New winter oilseed rape varieties – seed quality and morphological traits depending on sowing date and rate

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ABSTRACT
Many studies have focused on research about impact of time and density of sowing on the agronomic characteristics of different crops. However, the number of studies investigating such a response on the qualitative composition of different types of winter oilseed rape varieties is still limited. The aim of the research was to determine the effect of sowing date and density on yield, protein and oil content and quality of winter oilseed rape varieties: open-pollinated, a typical hybrid of traditional type of growth and a new semi-dwarf hybrid, which biology and yielding have not been thoroughly established. This experiment was conducted applying four sowing dates (August 14, August 25, September 4, September 15), three winter oilseed rape cultivars (PR45D03 - semi-dwarf hybrid, PR46W31 - hybrid, Californium - open-pollinated) and four sowing rates (30, 40, 50, 60 seeds/m²). Among the compared sowing dates, August 25 proved to be optimal for yielding of the tested winter oilseed rape cultivars. Semi-dwarf variety contained less protein and glucosinolate in seeds, but more oil in comparison to other studied varieties (hybrid and open-pollinated). The yields did not differ significantly within a density of 40, 50, 60 seeds/m², so it is important result, especially for the agricultural practice.

Introduction
Poland and Great Britain have been ranked interchangeably in sixth place in the production of winter oilseed rape (Brassica napus L.) in the world, after China, Canada, India, Germany and France (FAOSTAT, 2014). In Poland, winter oilseed rape is the most important oil-protein plant. Increasing use of oil seed rape for biofuel production resulting from the implementation of the European Union (EU) recommendations of the Directive (2009/28/WE, 2009) has increased the demand for seeds of this crop. As a result, the production of raw materials for oil industry has become one of the new tasks for modern farming. Increased acreage of winter oilseed rape, both in Poland and in the world is a huge challenge for agriculture. It requires intensification of production which is related with threats from pests but also the environmental impacts.

The content of oil, protein and anti-nutritive substances, as glucosinolates in rapeseeds decide on their utility value. It is influenced by genetic and environmental factors, as well as agricultural technology (Hu et al., 2007; Krzymański et al., 2009; Mert-Turk et al., 2008). Changes to the growing environment, as influenced by agronomic practice or the climate, are preventing the genetic potential from being realized (Berry & Spink, 2006). While selecting new plant varieties, the level of their yield is particularly important, as it has a significant impact on oil yield (Basalma, 2008). The choice of the appropriate date and sowing density is one of the optimization methods for oil crop yield (Różyło & Pałys, 2014; Yousaf et al., 2002). There are many publications focused on studies about the impact of time and sowing density on the agronomic characteristics of different crops. However, the number of studies concerning the influence of both sowing density and sowing date on the qualitative composition of winter oilseed rape varieties of different types is limited (Turhan et al., 2011). The verification of recommendations for the cultivation of new semi-dwarf varieties of winter oilseed rape is especially important. Therefore, the aim of the research was to determine the effect of both sowing date and density on yield, protein and oil content as well as quality of seeds of winter oilseed rape varieties: open-pollinated, semi-dwarf hybrid and a hybrid of typical type of growth. Since rapeseed is used for energy purposes (Venturi & Venturi, 2002) and has high value as forecrops (Budzyński & Bielski, 2004), there is growing economic importance of this plant. As a result, studies on improving agricultural technology of winter oilseed rape are fully justified and desirable.
Materials and methods

A field experiment was carried out in 2008–2010 at the Złotniki experimental station (N 52° 29.193′; E 016° 20.569′). This experimental station belongs to the Gorzyń Experimental and Teaching Station of the Poznań University of Life Sciences. Climate data for the experimental area are presented in Figure 1. Months (VIII-XI and III-VII) for two oilseed rape cultivation period were applied to the climate diagram on the horizontal axis. On the vertical axis one section means 10 °C or 20 mm precipitation. The curves describe monthly averages values of temperature and precipitation. The ratio of section 10 °C = 20 mm precipitation i.e. 1:2 is preserved in all diagrams. It presented relation curve of temperature to curve of precipitation. This indicate relatively wet period (curve of temperature is below the curve of precipitation) and drought period (curve of temperature is above curve of precipitation). Reduced precipitation is an auxiliary curve for precipitation, plotted according to ratio 10 °C = 30 mm precipitation i.e. 1:3. It visualize semi-drought period.

The three-factor experiment evaluated the effect of sowing date and plant density on yields and seed quality in different winter oilseed rape varieties. Sowing dates were as follows: August 14, August 25, September 4 and September 15. The winter oilseed rape cultivars were as follows: PR45D03 (semi-dwarf hybrid F1), PR46W31 (hybrid F1) and Californium (open-pollinated). Sowing time was done in the main plots according to cultivars sub-plots. Sowing rate (30 seeds·m⁻², 40 seeds·m⁻², 50 seeds·m⁻², 60 seeds·m⁻²) was the sub-sub-plots. The trials were established by the random block method in the split-split-plot design as a 3-factorial experiment in four field replications. Each plot (14 m × 1 m) consisted of four rows with an inter-row spacing of 0.35 m. After the harvest of spring barley, nitrogen, phosphorus and potassium fertilizers were applied (25 kg N·ha⁻¹, 21.8 kg P·ha⁻¹ and 103.75 kg K·ha⁻¹). The nitrogen was applied at a rate of 66 kg·ha⁻¹ at March and April. Herbicides were applied for weed control. The application was as follows: Butisan Star 416 SC (metazachlor, dimethenamid-P, quinmerac) (3 l·ha⁻¹) after sowing, Fusilade Forte 150 EC (fluazifop-P-butyl) (1 l·ha⁻¹) after emergence of plants and Galera 334 SL (clopyralid, picloram) (0.35 l·ha⁻¹) in the spring. During the growing season, the crops were sprayed three times with insecticides: Fastac 100 EC (alpha-cypermethrin) (0.12 l·ha⁻¹), Karate Zeon 50 CS (lambda-cyhalothrin) (0.12 l·ha⁻¹), Nurelle D 550 EC (chlorpyrifos, cypermethrin) (0.6 l·ha⁻¹). The crops were also sprayed with fungicides: Horizon 250 EW (tebuconazole) (0.7 l·ha⁻¹) once – after emergence of plants, Pictor 400 SC (boscalid, dimoxystrobin) (0.5 l·ha⁻¹) once – at the beginning of flowering. At the stage of inflorescence emergence (BBCH 55–57) (Lancashire et al., 1991), the height of rape plants was measured at three randomly selected sites of each plot on ten successive plants in a row. At the stage of flowering (BBCH 61-64), the leaf chlorophyll index (SPAD) for upper leaves of the main shoot was determined using a Hydro N-tester (Minolta, Japan). The Leaf Area Index (LAI) was measured at the BBCH stage 75–78 using a SunScan Canopy Analysis System type SSI. Non-destructive measurements of SPAD and LAI were performed in each plot.

Figure 1. Climatic data characterizing weather conditions for the experimental area in growing seasons 2008/2009 and 2009/2010 prepared according to Walter (1976).
at least four replication. Moreover, lodging was assessed with a use of a 9-point scale, where: 9-clusters with siliques stand upward, plants in the canopy are upright; 8-slightly leaning clusters; 7-strongly leaning clusters, stem partly bends under the weight of clusters; 6-clusters leaning over the rows of neighbouring plants, the stem bends in the middle of its length; 5-clusters heavily bend over the adjacent rows of plants, the stem bends at 45°; 4-clusters heavily bend, but do not touch the ground, the stem bends at 45°; 3-clusters touch the ground with lower siliques, the stem bends at about 70°; 2-clusters bend over the ground, the stem bends at over 75°; 1-plants were lodged entirely, clusters have been deformed. The plot area and the varying angle of racemes were taken into account. The results were expressed as the weighted average. The direct seed harvesting was done with a Wintersteiger plot combine with in-built electronic scale and a hygrometer. The harvesting was performed on two central rows. 0.5 m from both ends of the rows was left as it represented the border effect. Next, the yield of clean seeds was determined in dt∙ha⁻¹ and given at a standardized (13%) water content. Random samples were taken from each plot for quality analysis. Protein, oil and glucosinolates were determined in the Plant Breeding Laboratory in Strzelce, Małyszyn department, with the use of near-infrared spectroscopy in a NIRS systems 6500 spectrometer (FOSS NIRS systems inc., Silver Spring, MD). Oil content was analyzed by nuclear magnetic resonance (NMR) and protein content by Kjeldahl method. Their values were used for NIRS calibrations for oil and protein contents. NIRS allows for a simultaneous analysis of seed components in intact samples such as: acid detergent fibre (ADF), neutral detergent fibre (NDF), total glucosinolate, total alkenyl glucosinolates, glucosinapin, glucobrassicinapin, progolitrin, napoleiferin, glucobrassnicin, 4OHIN- 4-hydroxyglucobrassicin according to the methods described by Hom et al. (2007), Wittkop et al. (2012). Analysis of glucosinolates composition was performed using spectrometer NIRS systems 6500 in spectrum from 400 to 2500 nm and ISIscan Routine Analysis Software. The calibration of the device was performed according to the Michalski et al. (1995). Calibration was performed after the reference analysis of the glucosinolates composition and content by gas liquid chromatography of trimethylsilyl derivatives of desulphated glucosinolates described by Raney and McGregor (1990). The content of individual components was expressed in % d.m. and in μM/g of seeds.

The obtained results were statistically analyzed using analysis of variance (ANOVA). Statistica (StatSoft, 2010 Polska) ver. 10 software package was used. Differences in means of treatment were compared by Tukey’s multiple comparison test. Differences were considered to be statistically significant when the P value was < 0.05. For highly significant differences, P value was < 0.01. For finding the regularities, correlation coefficients were calculated using Statistica software. Simple correlation coefficients between quality traits were estimated to determine the association between traits.

Results

The results of ANOVA for yields are presented in Table 1. The effect of all treatments except for interaction between sowing rate with studied factors were significant. Seed yield in the first season was significantly higher than the yield in the second season. In the first season beyond April, precipitation covered the water needs of winter oilseed rape. The second season intensive precipitation in May, significantly extended the period of flowering and delayed maturation of plants. In addition, heavy rain in May 2010 made the application of protective treatments (especially fungicidal) difficult or even impossible. In June, high temperatures and too little rain limited the growth of seeds in pods. As a result, they were small and not fully developed. Therefore the seed yield was affected. In the years of the study, plants sown on August 25 produced the greatest

| Table 1. Seed yield, protein and oil percentage content in dry mass of winter oilseed rape. |

| Factors | Seed yield | Protein | Oil |
|---------|-------------|---------|-----|
|         | dt∙ha⁻¹ | % d.m. | % d.m. |
| Season  |         |         |       |
| 2008/2009 | 48.5 a  | 22.5 a  | 41.3 a |
| 2009/2010 | 33.0 b  | 22.4 a  | 41.9 a |
| Sowing date (D) | 558.0** | 19.6** | 17.7** |
| August 14 | 46.6 b  | 21.8 c  | 42.5 a |
| August 25 | 52.4 a  | 22.2 bc | 42.0 ab |
| September 4 | 40.5 c  | 22.5 b  | 41.6 b |
| September 15 | 23.4 d  | 23.3 a  | 40.4 c |
| Variety (V) | 36.5** | 2.0     | 6.6** |
| PR45D03 | 38.8 b  | 22.3 a  | 42.1 a |
| PR46W31 | 43.9 a  | 22.6 a  | 41.6 ab |
| Californium | 39.5 b  | 22.5 a  | 41.1 b |
| Sowing rate (seeds∙m⁻¹) (R) | 5.04** | 0.2     | 0.1 |
| 30       | 38.9 b  | 22.4 a  | 41.5 a |
| 40       | 41.0 a  | 22.4 a  | 41.7 a |
| 50       | 41.5 a  | 22.4 a  | 41.7 a |
| 60       | 41.4 a  | 22.5 a  | 41.5 a |
| S×D     | 177.6** | 1.4     | 1.7  |
| S×V     | 4.85**  | 1.5     | 3.9** |
| D×V     | 3.99**  | 1.4     | 0.8  |
| S×R     | 0.35    | 0.0     | 0.1  |
| D×R     | 1.35    | 0.2     | 0.1  |
| V×R     | 0.43    | 0.3     | 0.2  |
| S×D×V   | 5.16*   | 0.9     | 0.6  |
| S×D×R   | 0.70    | 0.1     | 0.2  |
| S×V×R   | 1.05    | 0.1     | 0.1  |
| D×V×R   | 0.51    | 0.1     | 0.2  |
| S×D×V×R | 0.65    | 0.2     | 0.2  |

Notes: Bold values – F-value, mean value within a columns followed by the same letter are not significantly different according to Tukey’s test (p ≤ 0.05); dt∙ha⁻¹-decitonne per hectare; % d.m.- percentage of content in dry matter of seed.

*Statistically significant differences (p < 0.05).

**Statistically highly significant differences (p < 0.01).
yields. Acceleration of sowing by 10 days caused a reduction of yields by 5.8 dt∙ha⁻¹, while a delay till September 4 resulted in a decrease by 11.9 dt∙ha⁻¹. A further delay by 10 days caused even greater yield reduction by 29.0 dt∙ha⁻¹ in comparison to the optimal sowing date (August 25). On average in the years of the study significantly the highest yields were produced by cv. PR46W31, exceeding those of cv. PR45D03 by 5.1 dt∙ha⁻¹ and the open-pollinated Californium by 4.4 dt∙ha⁻¹, respectively. A further increase in sowing density from 30 to 40 plants∙m⁻² resulted in an increase in the seed yield of winter oilseed rape by 2.1 dt∙ha⁻¹. The increase in plant sowing density to 60 plants∙m⁻² caused no further significant changes, although the greatest seed yield was harvested at sowing density of 50 plants∙m⁻² (Table 1). All the analyzed cultivars reached the highest yielding potential when they were sown on August 25 (Figure 2). In all cultivars, both: the anticipation and a delay in sowing caused reduction in their seed yields. The shown interaction resulted from the differences in the size of these changes. The greatest mean yield (56.5 dt∙ha⁻¹) was obtained when the hybrid cv. PR46W31 was sown on August 25.

This study showed interactions between cultivar and sowing date in the effects of the LAI and chlorophyll index (SPAD) values (Figure 3). The earliest sowing date (August 14) was proven to be the most advantageous for the open-pollinated Californium, while for the hybrid cultivars LAI was higher for the sowing date of August 25. A greater tolerance to delayed sowing, manifested in the LAI values was observed in the hybrid cultivars, particularly the semi-dwarf hybrid PR45D03. The reduction of LAI was by 30% smaller in PR45D03 than in Californium. The delay of

Figure 2. Seed yield of winter oilseed rape (dt∙ha⁻¹) depending on sowing date and variety. Vertical bars represent 95% confidence intervals of means. Different letters at the top of graph bars indicate significant differences at $p < 0.05$ (Tukey’s multiple range test).

Figure 3. Leaf area index (LAI) and leaf chlorophyll content index (SPAD) for winter oilseed rape depending on sowing date and variety. Vertical bars represent 95% confidence intervals of means. Different letters at the top of graph bars indicate significant differences at $p < 0.05$ (Tukey’s multiple range test).
sowing date from the August 14 to September 4 (PR45D03) and from August 25 to September 15 (Californium) resulted in an increase in SPAD units. The greatest response was recorded in cv. Californium. Response of the analyzed cultivars to a delayed sowing date, manifested in plant height at the stage of inflorescence emergence and before harvest. The results obtained for the analyzed cultivars were similar (Figure 4). As could have been expected, plants of the semi-dwarf hybrid PR45D03 were characterized by the lowest height. With the increasing delay of the sowing date, the plants became shorter. However, this response expressed as the reduction of their height before harvest was less violent for the September sowing dates in comparison to plant height measured earlier, at the stage of inflorescence emergence. The greatest tolerance to lodging was found for PR45D03 sown on August 14. The open-pollinated cultivar showed an opposite response. At both the earliest and latest sowing dates, lodging rates were greater than in cv. Californium. When plants were sown on August 25 and September 4, the lowest lodging rates were recorded for the hybrid cultivar with the traditional habit PR46W31.

In our studies, no impact of season on the content of both: proteins and oil was noticed in the seeds. The sowing date of winter oilseed rape significantly influenced the protein content in the dry matter of rapeseed (Table 1). The highest protein content in % of dry matter was recorded in seeds which were sown late (September 15). The lowest protein content, in turn, was recorded in seeds which were sown in the early date (August 14). With a delay in sowing date, the content of oil in rapeseed has significantly decreased. The differences compared to early sowing (August 14) were 0.5, 0.9 and 2.1% points, respectively.

Hybrids and open-pollinated accumulated protein in dry matter of seed from 22.3 (PR45D03) to 22.5% (Californium). PR45D03 hybrid showed the highest oil content in the seeds. That was 0.5% points higher than a hybrid of the traditional type of growth and 1% point higher than open-pollinated variety. Sowing density did not affect the concentration of protein and oil in rapeseed.

The results of ANOVA and comparisons of means for a range of quality traits are presented in Table 2. There were significant differences between the seasons for this quality traits except for glucoraphanin, glucobrassicin and 4-hydroxyglucobrassicin content. Similarly as yield, all quality traits in the first season were significantly higher than that of the second season. Sowing date did not affect quality traits except for glucobrassicin and 4-hydroxyglucobrassicin. Delay in sowing to September 15 caused an increase in the value of these components in rapeseed.

The highest content of the two fibre fractions was characterized by seeds of the variety Californium. Acid detergent fibre (ADF) concentration of PR45D03 and PR46W31 was 1.71 and 1.72% point lower, respectively, and the differences were significant. The differences in the content of neutral detergent fibre (NDF) were statistically insignificant and for Californium compared with hybrids PR45D03 and PR46W31 amounted to 0.34 and 0.12% point. The seeds of the PR45D03 semi-dwarf hybrid were characterized by significantly lower than other varieties contents of all tested glucosinolates. An exception was glucobrassicin, which was as low as in Californium variety. The PR46W31 variety, in turn, was characterized by significantly higher content of gluconapin, glucobrassinonapin, progoitrin, glucobrassicin. Similarly, high content of napoleiferin and total glucosinolates was also shown for a Californium variety. Sowing density was a factor that during the tests did not affect significantly the content of the analyzed components in winter oilseed rape. The relation between the yield of proteins and oil and quality characteristics of a tested varieties is shown in Table 3. The content of most of glucosinolates in PR45D03 variety was significantly negatively correlated with the yield of protein and oil. Such dependence has not been proven only for the progoitrin and napoleiferin with the yield of protein and for napoleiferin and the oil yield. Content of most of glucosinolates in PR46W31 was significantly positively correlated with the yield of protein and oil. The exception was a significant negative correlation of 4-hydroxyglucobrassicin with both yields, as well as the lack of significant correlations for glucobrassicine with yields of protein and oil. The lack of significant correlation for napoleiferin and total glucosinolate with the oil yield was also observed. However, in the Californium variety the content of most glucosinolates was significantly positively correlated only with the yield of protein. This relation has not been proven for gluconapin, glucobrassicine and total alkelyn. In this variant, only the contents of glucobrassicine correlated negatively with the yield of oil in a significant way. In all tested varieties, protein yield showed a tendency to negatively correlate with the protein content in the seeds. The strongest correlation was shown for PR45D03, but this correlation was on borderline of significane (p = 0.051). In all varieties, in turn, oil yield was significantly positively correlated with its contents in seeds.

The content of ADF, NDF and glucosinolates in rapeseed determine the feed value of extraction meal. In PR45D03 and Californium varieties, the content of ADF was significantly positively correlated with the yield of protein and oil. Of note the NDF fraction correlated significantly positively only with the yield of oil in all tested varieties.

Discussion

The determination of sowing time is critical in winter oilseed rape production in terms of both seed yield and
Figure 4. Plant height (cm) (BBCH 57–59, BBCH 85–89) and lodging (9° scale) before harvest for winter oilseed rape depending on sowing date and variety. Vertical bars represent 95% confidence intervals of means. Different letters at the top of graph bars indicate significant differences at \( p < 0.05 \) (Tukey’s multiple range test).

Table 2. Detailed description for another quality traits in winter oilseed rape.

| Factors          | ADF     | NDF     | GLN     | GLB     | PRG     | NPLF    | INDOL   | 4OHIN   | SMAG    | SMAA    |
|------------------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|
|                   | % d.m.  | \( \mu \text{M} \cdot \text{g seeds}^{-1} \) |
| **Season (S)**    |         |         |         |         |         |         |         |         |         |         |
| 2008/2009         | 334.2** | 7.1**   | 0.02    | 17.1**  | 21.8**  | 88.11** | 0.90    | 3.01    | 10.92** | 6.46**  |
| 2009/2010         | 19.44 a | 28.96 a | 5.03 a  | 0.95 a  | 8.99 a  | 0.13 a  | 0.25 a  | 3.18 a  | 17.42 a | 14.74 a |
| Sowing date (D)   |         |         |         |         |         |         |         |         |         |         |
| August 14         | 17.81 a | 28.95 a | 5.04 a  | 0.93 a  | 8.66 a  | 0.12 a  | 0.24 b  | 3.02 b  | 16.64 b | 14.40 a |
| August 25         | 17.96 a | 28.96 a | 5.09 a  | 0.94 a  | 8.78 a  | 0.12 a  | 0.25 b  | 3.11 b  | 17.13 a | 14.61 a |
| September 4       | 18.06 a | 28.82 a | 5.03 a  | 0.92 a  | 8.73 a  | 0.12 a  | 0.25 ab | 3.14 b  | 17.12 a | 14.50 a |
| September 15      | 17.72 a | 28.21 a | 4.99 a  | 0.90 a  | 8.64 a  | 0.12 a  | 0.26 a  | 3.31 a  | 17.21 a | 14.36 a |
| **Variety (V)**   | 45.3**  | 4.4     | 41.1**  | 49.4**  | 59.4**  | 25.9**  | 7.44**  | 33.77** | 34.5**  | 24.9**  |
| PR45D03           | 17.32 b | 28.55 a | 4.73 c  | 0.85 c  | 8.09 c  | 0.11 b  | 0.25 b  | 2.96 c  | 15.68 b | 13.49 c |
| PR46W31           | 17.31 b | 28.77 a | 5.29 a  | 0.99 a  | 9.27 a  | 0.12 a  | 0.26 a  | 3.11 b  | 17.92 a | 15.33 a |
| Californium       | 19.03 a | 28.89 a | 5.09 b  | 0.93 b  | 8.74 b  | 0.12 a  | 0.25 b  | 3.34 a  | 17.47 a | 14.58 b |
| **Sowing rate (seeds m\(^{-2}\)) (R)** | 0.3 | 0.3 | 0.02 | 0.24 | 0.05 | 0.4 | 0.37 | 0.64 | 0.16 | 0.02 |
| 30                | 18.00 a | 28.75 a | 5.04 a  | 0.93 a  | 8.67 a  | 0.12 a  | 0.25 a  | 3.15 a  | 16.94 a | 14.42 a |
| 40                | 17.93 a | 28.79 a | 5.03 a  | 0.92 a  | 8.73 a  | 0.12 a  | 0.25 a  | 3.13 a  | 17.04 a | 14.50 a |
| 50                | 17.84 a | 28.79 a | 5.03 a  | 0.93 a  | 8.72 a  | 0.12 a  | 0.25 a  | 3.12 a  | 16.97 a | 14.47 a |
| 60                | 17.78 a | 28.61 a | 5.04 a  | 0.92 a  | 8.69 a  | 0.12 a  | 0.25 a  | 3.18 a  | 17.16 a | 14.48 a |
| SxD               | 17.3**  | 1.7     | 2.1     | 0.93    | 1.95    | 3.30**  | 1.08    | 2.42    | 2.0     | 1.48    |
| SxV               | 49.6**  | 2.5     | 41.3**  | 53.4**  | 27.96** | 8.93**  | 7.44**  | 33.77** | 34.5**  | 24.96** |
| DxV               | 0.8     | 1.0     | 1.4     | 1.81    | 1.26    | 1.57    | 0.91    | 0.93    | 0.48    | 0.99    |
| SxR               | 0.2     | 0.2     | 0.08    | 0.85    | 0.09    | 0.21    | 0.11    | 0.10    | 0.09    | 0.07    |
| DxR               | 0.2     | 0.2     | 0.43    | 0.37    | 0.33    | 0.69    | 0.18    | 0.22    | 0.51    | 0.40    |
| VxR               | 0.3     | 0.2     | 0.58    | 0.22    | 0.43    | 0.75    | 0.08    | 0.38    | 0.48    | 0.41    |
| Sx DxV            | 0.8     | 0.5     | 0.88    | 0.50    | 0.89    | 0.67    | 0.45    | 0.63    | 0.55    | 0.60    |
| Sx DxR            | 0.1     | 0.1     | 0.33    | 0.32    | 0.26    | 0.58    | 0.04    | 0.10    | 0.28    | 0.30    |
| Sx VxR            | 0.3     | 0.1     | 0.50    | 0.36    | 0.38    | 1.05    | 0.15    | 0.06    | 0.36    | 0.32    |
| D x VxR           | 0.2     | 0.1     | 0.30    | 0.46    | 0.27    | 0.59    | 0.16    | 0.21    | 0.27    | 0.30    |
| S x D x V x R     | 0.2     | 0.1     | 0.60    | 0.69    | 0.57    | 0.74    | 0.20    | 0.36    | 0.53    | 0.63    |

Notes: Bold values – \( F \)-value, mean value within a columns followed by the same letter are not significantly different according to Tukey’s test (\( p \leq 0.05 \)) ADF – acid detergent fibre, NDF – neutral detergent fibre, GLN – Gluconapin, GLB – Glucobrassicinapin, PRG – Progoitrin, NPLF – Napoleiferin, INDOL – Glucobrassicin, 4OHIN – 4-hydroksyglucobrassicin, SMAG – Total glucosinolate, SMAA – Total alkenyl glucosinolates; \( \mu \text{M} \cdot \text{g seeds}^{-1} \) micromol per gram of seeds. Statistically significant differences \( (p < 0.05) \), \* statistically highly significant differences \( (p < 0.01) \).
### Correlation of protein and oil yield with selected quality traits of winter oilseed rape.

| Traits | Variety | Protein | Oil | ADF | NDF | GLN | GLB | PRG | NPLF | INDOL | 4OHIN | SMAG | SMAA |
|--------|---------|---------|-----|-----|-----|-----|-----|-----|------|-------|-------|------|-----|
| Protein yield | PR45D03 | −0.17 | 0.19* | 0.19* | 0.08 | −0.31** | −0.25** | −0.12 | 0.04 | −0.18* | −0.34** | −0.27** | −0.18* |
| p = 0.051 | p = 0.034 | p = 0.031 | p = 0.374 | p = 0.000 | p = 0.004 | p = 0.162 | p = 0.655 | p = 0.045 | p = 0.000 | p = 0.002 | p = 0.038 |
| Oil yield | PR46W31 | −0.39** | 0.40** | 0.30** | 0.27** | −0.39** | −0.36** | −0.26** | −0.07 | −0.38* | −0.53** | −0.40** | −0.31** |
| p = 0.000 | p = 0.000 | p = 0.002 | p = 0.000 | p = 0.003 | p = 0.457 | p = 0.670 | p = 0.000 | p = 0.000 | p = 0.000 | p = 0.000 |
| Protein yield | California | −0.08 | −0.04 | 0.40** | 0.14 | 0.12 | 0.25** | 0.17* | 0.22* | −0.16 | 0.27** | 0.17* | 0.13 |
| p = 0.366 | p = 0.661 | p = 0.000 | p = 0.126 | p = 0.189 | p = 0.004 | p = 0.035 | p = 0.012 | p = 0.074 | p = 0.002 | p = 0.049 | p = 0.149 |
| Oil yield | | −0.31** | 0.19* | 0.41** | 0.31** | 0.01 | 0.14 | 0.04 | 0.08 | −0.34** | 0.06 | 0.01 | −0.01 |
| p = 0.000 | p = 0.000 | p = 0.000 | p = 0.000 | p = 0.882 | p = 0.126 | p = 0.643 | p = 0.385 | p = 0.000 | p = 0.482 | p = 0.883 | p = 0.882 |

Notes: ADF – acid detergent fibre, NDF – neutral detergent fibre, GLN – Gluconapin, GLB – Glucobrassiconapin, PRG – Progoitrin, NPLF – Napoleiferin, INDOL – Glucobrassicin, 4OHIN – 4-hydroxyglucobrassicin, SMAG – Total glucosinolate, SMAA – Total alkenyl glucosinolates.

*Statistically significant differences (p < 0.05).

**Statistically highly significant differences (p < 0.01).
The 3.4 value was obtained, which according to Suohu et al. (2004) theoretically does not ensure the maximum yield, but in our research this value provided the highest yield when sowing was done in this sowing date. In this study, the open-pollinated Californium had the lowest leaf area index among the tested cultivars (PR45D03, PR46W31, Californium). Leaf area index was significantly correlated with yield in Californium cultivar in all tested sowing dates, while in PR45D03 and PR46W31 this correlation was also proved for sowing dates, except August 14 (data not shown). In an experiment performed by Nowakowska et al. (2005), the SPAD unit number of the open-pollinated cultivar at the same developmental stage was 772.8. Moreover, those authors recorded SPAD index values the highest in hybrids varieties (average 780 SPAD units). In our study, contrary the value of SPAD index was highest in Californium cultivar. Significantly positive correlation of SPAD values with yield was proved only in PR45D03 cultivar for the sowing date of August 25 (data not shown).

According to Turhan et al. (2011), a lower plant height was observed as a result of a delay in sowing date. It was confirmed in our study, in which plant height at both the budding stage and before harvest decreased significantly after a delay in sowing date. Bagheri and Manafi (2011) also showed that early sowing dates had an advantageous effect on plant height. As it could have been expected, it was shown that the semi-dwarf PR45D03 hybrid was characterized by the lowest plant height. As a result, it was expected that resistance to lodging in this cultivar will be significantly greater and it was confirmed in this study. Wang et al. (2004) assumed that semi-dwarf hybrids may exhibit high resistance to lodging only at high nitrogen fertilization.

Our results indicated that optimal sowing date affects not only the yield but also chemical composition of seed. During research, unfavourable distribution of precipitation and lack of water in flowering stage could cause changes in the chemical composition of seeds. This increases a protein content and decreases the amount of oil. Si and Walton (2004) as well as Tobe et al. (2013) also observed that delayed sowing of canola led to increased protein and decreased oil content of the grain. Similarly, Sattar et al. (2013) and Ozer (2003) reported that delayed sowing not only reduced seed yield but also decreased oil level in winter oilseed rape. Ahmadi and Bahrami (2009) showed that flowering was the most sensitive stage for water stress damage. As a result, a reduction of 29.5 and 31.7% was observed for seed and oil yields, respectively. Other authors claim that this result can be attributed to the shortened vegetative growth period and increasing temperature during the flowering period (Hocking & Stapper, 2001; Nuttall et al., 1992; Turhan et al., 2011). Our findings show that the delay in sowing date has increased the content of glucobrassicin and 4-hydrokysylgucobrassicin in the seeds. This indicates the response of plants to deteriorating growing conditions. The content of other glucosinolates did not change. The increase in concentration of glucosinolates is unfavourable. The presence of these compounds in the expeller and the meal of rapeseed limits the use of oil processing residuals in feeding of monogastric animals. It is widely accepted that the glucosinolate content is affected by environmental factors, agronomic practices (Turhan et al., 2011) or nutritional availability (Mert-Turk et al., 2008). Moghadam et al. (2011) reported that under drought stress conditions, the average glucosinolate content increased to 15%, for all varieties. This showed that glucosinolate contents increased when the water stress increased. Results of our studies also indicated that in the first growing season, drought period in April could lead to increase in glucosinolate content such as: glucobrassiconapin, progoitrin, napoleiferin, total glucosinolate and total alkenyl glucosinolates in seeds.

According to Sattar et al. (2013), seed oil concentration is purely genetically controlled and plays a vital role in determining total oil yield per unit area. Increasing the concentration of seed oil is a constant direction of breeding studies (Delourne et al., 2006). Our results proved that semi-dwarf PR45D03 variety had higher seed oil content in comparison to conventional Californium. What is more its total glucosinolate content was the lowest among studied varieties. Contrary to our results, Różyło and Pałys (2014) showed that the conventional variety contained significantly more oil than the hybrid varieties. Of note similarly as in our studies glucosinolates content was the lowest in semi-dwarf variety. In turn, Feiffer and Koch (2007) observed that oil content of the semi-dwarf in the less fertile condition was 1% higher than conventional hybrid. Oil content in traditional plant at high nitrogen supply was significantly lower in comparison to semi-dwarfs. However, at low nitrogen supply no significant difference in oil content was detected among different growth types (Miersch, 2014). Turhan et al. (2011) indicated that different genotypes should be tested for several years in different locations to enable the reduction in the variability caused by environmental effects. It is important to develop specific variety suitable for a given region.

In our study, interaction between sowing date and variety for oil and protein content was found to be insignificant, similarly as in Turhan et al. (2011) experiments. Lu et al. (2011) also proved that traits formation of winter type early maturity rapeseed varieties were seriously affected by the agroecological environment in South China. According to Khan et al. (2008), high genotypic variance has less environmental influence hence possess high heritable variation. The concentration of oil, glucosinolate, oleic acid,
linolenic acid and erucic acid possessed high heritability values. It is suggested that with the use of these traits as selection criteria one could lead to the improvement in seed yield and quality. The results of our study showed that plant variety selection as well as season interactions were significant for the concentration of oil, acid detergent fibre and all tested glucosinolates. Schierholt and Becker (2001) suggested that higher heritability could be caused by environmental influence which could be overcome with biparental or pedigree selection. Contrary to this, Zhang and Zhou (2006) reported lower heritability, which may be due to difference of genotypes or environmental influence. Our results confirm the previous studies conducted by Schierholt and Becker (2001). The study showed that glucosinolates content is affected by genotype and season interaction. Khan et al. (2008) suggests that non-significant results observed for protein content might be caused by the environmental fluctuation, adoptability and narrow genetic background of genotypes. Genotype-by-environment interaction is not desirable for plant breeders, so it is important in plant breeding to understand such interactions to improve stability of crop yield in a target production (Akbarpour et al., 2014; Hristov et al., 2009).

Our study did not prove a significant effect of lower plant density on quality traits. This is corroborated by the research of two teams i.e. Różylo and Palys (2014) as well as Spychaj-Fabisiak et al. (2011).

Correlations between traits indicate whether the selection for one trait has an effect on another. It was not shown in presented tables, but coefficient of correlation for oil content with protein content and glucosinolates amounted to −0.94 and −0.42, respectively, for all tested varieties. Thus, our findings similarly as in Khan et al. (2008) showed that oil has highly significant but negative relation with protein content. Contrary to our study Khan et al. showed a non-significant but positive relation with glucosinolates. In our study, this relation was significant and negatively correlated, similarly to the results showed by Turhan et al. (2011).

**Conclusion**

Both hybrid varieties, including semi-dwarf and open-polli-nated varieties produced the highest yield when sowing was done after 25 August in the South-East Baltic region. Both early and delayed sowing, resulted in a drop in yields. The semi-dwarf hybrid of winter oilseed rape showed a greater tolerance to delayed sowing and produced comparable yields to the open-polli-nated cultivar. Moreover, semi-dwarf variety in comparison to other studied varieties (hybrid and open-polli-nated) contained in it seeds less protein and glucosinolate but more oil. Delay in sowing date and unfa-vourable weather conditions during growing season affected glucosinolate content in rapeseeds. Moreover, delaying sowing date caused decrease in oil content in seeds, while contrary the protein content has increased. The effect of plant density on quality traits of winter oilseed rape varieties was not proved in this study. An economically important result, especially for the agricultural practice is to show that the yields of winter oilseed rape did not differ significantly within a density of 40, 50, 60 seeds·m⁻².

**Disclosure statement**

No potential conflict of interest was reported by the authors.

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