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Assessment of New Winter Rapeseed Hybrids (*Brassica napus* L.) for Productivity and Seed Quality Traits

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ABSTRACT

Winter oilseed rape is an important oil crop in Bulgaria. In recent years, due to the change of climate requires the ongoing development and examination of new and world-wide rapeseed hybrids that are most appropriate and effective for specific micro-regions within the country. The selection of the appropriate hybrid is crucial for both yield quantities and the quality of the resulting produce. The objective of the study was to determine the seed yield and its components, along with certain qualitative aspects of five introduced rapeseed hybrids cultivated in Central Bulgaria. The field experiment was conducted of the selected area in Voivodinovo village in region Plovdiv during the period 2021-2024. The experiment was performed on alluvial-meadow soil type by means of a block method with four repetitions; experimental field area - 15 m^2, after the predecessor winter wheat. The following hybrids were tested; InVigor 1266 CL, Beatrix CL, Matrix CL, Immortal CL and Robot CL. All the stages of the established technology for rapeseed growing were followed. The indices height of the plants, number of branches per plant, number of pods per plant, pod length, number of seeds per pod, weight of seeds per plant, seed yield, oil yield, 1000 seed weight, test weight, oil content and crude protein were determined. The highest seed yield was obtained by Immortal CL hybrid due to the higher values of yield structural elements, while the highest oil yield and oil content were reported by the hybrid Matrix CL. Hybrid InVigor 1266 CL is distinguished with the highest values of the crude protein. Seed yield and the crude protein content were negatively related. The values of the indicators 1000 seeds weight and test weight were highest by the hybrid Robot CL.

Keywords: rapeseed, hybrids, seed yield, quality, oil, protein.

INTRODUCTION

Rapeseed (*Brassica napus* L.) is one of the most important oilseed crops grown in the world. It is mostly cultivated for its seeds, which contain 43% to 47% oil and 19% to 20% protein of the entire composition (Poisson et al., 2019; Radić et al., 2021; Yahbi et al., 2022). Rapeseed oil comprises useful components, such as fatty acids and phenols, recognized for their health and nutritional advantages (Niță et al., 2022; Guirrou et al., 2023). The productive potential of rapeseed is manifested when an optimal combination of various factors is attained, including the hybrid, agroecological and climatic conditions, and the agricultural technology employed (Miah et al., 2015; Nowosad et al., 2016; Hu et al., 2017; Khalipsky et al., 2019; Szała et al., 2019; Khan et al., 2020; Bopp et al., 2022).

The hybrid type with its specific genetic potential is the most important management practice to realize higher seed yield (Alam et al., 2014; Long et al., 2018; Brown et al., 2019; Das et al., 2020; Spasibionek et al., 2020; Rajković et al., 2021; Xu et al., 2022; Ji-kui et al., 2024). The primary objective of plant breeders is to create novel commercial genotypes that can acclimatize to diverse environmental circumstances (Angadi et al., 2000; Takashima et al., 2013; Nelson et al., 2016; Gauthier et al., 2017; Sharif et al., 2017; Alizadeh et al., 2022).

Marjanović-Jeromela et al. (2019) assert that water availability is the main factor influencing seed production and oil content, particularly in conjunction with colder temperatures during seed development. The researchers examined the impact of annual climate variables on the agronomic characteristics of winter rapeseed.

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Consequently, the implementation of suitable agronomic methods at designated growth phases guarantees elevated seed and oil yields.

Selecting the most appropriate hybrids for a specific region based on factors such as moisture content, light availability, temperature regimes, geographical location, altitude, soil and climatic conditions, and cultivation technology results in achieving desired outcomes and ensures consistent yields (Weymann et al., 2015; Turinek et al., 2017; Dreccer et al., 2018; Luo et al., 2020; Butkevičienė et al., 2021; Matsera, 2021; Nath et al., 2021; Zheng et al., 2022; Sachan et al., 2024).

The absence of selection activities in our country requires testing and the implementation of foreign hybrids across different regions of Bulgaria (Ivanova, 2012; Todorov, 2023). Consequently, the objective of the experiment was to determine the seed yield and its components, along with certain qualitative aspects of five introduced rapeseed hybrids cultivated in Central Bulgaria.

MATERIAL AND METHODS

Field experiment

The field experiment was conducted of the selected area in Voivodinovo village in region Plovdiv (Central Bulgaria) during the period 2021-2024. The experiment was performed on alluvial-meadow soil type by means of a block method with four repetitions; experimental field area - 15 m^2, after the predecessor winter wheat. The following hybrids were tested; InVigor 1266 CL, Beatrix CL, Matrix CL, Immortal CL and Robot CL.

The basic steps of soil management are reversing stubble in July at a depth of 10-12 cm, conducting deep plowing to a depth of 18-20 cm in August, performing three disking operations, and executing both pre-sowing and post-sowing rolling. The phosphorus (80 kg ha^{-1}) and potassium (40 kg ha^{-1}) fertilizers, along with a portion of nitrogen fertilizer (50 kg ha^{-1}), were applied once during basic tillage prior to sowing, while an additional 100 kg ha^{-1} of nitrogen was introduced in the spring, following the beginning of the winter rape growing season. Sowing occurred annually between September 10 and 20, with row spacing of 12-15 cm and a seed rate of 55 germinating seeds per m^2 at a depth of 2-3 cm. The management of weeds and pests was executed using appropriate herbicides and insecticides. The winter rapeseed harvested at full maturity. All the stages of the established technology for rapeseed growing were followed. The indices height of the plants, number of branches per plant, number of pods per plant, pod length, number of seeds per pod, weight of seeds per plant, seed yield, oil yield, 1000 seed weight, test weight, oil content and crude protein were determined.

The values of productivity and quality indicators were statistically analyzed using the analysis of variance ANOVA and correlation method, and differences across variations were assessed by Duncan's Multiple Range Test.

Weather conditions

The production of winter rapeseed is dependent on weather conditions (Marjanović-Jeromela et al., 2019). According to Weymann et al. (2015) about 40% of seed yield variability is explained by weather conditions during specific growth phases. The primary climate factors influencing rapeseed growth and development are air temperature and total precipitation, along with their interplay and distribution during the vegetative period (Angadi et al., 2000; Dreccer et al., 2018; Brown et al., 2019; Xu et al., 2022). The analysis of these factors showed that the average monthly temperatures during the years of the study (2021-2024) were close to or above the stated values for a multiple-year period, with no substantial discrepancies from the crop requirements (Figure 1). The variations among the three years of the study were determined by the quantity of rainfall throughout the growing season (Figure 2).

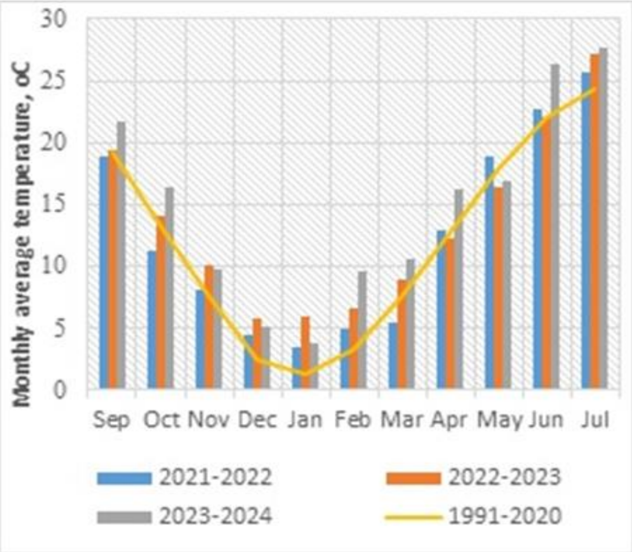

Figure 1. Monthly average temperature, °C

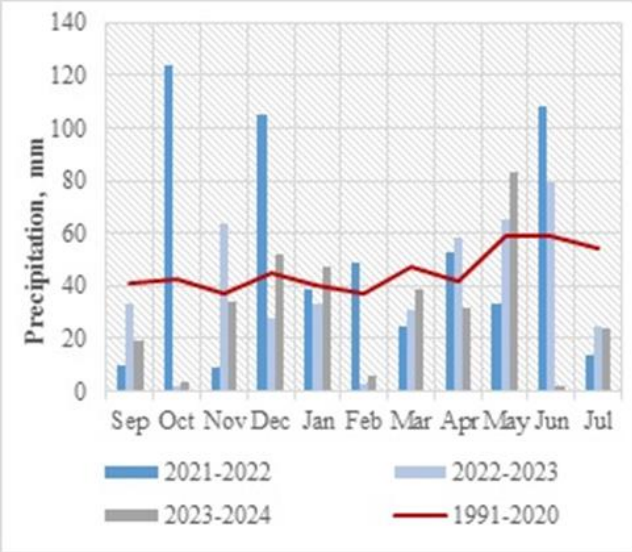

Figure 2. Precipitation, mm

The first experimental year (2021-2022) was characterized by enough and evenly distributed precipitation, fully satisfying the moisture demands of the plants from emergence to till ripening (569.0 mm). The lowest amount of precipitation recorded in the 2023-2024 economic year was 341.2 mm, versus 505.2 mm for multiple-year period, i.e. about 164.0 mm less. The year was marked by an irregular distribution of rainfall, insufficient to satisfy the water requirements of plants throughout critical stages.

During the initial stages of vegetation (X-XI), particularly during germination and the early development phase of the crop, the moisture content from rainfall was 37.2 mm, compared to an average of 80 mm across multiple-year period, resulting in a deficit of approximately 42.8 mm below the norm. The last experimental year was deemed less conducive to plant productivity than the preceding years. During the 2022-2023 season, the total rainfall amounted to 420.7 mm, which is 84.39 mm below the average for the period 1991-2020; nonetheless, it was relatively well distributed during the vegetative period.

The inaugural experimental year (2021-2022) proved most advantageous for the growth and development of rapeseed hybrids, marked by an optimal interplay of temperature and moisture during critical developmental phases, followed by the second year (2022-2023) and the third year (2023-2024) of the experiment, having an effect on productivity and quality of rapeseed.

RESULTS AND DISCUSSION

Seed yield

The data on seed yield (Table 1) indicate that, both annually and on average during the experimental period, the Immortal CL hybrid exceeded the seed yield of all other hybrids included in the study. The highest yields were achieved during the favorable rapeseed year of 2021-2022, when temperature and precipitation levels consistently satisfied the plant's requirements during the entire growing season, in contrast to the years 2022-2023 and 2023-2024. The yields obtained reached up to 4310 kg ha^{-1} in the Immortal CL hybrid. The hybrid's yield exceeded that of Matrix CL, Robot CL, Beatrix CL and InVigor 1266 CL hybrids by 4.7%, 8.1%, 10.5%, and 13.7%, respectively, with the differences being statistically significant. During the second experimental year (2022-2023), seed yields ranged from 3540 kg ha^{-1} for the InVigor 1266 CL hybrid to 4172 kg ha^{-1} for the Immortal CL hybrid, reflecting an average decrease of 5.1% compared to 2021-2022.

Mathematical processing of data showed that Matrix CL, Robot CL, Beatrix CL and InVigor 1266 CL hybrids significantly fell behind by 278, 372, 442 and 632 kg ha^{-1} than Immortal CL hybrid.

The lowest seed yields during the studied period were reported in the third year of the experiment (2023-2024), attributed to inadequate moisture during the crucial phases of growth and development of the rapeseed plants. The yields of rapeseed ranged from 3188 to 3650 kg ha^{-1}. Statistical evidence indicates that the InVigor 1266 CL hybrid exhibited the lowest yields, while Immortal CL recorded the highest, i.e, they were by 576 and 383 kg ha^{-1} lower in average in comparison with first and second year.

Table 2. Seed yield, kg ha $^{-1}$

Hybrid	Years of study			Average for the period (kg ha $^{-1}$)
	2021-2022	2022-2023	2023-2024	
InVigor 1266 CL	3790 ^{e}	3540 ^{e}	3188 ^{d}	3506
Beatrix CL	3900 ^{d}	3730 ^{d}	3412 ^{c}	3681
Matrix CL	4115 ^{b}	3894 ^{b}	3546 ^{b}	3852
Immortal CL	4310 ^{a}	4172 ^{a}	3650 ^{a}	4044
Robot CL	3986 ^{c}	3800 ^{c}	3425 ^{c}	3737

** Means within columns followed by different lowercase letters are significantly different (P<0.05), according to the LSD test.*

Throughout the experimental period (2021-2024), the Immortal CL hybrid achieved an average yield of 4044 kg ha^{-1}, exceeding the yields of the hybrids InVigor 1266 CL, Beatrix CL, Robot CL and Matrix CL by 15.3%, 9.9%, 8.2%, and 5.0%, respectively.

Table 2 presents the findings of the Analysis of Variance (ANOVA) regarding the impact of the factors hybrid and year, together with their interaction, on the seed yield indicator. The results indicate a statistically significant influence of the examined factors and an insignificant effect of their interaction.

Table 2. Analysis of variance ANOVA

Source of Variation	Sum of Square	df	Mean Square	F	P-value	F crit
Hybrid**	1770250	4	442562.4	35.872	0.00	2.578739
Year**	3985921	2	1992960	161.5399	0.00	3.204317
Interactions ^{ns}	89176.8	8	11147.10	0.903531	0.52	2.152133
Within	555177	45	12337.27			

** F-test significant at P<0.05; ** F-test significant at P<0.01; ns non-significant.*

Oil yield

The expression of oil yield, as one of the most important rapeseed quantitative traits, is greatly influenced not only by genotype, but also by environment and complex genotype x environment interactions (Sidlauskas and Bernotas, 2003; Marjanović-Jeromela et al., 2008b). Data in Figure 3 showed that averagely for the experimental period Matrix CL hybrid domineered over the rest of the hybrids included in the experiment. For the conditions of the first year oil yield varied from 1663.8 kg ha^{-1} for InVigor 1266 CL hybrid to 1888.9 kg ha^{-1} for Matrix CL hybrid. The Immortal CL, Robot CL and Beatrix CL hybrids received yields, which were 44.2 and 135.1 and 161.2 kg ha^{-1} lower compared to Matrix CL hybrid.

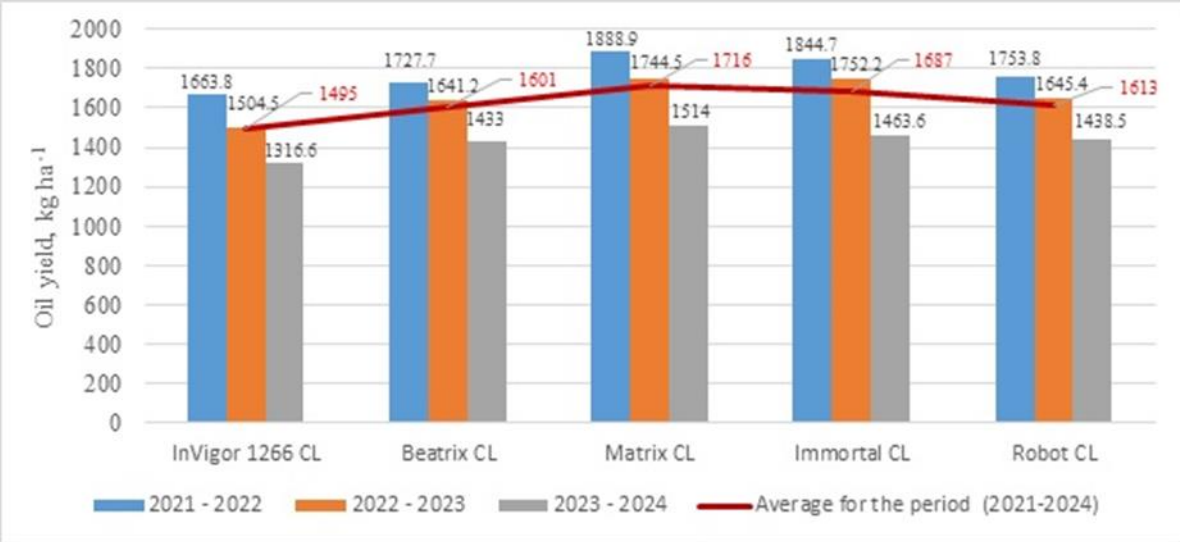

Figure 3. Oil yield, kg ha^{-1}

The experimental year 2022-2023 exhibited reduced precipitation levels compared to 2021-2022 during the growing season, totaling 410.7 mm, while the oil yield ranged from 1504.5 to 1752.2 kg ha^{-1}, i.e. by 7.8 to 10.6% lower. In the last year of the experiment, the oil yield ranged from 1316.6 to 1514.0 kg ha^{-1}. Mathematical data processing indicates that in the least favorable year for rapeseed production, the oil yield ranged from 347.2 to 374.9 kg ha^{-1}, which is 187.9 to 238.2 kg ha^{-1} lower compared to the years 2022-2023 and 2022-2021, respectively. During the three-year trial period, the Matrix hybrid produced the greatest average oil yield of 1716 kg ha^{-1}, surpassing the mean yield of the other hybrids by 7.5%.

The analysis of variance (ANOVA) demonstrates a significant statistically validated impact of both the examined hybrids and the years with their distinct climatic circumstances on the oil yield indicator. An interaction between hybrids and year was demonstrated (Table 3).

Table 3. Analysis of variance ANOVA

Source of Variation	Sum of Square	df	Mean Square	F	P-value	F crit
Hybrid**	373588.3	4	93397.09	246.6762	0.00	2.578739
Year**	1238825	2	619412.7	1635.965	0.00	3.204317
Interactions*	25607.91	8	3200.989	8.454308	0.00	2.152133
Within	17038	45	378.6222			

** F-test significant at P<0.05; ** F-test significant at P<0.01; ns non-significant.*

The results of the biometric parameters and the structural elements of the yield show that these indicators change under the influence of meteorological factors during the years as well as and by hybrid (Table 4). The highest values of the main structural elements of the yield were reported in 2021-2022, followed in 2022-2023, and the lowest in 2023-2024. From the studied hybrids Immortal CL is distinguished from the others with higher plants and longer pod, with more number of branches per plant, pods and seeds per plant, as well as with a larger weight of seeds per plant.

Plant height

The maximum height of plants is a crucial characteristic. The height of the plant influences the development of primary branches, which in turn supports secondary branches, main raceme length, and the number of pods per plant, thereby contributing to overall yield (Khan et al., 2019). The analysis of variance revealed significant differences (p≤0.05) among the rapeseed hybrids regarding plant height (Table 5). Due to the more advantageous climatic conditions in 2021-2022, the height of the plants at the conclusion of the growth season exhibited higher values across all evaluated hybrids, whereas the highest plants were of the Immortal CL hybrid, which measured 169.1 cm. The emergence of lower plants in 2023-2024 is attributed to the uneven distribution of precipitation during the crucial phases of rapeseed growth. Throughout this trial year, the height of the examined hybrids ranged from 119.4 cm to 143.4 cm. Furthermore, the hybrid Immortal CL exhibited the highest average plant height at 156.1 cm, while the InVigor 1266 CL displayed the least average plant height at 128.9 cm (Table 4).

Number of branches per plant

Notable variations (p≤0.05) were seen among the rapeseed hybrids regarding number of branches per plant. The hybrid Immortal CL exhibited the highest number of branches per plant - 9.7, 8.8, 8.2 at 2021-2022, 2022-2023 and 2023-2024, whereas the hybrid InVigor 1266 CL displayed the lowest values - 7.1, 6.3, 5.4 at 2021-2022, 2022-2023 and 2023-2024 (Table 4). The examination of branches data from plant revealed substantial variances across *Brassica napus* hybrides. The findings are corroborated by Khan et al. (2019) and Azadgoleh et al. (2009), who identified considerable variations among Brassica genotypes.

The analysis of variance (ANOVA) about the effect of the factors hybrid and year, as well as their interaction, on the number of branches per plant, shows a significant influence of the factors on the changes of the characteristic and statistically insignificant effect of the interaction between them (Table 5).

Pod length

Pod length is a significant yield-contributing characteristic that has a direct correlation with seeds per pod and, ultimately, seed output. Pod length data demonstrated considerable variation among rapeseed hybrids. The peak values for this indication were recorded for the Immortal CL hybrid, ranging from 6.57 to 8.14 cm. The length of the pods for the remaining hybrids during the experiment varied from 5.45 cm to 7.44 cm (Table 4). Our results closely align with those of Tahir et al. (2006), Azadgoleh et al. (2009) and Khan et al. (2019), who similarly observed significant variation in pod length.

Table 4. Biometrical parameters and yield components in winter rapeseed hybrids

Hybride	Year	Plant height, cm	Nr of branches per plant	Nr of pods per plant	Pod length, cm	Nr of seeds per pod	Weight of seeds per plant, g
InVigor 1266 CL	2021-2022	140.7 c	7.1 d	319 e	6.94 d	21.0 c	44.66 d
	2022-2023	126.7 d	6.3 d	298 d	6.58 d	19.1 c	38.04 d
	2023-2024	119.4 c	5.4 d	271 c	5.45 d	18.7 c	30.91 d
	Avarage for the period	128.9	6.3	296	6.32	19.6	37.87
Beatrix CL	2021-2022	160.8 b	8.0 c	378 d	7.44 b	26.9 b	50.42 c
	2022-2023	131.9 c	6.9 c	344 c	6.92 b	25.4 b	41.96 c
	2023-2024	129.3 b	6.0 c	304 b	5.96 b	23.6 b	32.83 c
	Avarage for the period	140.7	7	342	6.77	25.3	41.74
Matrix CL	2021-2022	159.8 b	8.4 b c	404 b	7.38 b	26.3 b	53.36 b
	2022-2023	132.5 c	7.6 b	350 b	7.11 b	25.2 b	43.25 b
	2023-2024	126.8 b	7.3 b	292 b	6.10 b	24.9 b	34.36 b
	Avarage for the period	139.7	7.8	349	6.86	25.5	43.66
Immortal CL	2021-2022	169.1 a	9.7 a	466 a	8.14 a	31.2 a	63.94 a
	2022-2023	155.7 a	8.8 a	432 a	7.41 a	29.9 a	57.89 a
	2023-2024	143.4 a	8.2 a	357 a	6.57 a	26.1 a	42.84 a
	Avarage for the period	156.1	8.9	418	7.37	29.1	54.89
Robot CL	2021-2022	157.3 b	8.5 b	386 c	7.02 c	27.4 b	55.10 b
	2022-2023	140.2 b	7.7 b	355 b	6.67 c	26.3 b	44.28 b
	2023-2024	128.5 b	6.8 b	310 b	5.74 c	24.0 b	36.39 b
	Avarage for the period	142	7.7	350	6.48	25.9	45.26

**Means within columns followed by different lowercase letters are significantly different (P<0.05), according to the LSD test.*

Number of pods per plant

The statistically analysis of data indicated that hybrids considerably differed (p<0.05) in terms of the quantity of pods per plant (Table 5). The hybrid Immortal CL demonstrated the highest average pod count per plant at 418, succeeded by hybrids Robot CL, Matrix CL, and Beatrix CL, which showed minimal variation among themselves, with average counts of 350, 349, and 342, respectively. The smallest number of pods per plant was documented in the third year of the study (2023-2024), varying from 271 for the hybrid InVigor 1266 CL to 357 for Immortal CL, due to less favorable climatic conditions relative to the preceding two experimental years. This year's pod count per plant is below the period average values of this indicator by 8.45% for InVigor 1266 CL, 11.11% for Beatrix CL, 16.33% for Matrix CL, 14.59% for Immortal CL, and 11.43% for Robot CL (Table 4).

Number of seeds per pod

The number of seeds in a single pod varies within a certain range. Throughout the study period, the Immortal CL hybrid demonstrated the highest average seed count at 29.1, whereas the other hybrids varied between 19.6 and 25.9 (Table 4).

The ANOVA variance analysis indicated a significant statistical effect of both parameters on the number of seeds per pod, although it could not demonstrate their interaction mathematically (Table 5).

Table 5. Analysis of variance ANOVA

Parameter	Source of Variation	Sum of Square	df	Mean Square	F	P-value	F crit
Plant height, cm	Hybrid*	4644.56	4	1161.14	27.17	0.00	2.58
	Year**	8737.11	2	4368.55	102.23	0.00	3.20
	Interactions ns	627.86	8	78.48	1.84	0.09	2.15
	Within	1922.92	45	42.73			
Nr of branches per plant	Hybrid*	46.04	4	11.51	42.72	0.00	2.58
	Year*	26.73	2	13.37	49.60	0.00	3.20
	Interactions ns	1.60	8	0.20	0.74	0.66	2.15
	Within	12.13	45	0.27			
Nr of pods per plant	Hybrid*	90275.07	4	22568.77	30.51	0.00	2.58
	Year*	50562.70	2	25281.35	34.18	0.00	3.20
	Interactions ns	6357.13	8	794.64	1.07	0.40	2.15
	Within	33286.75	45	739.71			
Pod length, cm	Hybrid*	4.32	4	1.08	45.33	0.00	2.58
	Year**	27.70	2	13.85	581.25	0.00	3.20
	Interactions *	2.42	8	0.30	12.68	0.00	2.15
	Within	1.07	45	0.02			
Nr of seeds per pod	Hybrid*	571.46	4	142.86	72.91	0.00	2.58
	Year*	94.57	2	47.29	24.13	0.00	3.20
	Interactions ns	24.19	8	3.02	1.54	0.17	2.15
	Within	88.18	45	1.96			
Weight of seeds per plant, g	Hybrid**	1928.01	4	482.00	421.30	0.00	2.58
	Year**	3256.72	2	1628.36	1423.29	0.00	3.20
	Interactions *	115.20	8	14.40	12.59	0.00	2.15
	Within	51.48	45	1.14			

**F-test significant at P<0.05; **F-test significant at P<0.01; ns non-significant.*

Weight of seeds per plant

Weight of seeds per plant is one of the main yield components that are greatly influenced by genotype, environment, and their interaction (Marjanović-Jeromela et al., 2011; Channaoui et al., 2019; Attia et al., 2021).

In 2021-2022, elevated values of those indicators, in conjunction with climatic conditions during the seed formation, filling, and ripening period, were documented. The maximum weight of seeds per plant occurred in the first year, ranging from 44.66 g to 63.94 g, in contrast to the subsequent two years, which ranged from 30.91 g to 57.89 g (Table 4).

The analysis of variance (ANOVA) indicates a robust statistically significant effect of both the examined hybrids and the years with their distinct climatic conditions on the characteristic: the weight of seeds per plant. The interaction between the two factors is mathematically proven (Table 5).

The impact of both variable hybrid and year on the qualitative components is presented in Table 6.

Weight of 1000 seeds

The results indicate that, under experimental conditions and within the examined parameter, the weight of 1000 seeds (g) ranged from 3.92 g to 6.85 g for the five hybrids. The Beatrix CL and Matrix CL hybrids exhibited close values for the mass per 1000 seeds across individual experimental years: 4.84 g and 4.81 g in 2021-2022; 4.25 g in 2022-2023; and 4.04 g and 3.92 g in 2023-2024. According to the results presented in Table 6, the average mass of 1000 rapeseeds utilized in the study was 5.05 g. Razavi et al. (2009) claimed that the mass of 1000 rapeseeds utilized in their study ranged from 3.06 to 4.84 g and Baran et al. (2016) indicated that the average 1000 seeds mass of the rapeseeds used in the study was 4.74 g. The analysis of variance summary for experimental years and the weight of 1000 seeds is displayed in Table 6. The parameters were affected by differing annual conditions as assessed by the F test at a 5% significance level.

Test weight

The typical test weight values for rapeseed ranged from 61 to 68 kg. This characteristic is affected by the seed's specific mass, moisture content, seed geometry, the arrangement of seeds inside the volume, and the presence and kind of external substances (Matei et al., 2017). The synthesis data concerning the test weight value from the experimental cycle was showed at Table 6. During the three-year period, values over 64 kg were documented for the hybrid Robot CL, with measurements of 66.8 kg (2023-2024), 67.4 k (2022-2023), and 68.9 kg (2021-2022) and for the hybrid Immortal CL, with recorded values of 64.3 kg (2023-2024), 65.5 kg (2022-2023), and 66.8 kg (2021-2022). The average test weight for the Robot CL hybrid is notably high at 67.7 kg. The lowest average value of test weight for the InVigor CL hybrid was observed at 62.3 kg. The tested hybrids appear to be less affected by environmental conditions associated with this trait, exhibiting minimal fluctuations in the recorded levels across the experimental years.

The ANOVA variance analysis revealed a substantial statistical effect of both parameters on test weight, although it could not mathematically illustrate their interaction (Table 6).

Oil content

Rapeseed oil content, as a quantitative property, is regulated by numerous genes and affected by environmental factors. Elevated temperatures during rapeseed maturation hinder the accumulation and conversion of nutrients into seeds. High temperature forces rapeseeds to mature earlier. As a result, seed weight and oil content decrease sharply (Vuorinen et al., 2014).

The tested rapeseed hybrids display a broad spectrum of oil content in their mature seeds, varied from 40.1 to 45.9%. The lowest oil content values in rapeseed were measured during the 2023-2024 period as follows: 41.3% for InVigor 1266 CL, 42.0% for Beatrix CL and Robot CL, and 42.7% for Matrix CL (Table 6). This results from elevated temperature values during the growing season, surpassing those of the perennial period by an average of +2.9°C, but especially during the seed ripening period with up to +4.2°C. The highest and lowest average seed oil contents were found for Matrix CL (44.5%) and Immortal CL (41.6%), respectively. The five rapeseed hybrids exhibited substantial differences in seed oil content (p<0.01); however, the interaction between the factors hybrid and year was not statistically significant (Table 6).

Table 6. Qualitative indicators in winter rapeseed hybrids

Variable	Year	1000 seed weight (g)	Test weight (kg)	Oil content (%)	Crude protein (%)
Years (A)	2021-2022	5.59 [a]	65.4 [a]	44.2 [a]	24.2 [a]
	2022-2023	5.05 [b]	64.5 [b]	43.3 [b]	26.1 [b]
	2023-2024	4.47 [c]	63.7 [c]	41.6 [c]	27.2 [c]
Hybrid (B)	InVigor 1266 CL	5.39	62.3	42.6	27.2
	Beatrix CL	4.38	64.2	43.4	25.6
	Matrix CL	4.33	63.2	44.5	26.0
	Immortal CL	5.10	65.5	41.6	25.3
	Robot CL	6.00	67.7	43.1	25.0
2021-2022	InVigor 1266 CL	6.11 [b]	62.9 [d]	43.9 [b]	25.3 [a]
	Beatrix CL	4.84 [d]	65.0 [c]	44.3 [b]	24.1 [b]
	Matrix CL	4.81 [d]	63.6 [d]	45.9 [a]	24.2 [b]
	Immortal CL	5.34 [c]	66.8 [b]	42.8 [c]	23.7 [c]
	Robot CL	6.85 [a]	68.9 [a]	44.0 [b]	23.6 [c]
2022-2023	InVigor 1266 CL	5.54 [b]	62.2 [e]	42.5 [d]	27.6 [a]
	Beatrix CL	4.25 [c]	64.4 [c]	44.0 [b]	25.9 [b]
	Matrix CL	4.25 [c]	63.3 [d]	44.8 [a]	26.5 [b c]
	Immortal CL	5.19 [b]	65.5 [b]	42.0 [d]	25.2 [b]
	Robot CL	6.03 [a]	67.4 [a]	43.3 [c]	25.4 [b]
2023-2024	InVigor 1266 CL	4.52 [b]	61.7 [e]	41.3 [c]	28.8 [a]
	Beatrix CL	4.04 [c]	63.1 [c]	42.0 [b]	26.7 [b c]
	Matrix CL	3.92 [c]	62.7 [d]	42.7 [a]	27.4 [b]
	Immortal CL	4.77 [b]	64.3 [b]	40.1 [d]	27.0 [b]
	Robot CL	5.12 [a]	66.8 [a]	42.0 [b]	26.0 [c]
ANOVA	A	**	*	**	**
	B	**	**	*	*
	AB	*	ns	ns	*

**Means within columns followed by different lowercase letters are significantly different (P<0.05), according to the LSD test. * F-test significant at P<0.05; ** F-test significant at P<0.01; ns non-significant.*

Crude protein

Protein is the main requirement for growth and development of all organisms (Balalić, et al., 2017). The protein content of rapeseed depends on various factors, including genetics of the hybrid and environmental factors, as well as the interaction between them. The variability of protein content in rapeseed, in addition to genetic factors, is greatly influenced by many environmental factors as location (Marinković et al., 2010), temperature (Piljuk, 2006) and year (Kulikovskij, 2006).

In contrast to seed yield and other productivity parameters, the crude protein content was higher during years of reduced rainfall. In the third year (2023-2024), precipitation measured 341.2 mm, which is 227.8 mm and 79.5 mm less than the first and second experimental years, respectively. In the 2023-2024 period, the five hybrids exhibit the greatest crude protein values: 28.8% (InVigor 1266 CL), 26.7% (Beatrix CL), 27.4% (Matrix CL), 27.0% (Immortal CL), and 26.0% (Robot CL). An increase in crude protein was reported from 2.36% (Robot CL) up to 13.92% (Immortal CL) relative to the prior two experimental years.

The obtained results are statistically significant. The ANOVA variance analysis indicates a substantial impact of the two parameters, hybrid and year, on crude protein content. Their interaction has also been substantiated (Table 6).

Correlation coefficients

The matrix of correlation among the studied parameters is shown in Table 7. The results of correlation evidenced that seed yield was positively and significantly associated with oil yield (r=0.900), as well as pod length and oil yield (r=0.915). This is in line with the observation of Marjanović-Jeromela et al. (2007), Aytaç and Kınacı, (2009) and Balalić et al. (2012). Strong positive values (r>0.8) were obtained between the indices: weight of seeds per plant, seed yield and oil yield; pod length, weight of seeds per plant and seed yield; number of pods per plant, number of seeds per pods and weight of seeds per plant; number of branches per plant, weight of seeds per plant and seed yield; height of plants, weight of seeds per plant, seed yield and number of branches per plant.

High to mean positive correlation (r>0.7, r>0.6) was found for oil yield and oil content; number of seeds per pod and weight of seeds per plant, seed yield as well as oil yield; pod length and oil content; pod length and number of pods per plant, seed yield as well as oil yield; number of branches per plant and number of pods per plant, pod length, number of seeds per pod and oil yield; height of plants and number of pods per plant, pod length, number of seeds per pod as well as oil yield. The similar positively relationships were reported also from a number of researchers (Naazar et al., 2003; Khan et al., 2006; Tuncturk and Ciftci, 2007; Marjanovic-Jeromela et al., 2008a; Aytaç and Kınacı, 2009; Radić et al., 2021).

Negative correlation was observed between the crude protein and all other the qualitative and quantitative indicators. The same result was stated from Aytaç and Kınacı (2009), who reported that protein content has negative correlation with oil content and oil yield. A significant negative correlation between oil content and protein content in rapeseed was also confirmed by Ping et al. (2003), Hao et al. (2004), Bashir Ahmad et al. (2013), Vujaković et al. (2014), Balalić et al. (2017).

Table 7. Values of the coefficient of correlation

No.	1. Height of plant	2. Nr of branches per plant	3. Nr of pods per plant	4. Pod length	5. Nr of seeds per pod	6. Weight of seeds per plant	7. Seed yield	8. Oil yield	9. Weight of 1000 seed	10. Test weigh	11. Oil content	12. Crude protein
1.	1											
2.	0.846	1										
3.	0.776	0.797	1									
4.	0.746	0.690	0.721	1								
5.	0.691	0.773	0.861	0.591	1							
6.	0.888	0.850	0.854	0.851	0.746	1						
7.	0.825	0.804	0.778	0.878	0.724	0.894	1					
8.	0.773	0.756	0.742	0.915	0.636	0.868	0.900	1				
9.	0.386	0.310	0.195	0.296	0.099	0.469	0.311	0.317	1			
10.	0.396	0.512	0.403	0.201	0.521	0.457	0.323	0.296	0.509	1		
11.	0.378	0.309	0.240	0.638	0.145	0.354	0.497	0.716	0.139	0.075	1	
12.	-0.783	-0.689	-0.681	-0.743	-0.631	-0.811	-0.798	-0.818	-0.474	-0.466	-0.535	1

** Significance level alpha = 0.05.*

CONCLUSIONS

The study demonstrates that the productivity and quality characteristics of the evaluated rapeseed hybrids are significantly influenced by the hybrid's genetics, annual meteorological conditions, and primarily by the quantity and distribution of vegetative rainfall.

In contrast to the crude protein content, the other quantitative indicators were elevated during the year with increased precipitation. The Immortal CL hybrid had the highest seed yield due to its higher values of yield structural features. Seed yield had a substantial positive correlation with oil yield, weight of seeds per plant, pod length, number of pods per plant and number of branches per plant. Oil content ranged between 40.1% (Immortal CL) and 45.9% (Matrix CL). The Matrix CL hybrid exhibited the greatest mean oil content and oil yield considerably. The values of the indicators 1000 seeds weight and test weight were highest by the hybrid Robot CL. Hybrid InVigor 1266 CL has the highest values of the crude protein 27.2%. The correlation between protein content and seed yield, weight of seeds per plant, as well as oil yield were highly significant negative.

The study results may assist in proposing hybrid rapeseed in the region. We assume that comprehensive assessments of yield components and qualitative features will improve the knowledge of yield formation processes and advance the optimization of winter rapeseed management.

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