JEE Journal of Ecological Engineering

Journal of Ecological Engineering 2024, 25(1), 27–36
https://doi.org/10.12911/22998993/173066
ISSN 2299–8993, License CC-BY 4.0

Received: 2023.08.13
Accepted: 2023.09.29
Published: 2023.12.04

The Effect of Microorganisms and Inorganic Preparations Applied into the Soil and Leaves on the Yield of Winter Rape (*Brassica Napus* L.)

Anna Sikorska[1*], Marek Gugała[2], Krystyna Zarzecka[2], Łukasz Domański[2]

[1] Department of Agriculture, Ignacy Mościcki University of Applied Sciences in Ciechanów, Ciechanów, ul. Narutowicza 9, 06-400 Ciechanów, Poland

[2] Faculty of Agrobioengineering and Animal Husbandry, University of Natural Sciences and Humanities in Siedlce, ul. Prusa 14, 08-110 Siedlce, Poland

* Corresponding author's e-mail: anna.sikorska@puzim.edu.pl

ABSTRACT

The research was carried out in 2018-2021 at the Agricultural Experimental Station, in Poland. The factors of the experiment were three morphotypes of winter oilseed rape: population morphotype, long-stemmed morphotype, semi-dwarf morphotype. The second factor of the experiment corresponded to three ways of using the preparations: 1. Control variant, 2. Organic preparation (Ugmax) 3. Biostimulator containing P_20_5 and K_2O, 4. Biostimulator containing silicon. The aim of the study was the reaction of three morphotypes of winter rape to soil and foliar application of microorganisms as well as inorganic preparations in different growing seasons. Elements of yield structure and yielding of winter rape were determined by a genetic factor. In all growing seasons, the best yielding was in the restored hybrid with the traditional type of growth, while the seed yield of the semi-dwarf form was lower by 5.8% on average, and by 10.0% on average in the population form. The number of seeds in the pod and the value of the yield index (HI) was the most favourable in the restored forms, and the thousand-seed weight and yield in the population form. The preparations applied to the soil and leaves increased the parameters of yield structure and yielding in all tested cultivars. Soil preparation with microorganisms as well as micro and macro elements applied in autumn before sowing seeds and in spring in the BBCH 21-36 phase significantly increased the number of seeds per pod by 3.4% on average; weight of a thousand seeds by 3.5% on average, seed yield by 15.7% on average, straw yield by 4.5% on average compared to the control variant. The ratio of seed yield-to-biomass yield was higher in the heterosis cultivars by an average of 9.2% compared to the population cultivar. The elements of the yield structure as well as the main and by-products were the highest in the growing season with the highest annual rainfall and the highest average air temperature.

Keywords: number of seeds in a pod, thousand-seed weight, seed yield, side yield, harvest index.

INTRODUCTION

The currently registered morphotypes of winter rape, both population and heterosis, differ significantly in biometric and functional characteristics and show a varied response to environmental as well as climatic conditions and agricultural practices. According to Jarecki (2021), the rapeseed yields in agricultural practice are much lower than those obtained in post-registration experiments. According to the researcher, it is important to examine the yield-forming potential of individual types of varieties, optimise their agricultural technology and suitability for a given cultivation region. Abiotic stresses, such as drought or high-temperature stresses, are among the most important stress factors caused by the environment, limiting the yield potential of rapeseed. That is why every action that will contribute to increasing the resistance of plants and stimulating their growth and development is important. Over the last decade, a significant increase in the use of biostimulators has been observed in agricultural practice. In modern agriculture, foliar and soil application of nutrients is becoming a commonly used procedure (Kolarić et al. 2021; Spalevic et al. 2022), but both new and known preparations in agricultural practice should be tested under field experiments (Beres et al. 2019, Rios et al. 2019).

Natural mineral and organic substances contained in bio-fertilisers affect the physiological processes taking place in plants, contributing to higher yields. Many authors (Siringam et al., 2011; Ahmad et al., 2014; Karim et al., 2016; Nawaz et al., 2015; Noreen et al., 2018, Florin et al. 2022) confirmed in their studies the beneficial effect of foliar application of nutrients on plants and the significant impact of this type of treatments on mitigating the effects of drought. Wenda-Piesik and Hoppe (2018) emphasise that fertilisation with macro- and microelements is of particular importance in winter oilseed rape agriculture. This applies to both the optimisation of soil and foliar fertilisation. According to Ganya et al. (2018) and Amiri et al. (2020), the effects of foliar fertilisation vary depending on the date of application and dose, and are modified by climatic conditions.

The aim of the study was the reaction of three morphotypes of winter rape to soil and foliar application of microorganisms and inorganic preparations in different growing seasons. The research thesis assumed that the number of seeds in a pod, the weight of a thousand seeds, the main and by-product yield and the harvest index will depend on the morphotype and the types of soil and foliar applied microorganisms and inorganic preparations, which will allow recommending the best type of genotype under changing climatic conditions in the research region.

MATERIAL AND METHODS

The research was carried out in 2018-2021 at the Agricultural Experimental Station belonging to the University of Natural Sciences and Humanities in Siedlce, in Poland. The experiment was carried out in three repetitions in a split-plot system. In this arrangement, the experience is divided into blocks, and each block is divided into units called first-order units. Moreover, first-order units are divided into smaller, second-order units. In such an experimental setup, second-order units are nested in first-order units, which in turn are nested in blocks. Levels (variants) of factor A are placed on first-order units, and levels (variants) of factor B are placed on second-order units. The factors of the experiment were three morphotypes of winter oilseed rape are as follows:

- population morphotype (Chrobry)
- heterosis long-stemmed morphotypes (PT 271)
- heterosis semi-dwarf morphotype (PX 113)

The second factor of the experiment included three ways of using the preparations, namely:

1. Control variant (without the application of preparations)
2. Organic preparation (Ugmax) applied twice: in autumn before sowing seeds and in spring in phase BBCH 21-36, in doses 0.9 $dm^3 \cdot ha^{-1}$.
3. Biostimulator containing 13.0% of P_2O_5 and 5.0% of K_2O (Rooter) applied twice: in autumn in phase BBCH 13-15 and in spring in phase BBCH 28-30, in doses 1.0 $dm^3 \cdot ha^{-1}$
4. Biostimulator containing silicon (Optisil) applied twice in autumn in phase BBCH 13-15 and spring in phase BBCH 51, in doses 0.5 $dm^3 \cdot ha^{-1}$.

Soil conditions

The experiment was carried out on soil classified to the Haplic Luvisol group, sandy, very good rye soil complex, valuation class IVa (WRBSR, 2014). The pH of the soil was slightly acidic and ranged from 5.68 to 5.75 in the years of research. The soil was characterised by low abundance in assimilable forms of phosphorus and medium assimilability in potassium and magnesium.

Yield structure elements:

Assessments and biometric measurements were performed in each plot. In the experiment on 20 plants, the following were determined:

- number of seeds in a pod (pcs.),
- thousand-seed weight (g),
- seed yield ($Mg \cdot ha^{-1}$),
- side yield ($Mg \cdot ha^{-1}$),
- harvest index (HI).

The yield was given per 1 ha, taking into account the humidity of 14%.

Statistical analysis

The obtained test results were subjected to the analysis of variance. The significance of the sources of variation was tested with the Fischer-Snedecor "F" test. F-Snedecor test, also known as the F test or homogeneity of variances test, is a statistical test used to compare the variances of two samples of a population. It is used to determine whether the variances of two groups are equal or not. The test is based on the F distribution, which is a probability distribution comparing the ratio of two variances. In turn, the assessment of the significance of differences at the significance level of $\alpha = 0.05$ between the compared means was carried out using multiple Tukey intervals.

Climatic conditions

The research seasons differed in terms of thermal and humidity conditions (Table 1). On the basis of meteorological data, it was shown that, the highest rainfall (average 419.0 mm) and the highest average air temperature, which was 10.1°C on average, were recorded in the second year of the study. On the basis of the calculated Sielianinow's hydrothermal coefficient, it was a very wet growing season (K = 2.68). In the first growing season, the lowest amount of precipitation was recorded (average 244.0 mm), and the average air temperature was 9.7°C. In the third year of the study, the lowest average air temperature was 9.3°C on average. It was a very wet research year (K=2.99).

RESULTS AND DISCUSSION

On the basis of the research, it was shown that the number of seeds in the pod was the highest in the restored hybrids PT271 and PX113 and averaged to 26.43 g and 26.00 g (Table 2). Jarecki (2021) showed, confirming statistically, the smallest value of this feature in the heterosis of Mentor F_1. Czarnik et al. (2015) found statistically insignificant differences in the value of this feature between the population variety Arot and the hybrid Primus.

The methods of applying soil and foliar preparations significantly increased the number of seeds in the pod. After application of the foliar preparation containing 13.0% P_2O_5 and 5.0% K_2O, the greatest significant increase in this feature was shown, on average, by 4.73 items compared to the control variant. Foliar application of silicon increased the number of seeds per pod by an average of 3.38 pcs. Microorganisms applied to the soil slightly but statistically significantly increased the value of this feature (Table 2). Different research results were obtained by Czarnik et al. (2015), who did not show a significant increase in the value of this parameter after foliar application of the fertiliser at the end of budding compared to the control variant. Similar conclusions were drawn by Jarecki et al. (2022) as a result of applying a varied number of foliar feeding treatments in spring. Climatic conditions significantly differentiated the number of seeds in pods. The highest value of this feature, on average

Table 1. Monthly precipitation sums (mm), average air temperature (°C), the value of the Sielianinov hydrothermal coefficient in years 2019–2021 (Agricultural Experimental Station, Poland)

Month	Years of research										
	2018-2019	2019-2020	2020-2021	Multi-year sum (1996-2010)	2018-2019	2019-2020	2020-2021	Multi-year average (1996-2010)	I	II	III
	Precipitation (mm)				Air temperature (°C)				The value of the Sielianinov hydrothermal *		
VIII	24.5	43.9	18.2	59.9	20.6	19.9	20.2	18.5	1.19	2.20	0.90
IX	27.4	17.4	38.8	42.3	15.9	14.2	15.5	13.5	1.72	1.22	2.50
X	23.3	9.5	52.7	24.2	9.6	10.7	12.0	7.9	2.42	0.89	4.39
XI	9.8	17.8	34.0	20.2	3.3	6.1	5.0	4.0	-	-	-
XII	9.0	29.1	34.0	18.6	0.4	2.9	-1.0	-0.1	-	-	-
I	7.9	12.9	22.6	19.0	-3.0	1.9	-1.9	-3.2	-	-	-
II	4.7	26.8	10.4	16.0	2.2	2.9	-2.5	-2.3	-	-	-
III	15.0	5.9	9.6	18.3	4.8	4.5	2.7	2.4	3.13	1.31	3.55
IV	5.9	6.0	42.0	33.6	9.8	8.6	6.6	8.0	0.60	0.70	6.36
V	59.8	63.5	29.5	58.3	13.3	11.7	12.4	13.5	4.49	5.42	2.38
VI	35.9	118.5	33.8	59.6	21.4	19.3	20.4	17.0	1.68	6.14	1.66
VII	29.7	67.7	50.0	57.5	18.5	19.0	22.7	19.7	1.60	3.56	2.20
Sum VIII-VII/ Mean	244.0	419.0	375.6	427.5	9.7	10.1	9.3	8.2	2.10	2.68	2.99

Note: *Coefficient value according to Skowera (2014): extremely dry (ss) k≤0.4; very dry (bs) 0.4-0.7; dry (s) 0.7-1.0; rather dry (ds) 1.0<k≤1.3; optimal (o) 1.3<k≤1.6; rather wet (dw) 1.6<k≤2.0; wet (w) 2.0<k≤2.5; very wet (bw) 2.5<k≤3.0; extremely wet (sw) k>3.0.

28.21 g, was found in the second, very wet growing season, and the lowest in the year with the lowest annual rainfall (Table 1, 2).

No interaction of cultivars with the years of research was demonstrated, which confirms that the cultivars reacted similarly to climatic conditions in the years of research. The interaction found between the cultivars and the methods of application of soil and foliar preparations shows that the cultivars reacted differently to the preparations applied to the soil and leaves. On all studied objects, the restored hybrids were characterised by a significantly higher value of this feature, while the differences between the semi-dwarf variety and the long-stemmed hybrid were statistically insignificant (Table 2).

The interaction of years and methods of application of soil and foliar preparations has been statistically proven, which proves that these preparations act differently under changing climatic conditions in the years of research (Fig.1). In all objects, the highest value of this feature was shown in the 2019–2020 growing season, and the lowest in the first year of the study with the lowest annual rainfall and average air temperature of 9.7°C on average:

- B1 – Control object (without the application of preparations)
- B2 – Soil preparation with microorganisms as well as micro and macro elements (Ugmax)
- B3 – Foliar preparation with 13.0% P_2O_5 and 5.0% K_2O (Rooter)
- B4 – Foliar preparation with silicon (Optisil)

The weight of a thousand seeds was determined by the genetic factor. The value of this parameter was the highest in the population variety and averaged 5.52 grams. Restored hybrids had a lower value of this trait on average by 0.14 grams (Table 3). Different research results were obtained by Sikorska et al. (2020), who showed a higher value of this trait by an average of 0.37

Table 2. Yield structure elements – number of seeds in the pod (pcs.) depending on experience factors

Experiment factors	Years of research			Ways of application of soil and foliar preparations				
	I	II	III	Control object	Soil preparation with microorganisms as well as micro and macro elements	Foliar preparation with 13.0% P_2O_5 and 5.0% K_2O	Foliar preparation with silicon	Average
Chrobry	21.63	27.39	25.63	23.22	26.99	25.33	23.98	24.88
PT271	23.28	28.70	27.31	24.68	28.57	27.44	25.03	26.43
PX113	22.36	28.53	27.12	24.12	28.29	27.02	24.57	26.00
Average	22.42	28.21	26.68	23.22	24.01	27.95	26.60	-

Note: LSD $_{0.05}$ for: cultivars – 0.34; years – 0.34; ways of application of soil and foliar preparations –– 0.59 interactions: cultivars x years – n.s. cultivars x ways of application of soil and foliar preparations – 0.58.

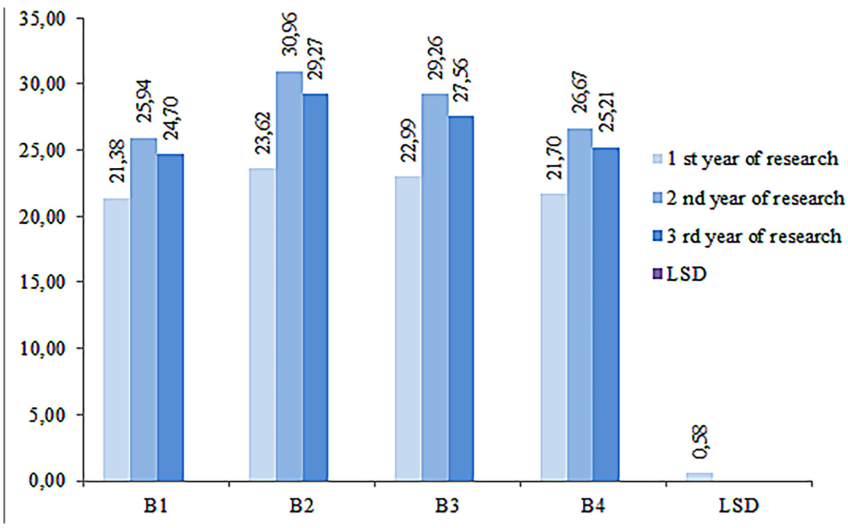

Figure 1. Yield structure elements – number of seeds in the pod (pcs.) depending on years and ways of application of soil and foliar preparations

Table 3. Elements of the yield structure – thousand-seed weight (g) depending on the experimental factors

Experiment factors	Years of research			Ways of application of soil and foliar preparations				
	I	II	III	Control object	Soil preparation with microorganisms as well as micro and macro elements	Foliar preparation with 13.0% P_2O_5 and 5.0% K_2O	Foliar preparation with silicon	Average
Chrobry	5.46	5.86	5.64	5.59	5.74	5.67	5.63	5.66
PT271	5.25	5.77	5.55	5.39	5.66	5.57	5.48	5.52
PX113	5.47	5.57	5.53	5.45	5.60	5.55	5.48	5.52
Average	5.40	5.73	5.58	5.48	5.67	5.60	5.53	-

Note: $LSD_{0.05}$ for: cultivars – 0.017; years – 0.017; ways of application of soil and foliar preparations – 0.019 interactions: cultivars x years – 0.030; cultivars x ways of application of soil and foliar preparations – 0.034.

grams in the semi-dwarf hybrid (PX 115) compared to the population variety Monolit.

The soil preparation with microorganisms as well as micro and macro elements used in the experiment caused the most significant increase in the weight of a thousand seeds compared to the control variant. After the application of foliar preparations containing 13.0% P_2O_5, 5.0% K_2O and silicon, the value of this feature was 5.60 and 5.53 grams (Table 3). Similarly, Jarecki and Bobrecka-Jamro (2008) after the application of mixed foliar fertilisers showed a significant increase of 24% in the weight of 1,000 seeds in comparison to the control object. In subsequent studies, the authors (Jarecki et al. 2019) confirmed the beneficial effect of the foliar preparation Insol 5 on the value of this feature, while further studies (Jarecki et al. 2022) did not show a significant impact of a varied number of spring foliar fertilisers on the value of this feature. Sikorska et al. (2020) obtained the largest increase in the weight of a thousand seeds by an average of 3.4% compared to the control variant on the objects with foliar application of sulphur, boron and a biostimulator with amino acids, while Jankowski et al. (2016a) after the application of foliar fertilisers found an increase in the value of this feature on average from 1.3% to 3.8%. Many authors (Czarnik et al. 2015; Szczepanek et al. 2016) did not confirm the statistically significant effect of foliar feeding on the weight of a thousand seeds.

As a result of own research, it was found that the weight of a thousand seeds was the highest in the second year of research, in which the highest total precipitation was recorded (average 419.0 mm) and the highest average air temperature (Table 3). Statistical calculations also showed the interaction of years and the tested cultivars, which proves the different response of the cultivars to changing climatic conditions in individual growing seasons, as well as the cultivars and ways of applying soil and foliar preparations, which confirms the differentiated response of the tested cultivars to the applied preparations (Table 3).

In own research, the highest seed yield, on average 4.10 $Mg \cdot ha^{-1}$ was recorded in the long-stemmed hybrid PT271, and the lowest, on average 3.69 $Mg \cdot ha^{-1}$ in the population form Chrobry (Table 4). Similar research results were obtained by Oleksy et al. (2019), who also showed a higher seed yield in the hybrid variety (Nelson) than in the population variety (Digger). Hoppe and Wenda-Piesik (2018) found that hybrid morphotypes of winter rape were distinguished by a 2% higher average seed yield than population varieties. However, Sikorska et al. (2020) indicated that among the compared varieties, the restored hybrid with a semi-dwarf type of growth (PX 115) stood out with the highest yield. The value of this parameter was higher on average by 0.42 $Mg \cdot ha^{-1}$ in comparison to the population morphotype Monolit. Different results of studies conducted in north-eastern Poland were obtained by Jankowski et al. (2016 c), who showed that the population variety was characterised by a higher yield index compared to the semi-dwarf form. Bujak et al. (2008) and Czarnik et al. (2015) found no differentiation in the value of this feature between the population and hybrid form.

The greatest significant increase in seed yield compared to the control variant was recorded after the application of the soil preparation with microorganisms as well as micro and macro elements, and the smallest after application of the foliar preparation with silicon. In the research of Czarnik et al. (2015), foliar fertilisation increased the seed yield by an average of 12.3% compared to the control. Similarly, Grzebisz et al. (2010) confirmed an increase in yields from 0.36 to 0.49 $Mg \cdot ha^{-1}$ after foliar application of micronutrient fertilisers. Jarecki and Bobrecka-Jamro (2008) after the application of Basfoliar 36 Ex fertiliser together with Solubor DF or Basfoliar 12-4-6 + S fertiliser together with Solubor DF, the seed yield increased by 14.1% on average, and in later studies the authors (Jarecki et al. 2023) obtained a significantly higher seed yield after double and triple spring foliar spraying compared to the control. According to Jankowski et al. (2016b), intensive variants of foliar fertilisation of winter rape increase seed yield on average from 0.43–0.69 $Mg·ha^{-1}$, and in subsequent studies, the authors (Jankowski et al. 2019) showed that foliar application of macro and microelements in autumn (BBCH 14 or BBCH 14 and 16) increased the seed yield by 0.19–0.23 to 0.30–0.34 $Mg·ha^{-1}$.

In own research, the highest seed yield, on average 4.72 $Mg·ha^{-1}$ was shown in the second, very wet growing season calculated on the basis of the Sielianinov coefficient (Table 4). A significant interdependence between years and cultivars was demonstrated, which proves different reactions of rapeseed cultivars to changing weather conditions in the years of research. All the tested morphotypes yielded the best in the 2019–2020 growing season. Statistically insignificant differences in seed yield were found between hybrids restored in the second and third year of the study. The population variety and the semi-dwarf hybrid had the lowest seed yield in the first year of the study. On the basis of the analysis of variance, an interaction was found between the years of research and the methods of applying soil and foliar preparations. In all variants, the highest seed yield was shown in the second year of the study, and the lowest in the 2018–2019 growing season (Table 4).

The highest straw yield, on average, 5.79 $Mg·ha^{-1}$ was obtained in the population cultivar, and the lowest, on average 5.29 $Mg·ha^{-1}$ in the semi-dwarf hybrid (Table 5). It is consistent with the results of Sikorska et al. (2020). The authors also obtained the highest straw yield in the population variety Monolit, and significantly the lowest, on average, by 0.38 $Mg·ha^{-1}$ in the semi-dwarf hybrid PX114.

The largest by-product was obtained on object 2, where a soil preparation with microorganisms as well as micro and macro elements was applied. On the objects where the preparations containing 13.0% P_2O_5, 5.0% K_2O and silicon were applied to the foliage, the side yield was 5.57 and 5.60 $Mg·ha^{-1}$, respectively (Table 5). Similarly, according to Jankowski et al. (2016c), intensive variants of foliar fertilisation of winter rape increase straw yield by an average of 0.59–1.69 $Mg·ha^{-1}$. In turn, Sikorska et al. (2020) recorded the largest by-product on objects where sulphur and boron as well as sulphur, boron and amino acid were applied by foliar application.

Climatic conditions significantly affected the value of this feature. The highest straw yield was obtained in the season with the highest annual rainfall (Table 5). On the basis of own research, the interaction of years with varieties was shown, which means that varieties reacted differently to changing climatic conditions. In all tested cultivars, the highest straw yield was recorded in the second year of the research and amounted to 7.41 $Mg·ha^{-1}$ for the population variety, and 7.10 $Mg·ha^{-1}$ for the long-stemmed hybrid (Table 5).

The cultivars reacted differently to the types of preparations used. It should be emphasised that the population variety and the long-stemmed hybrid had the highest straw yield after application of the soil preparation with microorganisms. The research showed that in the population variety and the semi-dwarf hybrid, after foliar application on objects 3 and 4, the differences were statistically insignificant (Table 5).

Table 4. Seed yield ($Mg·ha^{-1}$) depending on the experimental factors

Experiment factors	Years of research			Ways of application of soil and foliar preparations				
	Chrobry	PT271	PX113	Control object	Soil preparation with microorganisms as well as micro and macro elements	Foliar preparation with 13.0% P_2O_5 and 5.0% K_2O	Foliar preparation with silicon	Average
I	3.36	3.98	3.52	3.28	4.00	3.80	3.39	3.62
II	4.09	4.43	3.88	4.07	4.53	4.33	4.14	4.27
III	3.62	3.88	3.78	3.52	4.07	3.86	3.59	3.76
Average	3.69	4.10	3.86	3.63	4.20	4.00	3.71	-

Note: $LSD_{0.05}$for: cultivars – 0.047; years – 0.047; ways of application of soil and foliar preparations – 0.057; interactions: cultivars x years – 0.08; years x ways of application of soil and foliar preparations – 0.099.

Table 5. Straw yield (Mg·ha^{-1}) depending on the experimental factors

Experiment factors	Years of research			Ways of application of soil and foliar preparations				
	I	II	III	Control object	Soil preparation with microorganisms as well as micro and macro elements	Foliar preparation with 13.0% P_2O_5 and 5.0% K_2O	Foliar preparation with silicon	Average
Chrobry	4.90	7.41	5.05	5.69	5.88	5.78	5.79	5.79
PT271	4.69	7.10	4.84	5.40	5.62	5.54	5.62	5.54
PX113	4.58	6.59	4.71	5.02	5.34	5.40	5.40	5.29
Average	4.72	7.03	4.86	5.37	5.61	5.57	5.60	-

Note: LSD $_{0.05}$ for: cultivars – 0.053; years – 0.053; ways of application of soil and foliar preparations – 0.04; interactions: cultivars x years – 0.092; cultivars x ways of application of soil and foliar preparations – 0.07.

The analysis of variance showed interactions between the years of research and the methods of application of soil and foliar preparations in relation to the by-product, which proves the varied effect of the preparations used in changing climatic conditions in the years of research. It should be emphasised that the highest residual yield in all variants was shown in the second year of the study, and the differences in the value of this feature after the use of microorganisms and inorganic preparations (objects 2, 3, 4) were statistically insignificant. A similar trend was demonstrated in the first year of research, where the lowest value of this feature was recorded (Fig. 2):

- B1 – Control object (without the application of preparations).
- B2 – Soil preparation with microorganisms as well as micro and macro elements (Ugmax).
- B3 – Foliar preparation with 13.0% P_2O_5 and 5.0% K_2O (Rooter).
- B4 – Foliar preparation with silicon (Optisil)

The ratio of seed yield to biomass yield (harvest index – HI) was the highest in the restored hybrids (Table 6). Similar conclusions were drawn by Sikorska et al. (2020), who obtained the most favourable value of this indicator in a restored cultivar with a semi-dwarf type of growth. The highest value of the harvest index was recorded on object 2 after soil application of microorganisms. The foliar application of silicon reduced the value of this indicator compared to the control variants, but the recorded difference was not statistically significant (Table 6). Similarly, Jankowski et al. (2016b) as a result of application of foliar fertilisers showed a decrease in the value of this indicator. In turn, Sikorska et al. (2020) after application of the amino acid showed the same value of this feature as in the control variants. Other authors did not find a significant impact of the fertilisers containing zinc (Abdulkhaleq et al. 2018) and sulphur, nitrogen and phosphorus (Kaur et al. 2019) on the value of this indicator. The value of the harvest index was the highest in the first and last growing season, and the lowest in the first year of the study (Table 6). The cooperation between the tested cultivars and the climatic

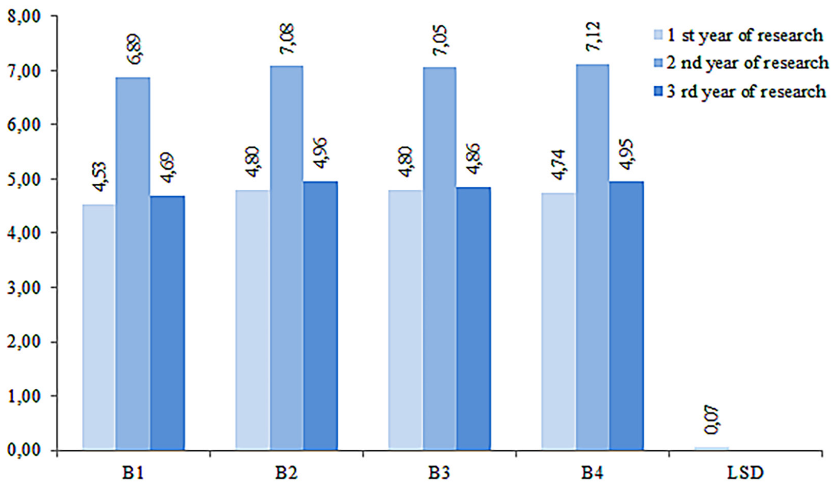

Figure 2. Straw yield (Mg·ha^{-1}) depending on years and ways of application of soil and foliar preparations

Table 6. Harvest index – HI depending on the experimental factors

Experiment factors	Years of research			Ways of application of soil and foliar preparations				
	I	II	III	Control object	Soil preparation with microorganisms as well as micro and macro elements	Foliar preparation with 13.0% P_2O_5 and 5.0% K_2O	Foliar preparation with silicon	Average
Chrobry	0.406	0.355	0.418	0.379	0.409	0.403	0.381	0.393
PT271	0.458	0.384	0.445	0.420	0.446	0.434	0.416	0.429
PX113	0.435	0.394	0.445	0.422	0.441	0.429	0.407	0.425
Average	0.433	0.378	0.436	0.407	0.432	0.422	0.402	-

Note: LSD $_{0.05}$ for: cultivars – 0.004; years – 0.004; ways of application of soil and foliar preparations – 0.004; interactions: cultivars x years – 0.007; cultivars x ways of application of soil and foliar preparations – 0.007.

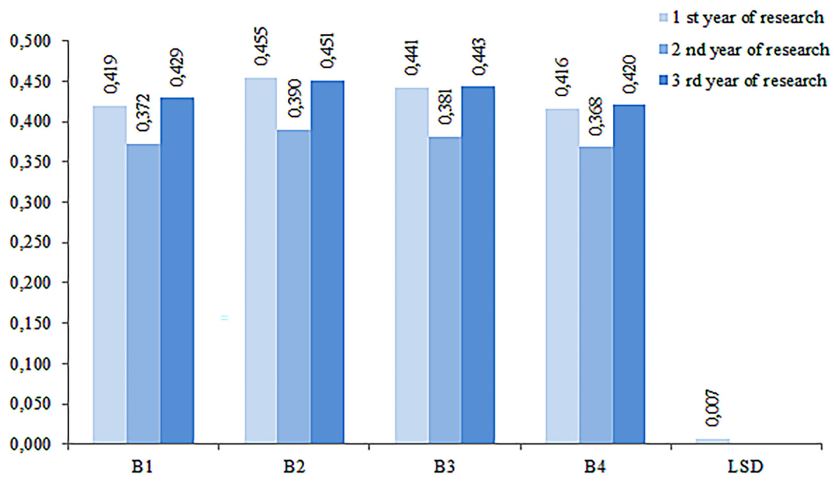

Figure 3. Harvest index depending on years and ways of application of soil and foliar preparations

conditions prevailing in the years of the study was demonstrated, and a varied response of the cultivars to the methods of application of soil and foliar preparations was found (Table 6). The analysis of variance showed the interaction of the years and the biostimulators used, which proves that the biostimulator works differently under the changing climatic conditions during the research (Fig. 3). In all years of research, the highest value of the harvest index was shown in object 2, where microorganisms were used. It should be emphasised that in the first year of research, the value of this feature on the control object was the same as on the object where silicon was used. A similar trend was demonstrated in the second year of the study:

- B1 – Control object without the application of preparations)
- B2 – Soil preparation with microorganisms as well as micro and macro elements (Ugmax)
- B3 – Foliar preparation with 13.0% P_2O_5 and 5.0% K_2O (Rooter)
- B4 – Foliar preparation with silicon (Optisil)

CONCLUSIONS

Elements of yield structure and yielding of winter rape were determined by a genetic factor. In all growing seasons, the best yielding was in the restored hybrid with the traditional type of growth, while the seed yield of the semi-dwarf form was lower by 5.8% on average, and by 10.0% on average in the population form. The number of seeds in the pod and the value of the yield index (HI) was the most favourable in the restored forms, and the thousand-seed weight and yield in the population form.

The preparations applied to the soil and leaves increased the parameters of yield structure and yielding in all tested cultivars. Soil preparation with microorganisms as well as micro and macro elements applied in autumn before sowing seeds and in spring in the BBCH 21-36 phase significantly increased the number of seeds per pod by 3.4% on average; weight of a thousand seeds by 3.5% on average, seed yield by 15.7%

on average, straw yield by 4.5% on average compared to the control variant. The ratio of seed yield to biomass yield was higher in the heterosis cultivars by an average of 9.2% compared to the population cultivar.

The elements of the yield structure as well as the main and by-products were the highest in the growing season with the highest annual rainfall and the highest average air temperature.

Acknowledgments

The results of the research carried out under the research theme No. 32/20/B were financed from the science grant granted by the Ministry of Science and Higher Education

REFERENCES

1. Abdulkhaleq D.A., Hama S.J., Ahmad, R.M., Ismael Tawfiq S. 2018. Response of some Rapeseed (*Brassica napus* L.) varieties to Zn fertilizer Under Dry-farming Conditions. Journal of Zankoi Sulaimani, Special Issue, 2nd Int. Conference of Agricultural Sciences, 143–155.
2. Ahmad R., E.A., Waraich M.Y., Ashraf S., Ahmad and T. Aziz. 2014. Does nitrogen fertilization enhance drought tolerance in sunflower? A review. Journal of Plant Nutrition, 37(6): 942–963. https://doi.org/10.1080/01904167.2013.868480
3. Amiri M., Shirani Rad A.H., Valadabadi A., Sayfzadeh S., Zakerin H. 2020. Response of rapeseed fatty acid composition to foliar application of humic acid under different plant densities. Plant Soil and Environment. 66, 303–308. https://doi.org/10.17221/220/2020-PSE
4. Beres J., Becka D., Tomasek J., Vasak J., 2019. Effect of autumn nitrogen fertilization on winter oilseed rape growth and yield parameters. Plant Soil and Environment. 65, 435–441. https://doi.org/10.17221/444/2019-PSE
5. Bujak H., Jedyński S., Kaczmarek J., Kotecki A., 2008. Ocena stabilności plonowania populacyjnych i mieszańcowych odmian rzepaku ozimego. Evaluation of yield stability of open-pollinated and hybrid cultivars of winter oilseed rape. Biuletyn IHAR 250, 261–271.
6. Czarnik M., Jarecki W., Bobrecka-Jamro D., Jarecka A. 2015. Wpływ gęstości siewu oraz nawożenia dolistnego na plonowanie odmian rzepaku ozimego. The effects of sowing density and foliar feeding on yielding of winter oilseed rape cultivar. ROŚLINY OLEISTE - OILSEED CROPS 36, 60–68. https://doi.org 10.5604/12338273.1195339
7. Crista F., Imbrea F., Radulov I., Bănățean D.I., Dragomirescu M., Lato A., Crista L. 2022. The impact of complex foliar fertilization on rapeseed cultivation. Journal of Pharmaceutical Negative Results, 13,9, 103–108.
8. https://doi.org/10.47750/pnr.2022.13.S09.012
9. Ganya S., Svotwa E., Katsaruware R.D. 2018. Performance of two rape (*Brassica napus*) cultivars under different fertilizer management levels in the smallholder sector of Zimbabwe. International Journal of Agronomy, 2351204, 1–7. https://doi.org/10.1155/2018/2351204
10. Grzebisz W., Łukowiak R., Biber M., Przygocka-Cyna K. 2010. Effect of multi-micronutrient fertilizers applied to foliage on nutritional status of winter oilseed rape and development of yield forming elements. Journal of Elementology, 15 (3), 477–491.
11. IUSS Working Group WRB. (2015). World Reference Base for Soil Resources 2014, update 2015 International soil classification system for naming soils and creating legends for soil maps. World Soil Resources Reports No. 106. FAO, Rome.
12. Jankowski K.J., Hulanicki P.S., Krzebietke S., Żarczyński P., Hulanicki P., Sokólski M. 2016a. Yield and quality of winter oilseed rape in response to different systems of foliar fertilization, Journal of Elementology, 21(4), 1017–1027. https://doi.org/10.5601/ jelem.2016.21.1.1108
13. Jankowski K.J., Sokólski M., Dubis B., Krzebietke S., Żarczyński P., Hulanicki Hulanicki P.S. 2016b. Yield and quality of winter oilseed rape (*Brassica napus* L.) seeds in response to foliar application of boron. Agricultural and Food Science, 25,3 164–176. https://doi.org/10.23986/afsci.57413
14. Jankowski K.J., Budzyński W.S., Załuski D., Hulanicki P.S., Dubis B. 2016c. Using a fractional factorial design to evaluate the effect of the intensity of agronomic practices on the yield of different winter oilseed rape morphotypes. Field Crops Research, 188, 50–61. https://doi.org/10.1016/j.fcr.2016.01.007
15. Jankowski K.J, Sokólski M., Szatkowski A. 2019. The Effect of Autumn Foliar Fertilization on the Yield and Quality of Winter Oilseed Rape Seeds, Agronomy 9, 12, 849. https://doi.org/10.3390/agronomy9120849
16. Jarecki W., Bobrecka-Jamro D. 2008. Reakcja rzepaku ozimego na dolistne dokarmianie. Reaction of winter rape to the extra feeding of its leaves. Annales UMCS, Sec. E, 63, 2, 86–96.
17. Jarecki W., Buczek J., Bobrecka-Jamro D. 2019. The response of winter oilseed rape to diverse foliar fertilization. Plant, Soil and Environment, 65, 125–130. https://doi.10.17221/5/2019-PSE
18. Jarecki W. 2021. Wielkość i jakość plonu nasion rzepaku ozimego w zależności od typu odmiany. The

size and quality of winter rape seed yield depending on the cultivar type. Agronomy Science, LXXVI (3), 5–14. http://doi.org/10.24326/as.2021.3.1

19. Jarecki W., Skrobacz K., Lachowski T. 2022. Wpływ nawożenia dolistnego na plonowanie i skład chemiczny nasion rzepaku ozimego (*Brassica napus L.*). Effect of foliar fertilization on the yield and chemical composition of winter oilseed rape (*Brassica napus* L.) seeds, Agronomy Science, 77, 4, 49–59. http://doi.10.24326/as.2022.4.4
20. Karim F., Iqbal J., Shabbir M., Kaleem S., Waqar M.Q. 2016. Response of cotton to foliar and soil applied nutrients under Dera Ghazi Khan conditions. Journal of Environmental and Agricultural Sciences, 7, 14–18.
21. Kaur M., Kumar S., Kaur A. 2019. Effect of foliar application of nitrogen, phosphorus and sulphur on growth and yield of Gobhi Sarson (*Brassica napus* L.) in central Punjab. Journal of Oilseed Brassica, 10(1), 47–50.
22. Kolarić L., Popović V., Živanović L., Ljubičić N., Stevanović P., Šarčević Todosijević Lj, Simić D., Ikanović J. 2021. Buckwheat yield traits response as influenced by row spacing, nitrogen, phosphorus, and potassium management. Agronomy 11, 2371. https://doi.org/10.3390/agronomy11122371
23. Nawaz F., Ahmad R., Ashraf M.Y., Waraich E.A., Khan S.Z. 2015. Effect of selenium foliar spray on physiological and biochemical processes and chemical constituents of wheat under drought stress. Ecotoxicology and Environmental Safety, 113, 191–200, https://doi.10.1016/j.ecoenv.2014.12.003
24. Noreen S., Fatima Z., Ahmad S., Athar H.-u.-R., Ashraf M. 2018. Foliar Application of Micronutrients in Mitigating Abiotic Stress in Crop Plants. In: Hasanuzzaman, M., Fujita, M., Oku, H., Nahar, K., Hawrylak-Nowak, B. (Eds.), Plant Nutrients and Abiotic Stress Tolerance. Springer Singapore, Singapore, pp. 95-117. https://doi.org/10.1007/978-981-10-9044-8_3
25. Oleksy A., Staroń J., Kołodziejczyk M., Kulig B., Brodowicz T. 2019. Wpływ dolistnego nawożenia mikro- i makroelementowego na plonowanie oraz zawartość tłuszczu w nasionach rzepaku. Influence of foliar fertilization with micro- and macroelements on yielding and fat content in seeds of oilseed rape. Fragmenta Agronomica, 36(1), 54–66. https://doi.org/10.26374/fa.2019.36.6
26. Rios J.J., Garcia-Ibañez P., Carvajal M., 2019. The use of biovesicles to improve the efficiency of Zn foliar fertilization. Colloid. Surf. B Biointerfaces 173, 899–905. https://doi.org/10.1016/j. colsurfb.2018.10.057
27. Sikorska A., Gugała M., Zarzecka. K. 2020. Winter oilseed rape yield depending on foliar fertilization. Acta Scientiarum Polonorum - Agricultura, 19(1), 11–20. https://doi.org/10.37660/aspagr.2020.19.1.2.
28. Sikorska A., Gugała M., Zarzecka K., Domański Ł. 2023. Effect of organic and inorganic stimulants on the content of glucosinolates in winter rape seed. Journal of Elementology 28(1), 189–198. https://doi.org/ 10.5601/jelem.2022.27.4.2344
29. Siringam K., Juntawong N., Cha-Um S., Kirdmanee C. 2011. Salt stress induced ion accumulation, ion homeostasis, membrane injury and sugar contents in salt-sensitive rice (*Oryza sativa* L. spp. indica) roots under isoosmotic conditions. African Journal of Biotechnology, 10, 1340–1346. https://doi.org/10.5897/AJB10.1805
30. Skowera B. 2014. Changes of hydrothermal conditions in the Polish area (1971−2010). Fragmenta Agronomica., 31(2), 74–87. (in Polish)
31. Spalevic V., Dudic B., Ercişli S., Janmohammadi M., Sabaghnia N. 2022. Foliar spray of Si and Ti nanoparticles affected enzymatic antioxidants in rapeseed (*Brassica napus* L.). Notulae Botanicae Horti Agrobotanici Cluj-Napoca, 50, 4, 12859. DOI:10.15835/nbha50412859 1-13
32. Szczepanek M., Wilczewski E., Grzybowski K. 2016. Response of winter oilseed rape (*Brassica napus* L.) on soil applied humus preparation and foliar potassium fertilizer. Acta Scientiarum Polonorum. Agricultura, 15(4), 85–94.
33. Wenda-Piesik A., Hoppe S., 2018. Evaluation of hybrid and population cultivars on standard and high-input technology in winter oilseed rape. Acta Agriculturae Scandinavica, Section B Soil & Plant Science, 68, 678–689. https://doi.org/10.1080/09064710.2018.146086