquad (1)$$

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

Bulk density and true density values did not differ significantly among the cultivars, which is in accordance with Izli *et al*. (2009). Seed moisture content was inversely proportional to seed weight, therefore, bulk density and true density of all cultivars decreased as moisture content increased. Bulk density and true density values ranged from the highest (620.45 and 1,028 kg m^{-3}) at the lowest seed moisture content, to the lowest (571.82 and 988 kg m^{-3}) at the highest moisture content.

Bulk density declined linearly with the rise of moisture content, because of accumulated water content that simultaneously reduced

[DOI: 10.22034/JAST.26.6.1317]

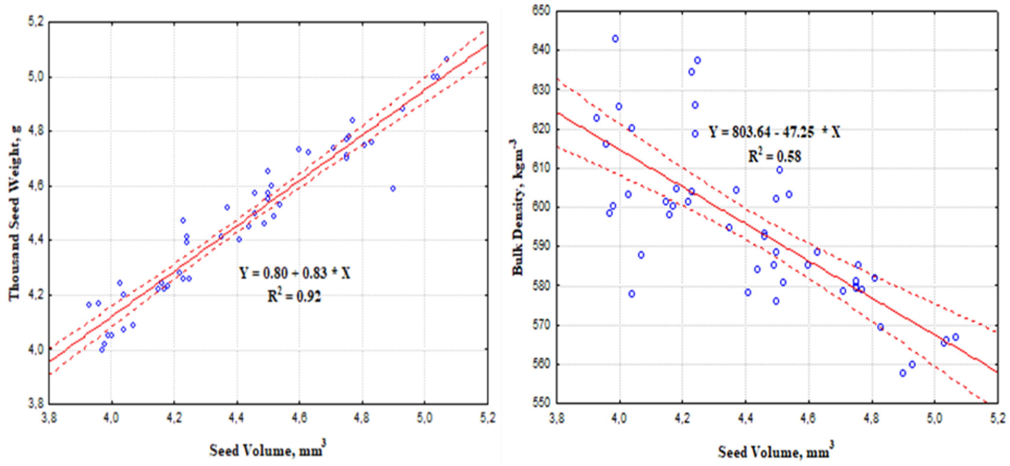

Figure 1. Interdependence of seed volume and 1,000-grain weight, seed volume and bulk density, porosity, and bulk density.

dry matter content in the total seed volume. Equation (2) shows the negative correlation between seed Volume (V) and Bulk density (□□):

V= 803.64–47.25□□, ($R^2 = 0.58$) (2)

The relationship between True density (□□) and Bulk density (□□) were positively correlated and can be expressed by Equation 3:

$\square_{B=}-191.2+0.78\square_{T}$, ($R^2 = 0.66$) (3)

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

A decrease in the value of the 1,000-grain weight is associated with an increase in the value of grain density. As variety Y had the highest 1,000-grain weight, the grain density of this variety was lower than the other two, which is in agreement with the results of Izli *et al*. (2009), Hazbavi *et al.* (2009), and Razavi *et al*. (2006). It is known that the porosity of the bulk mass depends on the characteristics of the variety: shape, surface, size and 1000-grain weight. Also, variety Y, due to larger grains with a smooth and flat surface of the grain coat, had higher porosity than the other two varieties. The highest measured dynamic angle of filling in variety Z was most likely due to the small grain. In addition, the grain had good flowability and less sphericity, so, when it was poured and fell on the pile, it did not roll down the steep sides, but remained close to them due to the effect of cohesive forces and friction.

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

All studied cultivars showed an increasing trend in static angle of repose as moisture content in seed gradually increased (Table 2). The lowest static angle of repose (24.97º) in all cultivars was found at the lowest moisture content (6%). As seed moisture content accumulated, static angle of repose grew gradually, to reach its highest value (29.01º) at the highest moisture content (21%). However, increase in static angle of repose in X and Y was found only at the extreme moisture contents, the lowest and the highest (interaction between cultivar and seed moisture content). Values found for

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

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

[a] Letters A and B indicate different influencing factors (cultivar and moisture content). Numbers (1), (2), (3), (4) indicate different levels of same factor (cultivar X, Y, Z and moisture content 6, 11, 16 or 21%). a-d: Mean values in columns marked by the same letters are not different ($P > 0.05$) according to LSD test. F–test: ns= $P > 0.05$; * $P \leq 0.05$; ** $P \leq 0.01$; *** $P \leq 0.001$. Value±SD (Standard Deviation).

static angle of repose follow those reported for the cultivar Jet Neuf (Izli *et al*., 2009).

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

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

[DOI: 10.22034/JAST.26.6.1317]

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

The differences among these values were probably due to different seed properties of the studied cultivars and different growing conditions. The positive correlation between dynamic (α_D) and static (α_S) angles of repose is shown in Equation (4).

$$\alpha_S = 7.31 + 0.85\,\alpha_D \qquad (R^2 = 0.77) \qquad (4)$$

On the other hand, dynamic angle of repose was negatively correlated with bulk density, and positively with seed porosity in Equations (5) and (6).

$$\square_B = 740.24 - 6.34\alpha_{D,}\ (R^2 = 0.74) \qquad (5)$$

$$P = 32.29 + 0.38\alpha_{D,}\ (R^2 = 0.72) \qquad (6),$$

Where, $P = \frac{V_V}{V_T}$,

V_V= Volume of void–space between seeds,

V_T= Total Volume of seeds.

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

The coefficient of friction varied significantly under the influence of the three investigated factors – type of friction surfaces, grade, and grain moisture (Table 3). It can be seen from Table 3 that the lowest grain friction coefficient was measured for grade X (0.288) and was significantly different from grades Y (0.322) and Z (0.321). Izli *et al*. (2009) studied Samurai, Jet Neuf, and Capitol cultivars and Razavi *et al*. (2009) studied Orient and SLM cultivars and proved that there is a difference in the coefficient of friction between cultivars regardless of friction surface and water content in the grain, which is consistent with our study.

Increasing the moisture content in the grain significantly increases the grain

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

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

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

friction coefficient of the tested grades on investigated friction surfaces. The lowest coefficient of friction (0.264) was measured at the lowest grain water content of 6%. With a gradual increase in grain water content, the coefficient of friction also increases, reaching its highest value of 0.354 at the highest grain water content of 21%. The increase in water content makes the grains sticky, so that the cohesive forces between the grains and the contact surface increase, leading to an increase in the coefficient of friction.

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

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

Chemical Properties

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

Protein Content

Protein content in oilseed rape depends on genetic and agroecological factors, as well as their interaction. Apart from genetic factors, variability of protein content is also reported to be under the influence of the environment (Piljuk, 2006; Kulikovskij and Srokov, 2006; Marinković *et al.*, 2010) and sowing date (Kapilovič and Srokov, 2006). Protein content in rape seed is negatively correlated to oil content, and both parameters are highly under the effect of agroecological growing conditions and genetic control. Therefore, the parameters that increase protein content in oilseed rape also decrease its oil content (Šidlauskas and Rife, 2000). Significant differences were not found between protein content in the studied oilseed rape cultivars (P> 0.05). Similarly, oil content differences in protein contents were not significant in this study, since all

[DOI: 10.22034/JAST.26.6.1317]

the cultivars originated from the same breeding program (Balalic *et al*., 2017). Oilseed rape protein content ranged from 19.49 to 20.86%, with the highest value detected in Z (20.86%) and the lowest in Y (19.49%), as shown in Table 4. These results agree with Marinković *et al*. (2010) who reported protein content of 19.26-25.93% depending on the environment, as well as Vujaković *et al*. (2014) who found it to be 18.06–20.00% and Balalic *et al*. (2017) who reported protein content of 17.13-23.32% depending on the year.

Fatty Acid Composition

Table 4 shows the results of fatty acid composition in the analyzed oilseed rape cultivars and the results of total content of saturated, monounsaturated and polyunsaturated fatty acids. The analyses confirmed the presence of 10 fatty acids in the studied oilseed rape oil. Taking into account the composition of fatty acids in the studied oilseed rape oil, the differences between C16:0, C18:0, C18:1 n9c, C18:2 n6c, and C18:3 n3 components and Saturated Fatty Acids (SFA), Monounsaturated Fatty Acids (MUFA), and polyunsaturated fatty acids (PUFA) were found to be significant (P≤ 0.05), unlike the differences between C20:0, C20:1, C22:0, C22:1, and C24:0 fatty acids that were not significant.

Among the fatty acids, oleic acid (C18:1 *n9c*) was the main component, followed by linoleic acid (C18:2 *n6c*), α-linolenic acid (C18:3 *n3*) and palmitic acid (C16:0). The content of oleic acid (C18:1 *n9c*) ranged from 57.25% to 60.67%, with the highest found in Y (60.36%) and the lowest in X (57.58%). The content of linoleic acid (C18:2 *n6c*) ranged from 21.01 to 22.65%, content of α-linolenic fatty acid (C18:3 *n3*) ranged from 9.22 to 11.82%, and palmitic acid (C16:0) from 4.44 to 4.75%. The content of total unsaturated fatty acids was significantly higher than the content of saturated fatty acids, namely, 93.17% in Y and 92.92% in X. The highest contribution of the total monounsaturated fatty acids was found in Y (61.57%), followed by X (58.89%) and Z (60.64%), while the total contribution of polyunsaturated fatty acids was found in X (34.02%), followed by Y

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

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

[*a*] OC: Oil Content; PC: Protein Content; SD: Standard Deviation; SFA: Sum of Saturated Fatty Acids; MUFA: Sum of Monounsaturated Fatty Acids; PUFA: Sum of Polyunsaturated Fatty Acids. Different Latin letters in the same row refer to significant differences between cultivars (X, Y and Z) according to Tukey's HSD test (P≤ 0.05).

[DOI: 10.22034/JAST.26.6.1317]

(31.60%) and Z (32.52%). According to Beyzi *et al*. (2019) average values were as follows: oleic acid 53.95-60.98%, linoleic 20.42-25.02%, and linolenic 8.74-9.56%; and other authors reported similar values: oleic 56.31-58.67%, linoleic 10.52-13.74%, and linolenic 8.83-10.32% (El–Beltagi and Mohamed, 2010). These small differences probably were related to genetic variability and different environmental conditions. The influence of the variety and physical properties on the chemical composition of the grain was not studied, but Rajković *et al*. (2022) reported that the oil content was positively correlated with grain yield, 1000-grain weight, and oil and protein yield.

CONCLUSIONS

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. When moisture content in the kernels increased, 1,000-grain weight, seed volume and porosity, static and dynamic angles of repose also increased in the 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 contents of the tested varieties ranged between 39.38 and 43.90%, while protein content ranged between 17.65 and 23.12%. The dominant fatty acids in oil of tested varieties were oleic, linoleic, α-linolenic, and palmitic acids. It is possible to significantly contribute to the oilseed rape breeding process in order to identify high–quality genotypes if its physical and chemical properties are known. The research results enabled the improvement of existing and the development of new applications and devices for testing the physical properties of materials, especially for determining the dimensions of grain using image processing, as well as for determining the amount of grain loss due to grain shattering, and determining the start of harvesting. The research results will be used in precision agriculture for early prediction of oilseed rape quality in terms of oil content, protein, grain yield, and 1000-grain weight based on genotype and year of production using neural networks.

ACKNOWLEDGEMENTS

This research was supported by the Ministry of Education, Science and Technological Development of the Republic of Serbia, grant number: 451–03–68/2022–14/ 200032, 451–03–47/2023–01/200032 and 451-03-47/2023-01/200088.

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تأثیر رقم و محتوای رطوبت بذر بر ویژگی‌های شیمیایی و فیزیکی دانه روغنی کلزا

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چکیده

داده های به دست آمده در مطالعه خواص فیزیکی دانه روغنی کلزا، برای ساخت ماشین آلات کاشت، برداشت، حمل و نقل، طراحی انبار و فرآوری بذر کاربرد عملی دارند. در طول برداشت دانه روغنی کلزا، رطوبت بذر می تواند متفاوت باشد، و درک خواص فیزیکی دانه ها برای تنظیم صحیح ماشین‌آلات ضروری است. دانه کلزا، بسته به شرایط آب و هوایی، می تواند رطوبت متفاوتی داشته باشد. این تحقیق شامل سه رقم زمستانه کلزا بود که به طور گسترده در کشورهای اروپایی رشد می کند. تأثیر درجه‌های مختلف رطوبت بذر (۶%، ۱۱%، ۱۶% و ۲۱%) بر ویژگی‌های فیزیکی دانه‌های روغنی کلزا، با استفاده از روش‌های استاندارد در سه فصل رشد (۱۳۹۷-۱۳۹۴) مورد بررسی قرار گرفت. با افزایش رطوبت در دانه ها، وزن هزار دانه، حجم و تخلخل دانه، زوایای استاتیک و دینامیکی سکون (static and dynamic angles of repose)نیز در ارقام مورد آزمایش افزایش یافت. افزایش رطوبت بذر نیز جرم مخصوص (چگالی) واقعی و ظاهری سه رقم مورد آزمایش را کاهش داد. بیشترین ضریب اصطکاک روی تخته سه‌لا و کمترین آن روی ورق فولادی ضد زنگ مشاهده شد. محتوای روغن و پروتئین ارقام مورد آزمایش به ترتیب بین ۳۹.۳۸% و ۴۳.۹۰% و بین ۱۷.۶۵% و ۲۳.۱۲% متغیر بود. اسیدهای چرب اولئیک، لینولئیک، α-لینولنیک و پالمیتیک نماینده ترین اسیدهای

[DOI: 10.22034/JAST.26.6.1317]

چرب بودند. با دانستن ویژگی‌های فیزیکی و شیمیایی دانه‌های روغنی کلزا، ممکن خواهد بود که به‌منظور شناسایی ژنوتیپ‌های باکیفیت زیاد به فرآیند اصلاح نژاد کمک شایان توجهی کرد.

[DOI: 10.22034/JAST.26.6.1317]