https://doi.org/10.17221/98/2024-PSE

Effect of seed weight and biostimulant seed treatment on establishment, growth and yield parameters of winter oilseed rape

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Citation: Bečka D., Bečková L., Satranský M., Pazderů K. (2024): Effect of seed weight and biostimulant seed treatment on establishment, growth and yield parameters of winter oilseed rape. Plant Soil Environ., 70: 296–304.

Abstract: This study evaluated the effect of seed weight and seed treatment on yield and growth parameters in a three-year field trial. Seed weight treatments were tested in three levels of thousand seed weight (TSW): low 4.28 g, medium 5.00 g and high 5.69 g, with and without a biostimulant seed treatment of Lumibio Kelta. Although statistically significant differences were not found in all experimental years, the three-year results showed that sowing seeds with higher seed weight increased the initial and final stand counts, root length, seed yield and oil content. The final stand at harvest time averaged over the three years ranged from 23.0 (low TSW) to 29.5 plants per 1 m^2 (high TSW). Plants from high TSW seed had an average of 1.1 cm longer roots than plants from low TSW seed. The average yield increased with TSW: 5.49 t/ha (low TSW), 5.86 t/ha (medium TSW), and 5.94 t/ha (high TSW). High TSW also yielded higher oil content (45.77%) compared to the medium (45.25%) and low TSW (45.27%). No statistical difference could be detected in the initial emergence counts or final seed quality according to seed treatment. Seed treatment with the biostimulant increased root length and seed yield. Plants from seeds treated with the biostimulant had roots with an average of 0.6 cm longer, yielding 0.2 t/ha higher than the non-treated ones.

Keywords: winter rapeseed; *Brassica napus* L.; seed size; seed stimulation; field emergence; number of plants; leaf growth; root growth; yield; oiliness

Rapeseed is the world's third most important oilseed crop in terms of oil production and the most important in Europe. While spring oilseed rape is most widely grown worldwide, winter oilseed rape predominates in Europe. In the European Union, 5.89 million ha were grown to produce 19.4 million tonnes in 2022 (EUROSTAT 2023). Rapeseed has relatively small seeds with a variable seed weight that is determined by genetics and conditions during production. The thousand seed weight (TSW) of winter oilseed rape varies usually between 4–6 g.

Seed size has been studied to effect germination, establishment, early growth and final yield of different crops. According to Guberac et al. (1998), the large seed fraction of oat had the highest germinability, germ length, root length and yield compared to the small seed fraction. Moshatati and Gharineh (2012) found that the grain weight of wheat had a significant effect on the seedling length and dry weight. Three size wheat classes demonstrated that the large seed size resulted in the highest shoot and root length (Shahi et al. 2015).

The effect of seed size has been shown in Brassica crops, too. Emergence, dry weight, and final yield increased with increasing seed size in hybrid broccoli cultivars of *B. oleracea* L. ssp. Italica (Heather and Sieczka 2019). In summer turnip rape cultivars (*B. rapa*), large seeds had better establishment, higher plant weights and higher seed yield compared to small seeds (Elliott et al. 2007). Rapeseed cultivars (*B. napus*) seedlings from large seeds improved establishment, shoot weight, biomass and yield compared

https://doi.org/10.17221/98/2024-PSE

to small seeds (Elliott et al. 2008). Further studies confirm a positive association between seed size and early rapeseed biomass, but the effect on crop emergence and yield is inconsistent (Hwang et al. 2014, Harker et al. 2015). In other cases, such as Lamb and Johnson (2004), no effect could be observed in the seed weight of two rapeseed cultivars on emergence, plant height, seed yield or oil concentration. Differences in establishment, weight and yield between large and small seeds are most pronounced under water stress and saline stress (Steiner et al. 2019) or during pest attack (Bodnaryk and Lamb 1991, Elliott et al. 2007, 2008).

Plant biostimulants are products containing substances or microorganisms applied to plants to enhance nutrition efficiency, tolerance to abiotic stress and crop quality (Du Jardin 2015). Biostimulants' composition usually includes one or more biologically active organic substances, such as humic and fulvic acids, amino acids and peptides, vitamins, enzymes, plant hormones and macro and microelements. Meanwhile, a separate group consists of microorganisms containing various types of beneficial bacteria and fungi (Van Oosten et al. 2017). From an extensive literature review, Van Oosten et al. (2017) concluded that a diverse number of biostimulants have protective effects against abiotic stress and a beneficial effect on the growth and productivity of plants.

Seed treatments with micronutrients have the potential to meet crop micronutrient requirements and improve stand establishment, seedling growth, yield, and micronutrient grain content in most cases (Farooq et al. 2012). Micronutrients are important cofactors in enzyme systems and are involved in key physiological processes of photosynthesis and respiration. Seed treatment can be an inexpensive and easy method of micronutrient delivery compared to applying micronutrients later.

Rapeseed emergence is often uneven due to the hot and dry conditions at sowing, but care may be taken to the condition of the seed to improve germination. Therefore, seed weight and inclusion of a seed treatment were tested for their effect on growth and yield parameters of oilseed rape and to assess the suitability of using the biostimulant with growth promotor and micronutrients to treat winter oilseed rape seed.

MATERIAL AND METHODS

Experimental conditions. A small-plot field trial was established at the Research Centre of the Czech University of Life Science in Červený Újezd in vegetation years 2019/20, 2020/21 and 2021/22. Field experiments were located at latitude 50°04', longitude 14°10', at an altitude of 405 m a.s.l.; the prevailing soil type is Haplic Luvisol. The average annual precipi-

Table 1. Average monthly temperatures and cumulative precipitation during the vegetative years 2019/20–2021/22 in comparison with standard climatological normal (1991–2020)

Month	Average temperature (°C)				The sum of precipitation (mm)			
	2019/20	2020/21	2021/22	normal	2019/20	2020/21	2021/22	normal
August	20.0 *an*	20.5 *van*	17.0 *vbn*	18.7	98 *an*	111 *an*	102 *an*	66
September	14.5 *n*	15.7 *an*	15.7 *an*	13.9	57 *an*	58 *an*	8 *vbn*	39
October	10.5 *an*	9.7 *n*	8.8 *n*	8.7	30 *n*	88 *van*	16 *n*	34
November	5.2 *an*	4.2 *n*	4.0 *n*	3.8	34 *n*	13 *bn*	39 *an*	29
December	2.4 *an*	2.1 *an*	1.2 *n*	0.4	13 *bn*	13 *bn*	31 *n*	26
January	1.3 *n*	–0.3 *n*	1.6 *an*	–0.7	8 *vbn*	43 *van*	26 *an*	21
February	4.5 *ean*	0.2 *n*	3.8 *van*	0.3	57 *ean*	36 *van*	18 *n*	18
March	5.0 *n*	4.6 *n*	4.6 *n*	4.0	45 *an*	24 *n*	16 *n*	28
April	10.2 *n*	6.3 *bn*	7.5 *bn*	9.2	13 *bn*	9 *vbn*	45 *van*	27
May	12.1 *n*	11.2 *bn*	15.6 *an*	13.6	50 *n*	102 *an*	42 *n*	60
June	17.4 *n*	19.9 *ean*	19.9 *ean*	17.0	72 *n*	83 *n*	139 *van*	71
July	19.1 *n*	19.8 *n*	19.6 *n*	18.9	29 *vbn*	82 *n*	58 *n*	77

Evaluation of air temperature and precipitation normality of months according to Kožnarová and Klabzuba (2002): *ebn* – extraordinary below normal; *vbn* – very below normal; *bn* – below normal; *n* – normal; *an* – above normal; *vab* – very above normal; *ean* – extraordinary above normal

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Table 2. Dates of sowing, plant sampling, first nitrogen application and harvest

Season	Sowing	Plant sampling	First nitrogen fertilisation in spring	Harvest
2019/20	26 August	11 November	22 February	27 July
2020/21	24 August	9 November	3 March	28 July
2021/22	2 September	11 November	25 February	26 July

tation reaches 495 mm, and the average annual air temperature is 9.0 °C (Table 1). Selected soil properties in the experimental locality by Mehlich III (average 2019/20–2021/22) were: pH_{CaCl_2} – 6.8; P – 1.9 mg/kg; K – 164 mg/kg; Mg – 110 mg/kg; Ca – 2 247 mg/kg.

Growing technology and experimental design. Winter wheat preceded the winter oilseed rape in all experimental years. Dates of sowing, field operations and harvest are given in Table 2. The sowing rate of the entire experiment was 50 seeds/m^2. The stand was uniformly treated with herbicides and insecticides (herbicide pre-emergently, insecticide in autumn and spring as needed). In spring, all variants were fertilised uniformly in four doses, to a total of 180 kg N/ha. A Wintersteiger small plot harvesting machine was used for harvest. Experimental plots were established in four replications; each plot had an area of 15 m^2. Winter oilseed rape cultivar PT264 were separated into three different weight classes according to TSW: low 4.28 g, medium 5.00 g, and high 5.69 g. The experiment was planted in a factorial with 3 levels of seed weight (low, medium, and high) and 2 levels of seed treatment (with and without the biostimulant). Therefore, in each replication, a plot of each TSW category was treated with the LumiBio Kelta biostimulator, and one plot was not treated (Table 3). The chosen cultivar, PT264, is a medium-early hybrid with pod shatter resistance, high yield, and oil content. LumiBio Kelta® is a new type of micronutrient fertiliser seed treatment and growth promoter developed by Marrone Bio Innovations Inc. It consists of organic acids, biopolymers, and micro and macronutrients.

Number of emerged plants, plant sampling, growth and yield parameters. During the growing season, the dynamics of field emergence of winter oilseed rape plants were evaluated for each treatment using a repeated measure of stand counts. The dates of counting and growth phases are given in Table 4. The counting was carried out at two marked sites (0.25 m^2) in each experimental plot.

During autumn, ten plants in four replications were sampled from each variant to determine above and below-ground biomass growth parameters. Sampling dates are given in Table 2. Plant sampling was done by carefully digging up the plants. After sampling, the plants were thoroughly washed of dirt. Several growth indication parameters were recorded in the ten plants: number of leaves (pcs.), longest leaf (cm), root neck thickness (mm), root length (cm), and dry matter mass of the above-ground biomass and roots (g). The first four indicators were measured in the fresh biomass. After measurement, plants were dried at 105 °C for 24 h. After drying, the dry matter of the above-ground biomass and root was weighed separately.

After the harvest, seed yield, oil content and TSW of harvested seeds were assessed. Seed oil content was determined by the nuclear magnetic resonance method.

Statistical analysis. The obtained data were statistically analysed in the Statgraphics Plus programme, version 4.0 (Statgraphics, Warrenton, USA) using the multifactor analysis of variance ANOVA (three factors – seed weight, seed treatment and year). The differences between the mean values were evaluated by the Tukey *HSD* (honestly significant difference) test at a 95% significance level.

Table 3. Experimental variants

Thousand seeds weight (TSW) variant	TSW (g)	Seed treatment	Treatment variant
Low TSW	4.28	non-treated	NT
		Bio-Stimulant LumiBio Kelta	BS
Medium TSW	5.00	non-treated	NT
		Bio-Stimulant LumiBio Kelta	BS
High TSW	5.69	non-treated	NT
		Bio-Stimulant LumiBio Kelta	BS

https://doi.org/10.17221/98/2024-PSE

Table 4. Plant counting dates and plant growth phases

Season	Np-1	Np-2	Np-3	Np-4	Np-5	Np-6	Np-7
	BBCH 9–10	BBCH 10–11	BBCH 12–13	BBCH 14–16	BBCH 16–18	BBCH 20–30	BBCH 83–85
2019/20	3 September	10 September	16 September	27 September	18 October	18 March	27 July
2020/21	3 September	10 September	17 September	8 October	7 December	3 March	15 July
2021/22	9 September	14 September	21 September	6 October	17 December	7 April	18 July

Np-1–7 – number of plants counting terms, BBCH by Lancashire et al. (1991)

RESULTS AND DISCUSSION

Number of emerged plants. Figure 1A shows the dynamics of field emergence of winter rapeseed from seeds of the three weight classes averaged over three years (2019–2021). It is evident that the number of emerged plants increased with seed TSW. During the first plant counting (Np-1), the number of emerged plants per 1 m^2 increased weight class from 25.6 (low TSW), 30.2 (medium TSW), and 33.2 plants/1 m^2 (high TSW). The number of emerged plants from high seed weight differed significantly from low seed weight. The situation was similar in all counting terms (Np-1–4). At the end of emergence (Np-4), the different weight classes reached 28.8, 32.6 and 34.8 plants per 1 m^2, respectively. The number of emerging plants with seed TSW increased in individual years, but differences were not statistically significant in each experimental year (data not shown).

Our results correspond with Elliott et al. (2008), who studied the effect of rapeseed cultivars' seed weight (TSW 1.9 to 4.0 g) on number of plants, biomass, flea beetle damage and yield. They found that the number of seedlings per row increased under field conditions as seed size increased. Seedlings from tiny seeds had the poorest establishment compared to large seeds. Differences were consistent among cultivars but varied over the years. In contrast, Harker et al. (2015) used four weight classes with larger seeds (TSW 4.0 to 5.7 g), closer in weight to our material, but did not find a significant effect of seed size on rapeseed emergence over nine locations in western Canada.

The biostimulant (BS) treatment of seeds did not influence the number of emerged plants compared to the non-treated (NT) (Figure 1B). Differences between treated and non-treated variants were small but not statistically significant, neither on average nor in individual years.

In similar conditions to this experiment, seed treatment with biologically active substances – phytohormones, humic and fulvic acids – positively influenced germination, but in soya (Procházka et al. 2019). It could be that rapeseed germination does not respond as well to biostimulants. Stoltz and Wallenhammar (2019) also did not see a great impact on plant emergence in experiments with seed treatments of mineral nutrients in spring oilseed rape.

Growth parameters. Results show few significant differences in leaf and root parameters (Table 5). When years were combined, only root length (RL) was significantly influenced by weight class at sow-

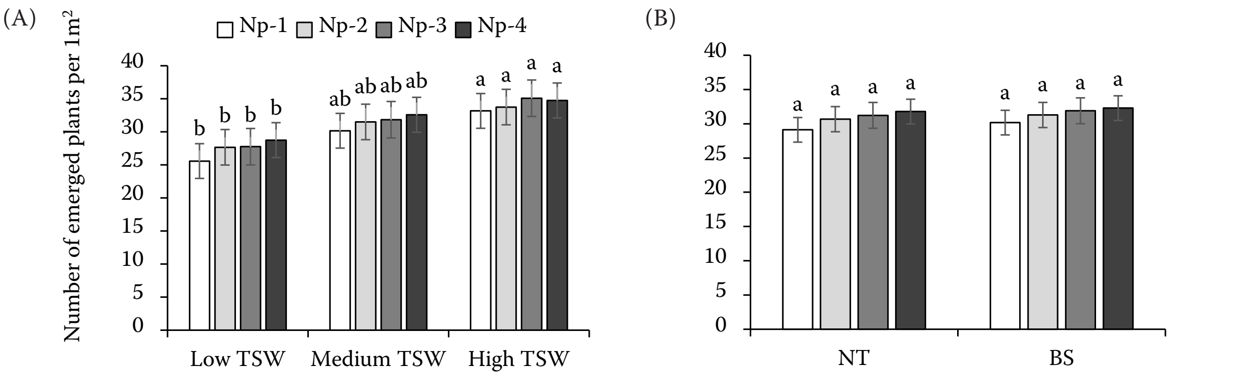

Figure 1. Number of emerged plants in four counting terms (Np-1, 2, 3, 4) in a three-year average (2019–2021), statistical significance ($HSD_{0.05}$) is counted for each term, (A) comparison of weight classes (thousand seed weight), and (B) comparison of seed treatment: NT – non treated; BS – treated with biostimulant

https://doi.org/10.17221/98/2024-PSE

Table 5. Growth parameters – leaves and root measurements, dry matter volume

Year	Variant	LN	LL	RNT	RL	LDM	RDM
2019/20	low TSW	7.3[a]	27.0[a]	10.7[a]	20.5[ab]	64.6[a]	21.3[a]
	medium TSW	7.0[a]	25.7[a]	9.3[b]	20.0[b]	52.7[a]	18.5[a]
	high TSW	7.1[a]	27.0[a]	10.2[a]	21.7[a]	61.1[a]	21.0[a]
	P-value	0.2645	0.2330	0.0015**	0.0082**	0.3500	0.1497
	$HSD_{0.05}$	0.51	2.07	0.95	1.34	20.98	3.79
	NT	7.0[a]	26.1[a]	9.9[a]	20.0[b]	57.1[a]	19.3[a]
	BS	7.3[a]	27.1[a]	10.3[a]	21.5[a]	61.8[a]	21.2[a]
	P-value	0.1834	0.1699	0.1977	0.0009**	0.4979	0.1341
	$HSD_{0.05}$	0.34	1.41	0.65	0.91	14.10	2.54
2020/21	low TSW	7.8[b]	32.6[a]	9.6[b]	20.5[a]	57.9[a]	11.3[b]
	medium TSW	9.0[a]	32.9[a]	10.7[a]	21.2[a]	74.8[a]	14.6[a]
	high TSW	8.2[ab]	33.5[a]	10.0[ab]	21.3[a]	63.8[a]	12.7[ab]
	P-value	0.0416*	0.5341	0.0330*	0.3982	0.0560	0.0321*
	$HSD_{0.05}$	1.07	2.01	0.94	1.51	16.75	2.95
	NT	8.6[a]	33.1[a]	10.2[a]	21.2[a]	67.8[a]	13.2[a]
	BS	8.0[a]	32.9[a]	10.0[a]	20.7[a]	63.1[a]	12.6[a]
	P-value	0.1001	0.7643	0.6830	0.3007	0.3902	0.5334
	$HSD_{0.05}$	0.73	1.37	0.64	1.03	11.25	1.98
2021/22	low TSW	7.2[a]	20.6[b]	6.5[a]	19.6[b]	44.0[a]	8.7[a]
	medium TSW	7.3[a]	22.3[a]	6.9[a]	20.5[ab]	51.6[a]	9.9[a]
	high TSW	7.1[a]	21.6[ab]	6.5[a]	20.9[a]	47.4[a]	9.7[a]
	P-value	0.7125	0.0085**	0.2369	0.0448*	0.4415	0.5239
	$HSD_{0.05}$	0.44	1.29	0.61	1.31	14.79	2.65
	NT	7.1[a]	21.2[a]	6.5[a]	19.9[b]	45.7[a]	9.1[a]
	BS	7.2[a]	21.8[a]	6.7[a]	20.8[a]	49.6[a]	9.7[a]
	P-value	0.5454	0.1329	0.2879	0.0389*	0.4118	0.4698
	$HSD_{0.05}$	0.30	0.88	0.42	0.89	9.93	1.78
3-year average	low TSW	7.4[a]	26.7[a]	8.9[a]	20.2[b]	55.5[a]	13.8[a]
	medium TSW	7.7[a]	27.0[a]	8.9[a]	20.6[ab]	59.7[a]	14.3[a]
	high TSW	7.5[a]	27.4[a]	8.9[a]	21.3[a]	57.4[a]	14.5[a]
	P-value	0.2141	0.3606	0.9792	0.0038**	0.5924	0.6177
	$HSD_{0.05}$	0.42	1.05	0.49	0.80	9.76	1.81
	NT	7.6[a]	26.8[a]	8.8[a]	20.4[b]	56.9[a]	13.9[a]
	BS	7.5[a]	27.3[a]	9.0[a]	21.0[a]	58.2[a]	14.5[a]
	P-value	0.5169	0.1847	0.3122	0.0198*	0.6962	0.3017
	$HSD_{0.05}$	0.29	0.71	0.33	0.55	6.63	1.23
	2019/20	7.1[b]	26.6[b]	10.1[a]	20.8[a]	59.4[a]	20.2[a]
	2020/21	8.3[a]	33.0[a]	10.1[a]	21.0[a]	65.5[a]	12.9[b]
	2021/22	7.2[b]	21.5[c]	6.6[b]	20.3[a]	47.7[b]	9.4[c]
	P-value	0.0000**	0.0000**	0.0000**	0.1576	0.0002**	0.0000**
	$HSD_{0.05}$	0.42	1.05	0.49	0.80	9.76	1.81

LN – number of leaves (pieces); LL – leaf length (cm); RNT – root neck thickness (mm); RL – root length (cm); $n = 40$; LDM – leaf dry mass from 10 plants (g); RDM – root dry mass from 10 roots (g); $n = 4$, ANOVA (Tukey's test *HSD* (honestly significant difference)) differences between the mean values are significant (*$P < 0.05$) in case they have a different letter. TSW – thousand seeds weight; NT – non-treated; BS – biostimulant

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Table 6. Final number of plants, yield, oil content and thousand seeds weight (TSW) of harvested seeds

Year	Variant	Np-5	Np-6	Np-7	Y	OC	TSW
	low TSW	39.5^{a}	34.8^{a}	29.8^{a}	6.53^{a}	46.31^{a}	4.335^{b}
	medium TSW	45.8^{a}	42.3^{a}	34.5^{a}	6.66^{a}	46.53^{a}	4.464^{ab}
	high TSW	42.3^{a}	38.3^{a}	35.3^{a}	6.93^{a}	46.99^{a}	4.550^{a}
	P-value	0.4094	0.1974	0.2749	0.1726	0.0683	0.0486*
2019/20	$HSD_{0.05}$	11.27	9.93	8.88	0.529	0.714	0.2065
	NT	42.2^{a}	38.2^{a}	33.7^{a}	6.62^{a}	46.56^{a}	4.486^{a}
	BS	42.8^{a}	38.7^{a}	32.7^{a}	6.79^{a}	46.66^{a}	4.413^{a}
	P-value	0.8611	0.8816	0.7392	0.3131	0.6927	0.2803
	$HSD_{0.05}$	7.64	6.73	6.02	0.355	0.479	0.1387
	low TSW	21.3^{b}	20.3^{b}	20.0^{b}	4.43^{a}	44.57^{a}	4.223^{a}
	medium TSW	27.4^{ab}	24.5^{ab}	24.0^{ab}	4.86^{a}	44.33^{a}	4.191^{a}
	high TSW	31.1^{a}	28.8^{a}	28.5^{a}	4.84^{a}	45.11^{a}	4.214^{a}
	P-value	0.0020**	0.0108*	0.0120*	0.0599	0.2499	0.9688
2020/21	$HSD_{0.05}$	6.34	6.55	6.59	0.489	1.177	0.3369
	NT	26.8^{a}	24.2^{a}	23.8^{a}	4.57^{a}	44.52^{a}	4.167^{a}
	BS	26.3^{a}	24.8^{a}	24.5^{a}	4.85^{a}	44.82^{a}	4.251^{a}
	P-value	0.8307	0.7777	0.7647	0.0991	0.4308	0.4435
	$HSD_{0.05}$	4.30	4.44	4.47	0.329	0.791	0.2263
	low TSW	20.3^{a}	20.3^{a}	19.3^{a}	5.51^{a}	44.93^{a}	4.457^{a}
	medium TSW	22.0^{a}	21.8^{a}	21.5^{a}	6.05^{a}	44.89^{a}	4.425^{a}
	high TSW	24.8^{a}	25.0^{a}	24.8^{a}	6.05^{a}	45.20^{a}	4.545^{a}
	P-value	0.1391	0.1457	0.0525	0.0690	0.2700	0.5568
2021/22	$HSD_{0.05}$	5.42	5.87	5.34	0.643	0.519	0.2872
	NT	22.0^{a}	21.8^{a}	21.5^{a}	5.78^{a}	45.04^{a}	4.470^{a}
	BS	22.7^{a}	22.8^{a}	22.2^{a}	5.96^{a}	44.97^{a}	4.482^{a}
	P-value	0.7162	0.6151	0.7122	0.4078	0.6535	0.8968
	$HSD_{0.05}$	3.68	3.98	3.62	0.432	0.390	0.1930
	low TSW	27.0^{b}	25.1^{b}	23.0^{b}	5.49^{b}	45.27^{b}	4.338^{a}
	medium TSW	31.7^{a}	29.5^{a}	26.7^{ab}	5.86^{a}	45.25^{b}	4.360^{a}
	high TSW	32.7^{a}	30.7^{a}	29.5^{a}	5.94^{a}	45.77^{a}	4.436^{a}
	P-value	0.0107*	0.0072	0.0008**	0.0010*	0.0102*	0.2711
	$HSD_{0.05}$	4.69	4.36	3.96	0.294	0.450	0.1520
	NT	30.3^{a}	28.1^{a}	26.3^{a}	5.66^{b}	45.38^{a}	4.374^{a}
3-year average	BS	30.6^{a}	28.8^{a}	26.4^{a}	5.86^{a}	45.48^{a}	4.382^{a}
	P-value	0.8574	0.6387	0.9354	0.0426*	0.4885	0.8824
	$HSD_{0.05}$	3.20	2.98	2.71	0.200	0.305	0.1033
	2019/20	42.5^{a}	38.4^{a}	33.2^{a}	6.70^{a}	46.61^{a}	4.450^{a}
	2020/21	26.6^{b}	24.5^{b}	24.2^{b}	4.71^{c}	44.67^{b}	4.209^{b}
	2021/22	22.3^{b}	22.3^{b}	21.8^{b}	5.87^{b}	45.01^{b}	4.476^{a}
	P-value	0.0000**	0.0000**	0.0000**	0.0000**	0.0000**	0.0001**
	$HSD_{0.05}$	4.69	4.36	3.96	0.294	0.450	0.1520

Np – number of plants: Np-5 – before winter; Np-6 – after overwintering; Np-7 – at the end of vegetation (pieces/m^2), *n* = 8; Y – seeds yield (t/ha); OC – oil content (%); TSW – weight of one thousand seeds (g); *n* = 4, ANOVA (Tukey's test *HSD* (honestly significant difference)) differences between the mean values are significant (*P < 0.05) in case they have a different letter. NT – non-treated; BS – biostimulant

https://doi.org/10.17221/98/2024-PSE

ing. Plants from seeds with high TSW had 1.1 cm longer roots than plants from seeds with low TSW.

Based on previous research, significant improvement to early shoot and above-ground growth related to seed size could have been expected; however, these results significantly increased root parameters (Table 5). Many authors have confirmed seed size's positive effect on rapeseed's early biomass. According to Hwang et al. (2014), sowing large seeds resulted in greater plant height and shoot weight than sowing smaller seeds under greenhouse conditions. Under field conditions, Elliott et al. (2008) found that seedlings from small seeds of four rapeseed cultivars had the lowest shoot weight and biomass, while seedlings from large seeds were more vigorous with improved shoot weight and biomass by 1.6–2 and 3–3.5 times, respectively. Greater early biomass of rapeseed linked to larger seed has also been demonstrated more recently (Harker et al. 2015).

A biostimulant was included, which showed a positive effect on root length (RL), which was statistically significant in the first and third years of the experiment (Table 5). On a three-year average, root length increased by 0.6 cm with biostimulant treatment.

Previous experiments with the auxin stimulator M-Sunagreen seed treatment also showed a positive effect on root length, as well as root weight, and better overwintering of oilseed rape (Bečka et al. 2013).

Final number of plants. Table 6 shows crop stand as plants per m^2 before winter (Np-5), after overwintering (Np-6) and at the end of vegetation (Np-7). Of the individual years, statistically significant differences were found only in the second year of the experiment individually, but with greater statistical strength of all years, the effect can also be seen in the 3-year average. Greater seed TSW resulted in greater crop stand before and after winter in 2020/2021. In the 3-year average, high TSW had higher plant stand than the low TSW in each counting period (Table 6), although medium and high TSW were not statistically different from each other.

Seed treatment with the biostimulant did not influence the final number of plants in any counting period compared with the non-treated in any experimental year.

Biostimulation has been observed to increase plant stand in oilseed rape (Sikorska et al. 2018) and in soya (Procházka et al. 2015); however, this research cannot confirm the benefit of this biostimulant in oilseed rape for plant stand throughout this experiment.

Yield and quality parameters. The seed weight class at sowing had a positive effect on yield (Y) and oil content (OC) when all years were included (Table 6). Average seed yield increased with seed TSW from 5.49 t/ha (low TSW) to 5.86 t/ha (medium TSW) and 5.94 t/ha (high TSW). Medium and high TSW of sown seed had significantly higher yields than the low TSW. Although plants from medium and high-weight classes achieved higher seed yields than plants from low-weight seeds when years were combined, the differences in individual years were not statistically significant. The situation was similar for oil content. Higher oil content was found from plots sown with high TSW seed than low and medium TSW in all experimental years, but differences were only statistically significant in the three-year average. Sowing with high TSW resulted in statistically significantly higher oil content than medium and low TSW (45.77, 45.25 and 45.27%, respectively; Table 6). Interestingly, though, there was no statistically significant effect of the initial weight class of the sown seed on the final TSW of harvested seeds when all years were considered. A statistically significant effect was only found in the first experimental year (Table 6).

In other research, rapeseed yields improved by 24% with medium-sized seeds (average TSW 2.7 g) and by 52% with large seeds (average TSW 3.6 g) compared to small seeds (average TSW 2.0 g) (Elliott et al. 2008). However, Harker et al. (2015) found no significant effect of sowing seed size (TSW 4.0 to 5.7 g) on rapeseed yield. Literature has not shown any effect of sowing seed size on final oil concentration (Lamb and Johnson 2004, Harker et al. 2015). In contrast to these results, both Elliott et al. (2008) and Harker et al. (2015) found a positive effect of seed size on the final TSW of harvested seeds.

Seed treatment with the biostimulant Lumibio Kelta had a positive effect on seed yield when combined over the years. However, the effect was not statistically significant in any year individually (Table 6). Plots with the treated seed reached 0.2 t/ha higher yield than non-treated variants on a three-year average. Biostimulant treatment had no statistically significant effects on oil content or final TSW of harvested seeds (Table 6).

There are a variety of products considered to be biostimulants marketed to improve crop growth and yield. Not all work the same, and evaluating each individually for suitability to the crop and environment is important. Gugala et al. (2019) observed

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a significant effect of biostimulation on TSW and seed yield of three winter oilseed rape cultivars, with the strongest effect after the application of the Asahi SL stimulator. Shah et al. (2017) also found a positive effect of phosphite-based biostimulants on the yield of winter oilseed rape. Amino acid-based biostimulants have tended to improve yields of winter oilseed rape, but the effects were not always significant. Seeds treated with mineral nutrients have also been evaluated in spring oilseed rape without any significant differences in yield compared to the control (Stoltz and Wallenhammar 2019). As stated by many authors, the effectiveness of biostimulators depends on the environmental conditions, and their beneficial effect is particularly evident under biotic and abiotic stresses (Shekhar Sharma et al. 2014, Shah et al. 2017, Van Oosten et al. 2017).

In conclusion, we can state that use of high TSW seed increased initial field emergence and final plant stand, improved root establishment, increased seed yield and oil content of winter oilseed rape. Seed treatment with the biostimulant Lumibio Kelta improved root establishment and increased seed yield, but not all growth parameters or seed quality.

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Received: March 4, 2024
Accepted: March 25, 2024
Published online: April 17, 2024