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ORIGINAL RESEARCH

Vegetative reproduction and yield of bear garlic (*Allium ursinum* L.) in field cultivation

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Abstract

Bear garlic (*Allium ursinum* L.) and its value for human health have been known for centuries. Its leaves, flowers, and bulbs contain many health-promoting compounds, and can be essential raw materials for the production of food and dietary supplements of natural origin. The purpose of the study was to evaluate the possibility of growing bear garlic in field conditions that differed significantly from those required by this plant, using unconventional treatments: catch crops (phacelia), shade plant (turnip rape), and biopreparations (Bio-Algeen S90 and Kelpak SL). The plowing of phacelia biomass had a beneficial effect on the number of *A. ursinum* progeny bulbs, the unit weight of bulbs and their yield per unit area, and the leaf yield not only in the first year of cultivation but also in the follow-up. Winter turnip rape applied as a shade crop caused a slight increase in the unit weight of bulbs and their yield in the first and second years of cultivation and in the number of progeny bulbs in the second and third years of cultivation. The cultivation of *A. ursinum* with turnip rape increased the percentage of garlic root weight and leaf yield. There was a positive effect of the applied biopreparations on the studied traits of *A. ursinum* bulb yield and leaf yield and on the formation of progeny bulbs in relation to the control object. The analysis of the interaction of the factors of the experiment showed that the combination with the application of the phacelia catch crop and the simultaneous cultivation of the shade crop had the most favorable effect on *A. ursinum* progeny bulb formation, bulb unit weight, root system development, and leaf yield. In all years of the study, the worst effect was obtained in the control object, i.e., in the cultivation without the catch crop, rapeseed, and application of biopreparations.

Keywords

catch crops; ramson; seaweed; shading plant; stressful conditions

1. Introduction

Bear garlic (*Allium ursinum* L.) and its value for human health have been known for centuries. Its flavorful qualities were used already in ancient times. Garlic herb and its bulbs have widely been used in folk medicine in many countries. It has antibacterial, antifungal, and anthelmintic properties. Its anti-inflammatory effects are appreciated, and its effectiveness in preventing atherosclerosis and cancer is mentioned as well. Its leaves, flowers, and bulbs contain many health-promoting compounds, such as phenolic compounds. *Allium ursinum* is classified as a functional food. All parts of this plant are edible (Chybowski, 1997; Teklić et al., 2021; Voća et al., 2021). The leaves and bulbs are a valuable source of various metabolites with high antioxidant potential and can be essential raw material for the production of food and dietary supplements of natural origin (Gordanić et al., 2022; Krivokapić et al., 2021; Najgebauer-Lejko et al., 2022; Todorović et al., 2023; Voća et al., 2021). Bear garlic is characterized by a unique flavor and aroma, just like common garlic (*Allium sativum* L.). It can be used as a spice and as an ingredient in many traditional dishes (Sobolewska et al., 2015; Todorović et al., 2023; Znamirowska et al., 2018). For several years, there has been a significant increase in the interest in the cultivation of bear garlic, not only in amateur cultivation but also on a broader scale (Sobolewska, 2018). The narrow range of ecological tolerance of *A. ursinum* greatly hinders its cultivation (Hæggström et al., 2016; Rola, 2012). It is, therefore, essential to conduct research to develop cultivation technologies for this species in field conditions.

Allium ursinum is a bulbous plant and a typical spring geophyte. It can be found in beech and oak-hornbeam forests. It grows best under tree crowns, in semi-shaded areas, with stable soil water supply, especially in spring (Djurdjevic et al., 2004; Fijałkowski & Chojnacka-Fijałkowska, 2009; Hiyasat et al., 2009; Oborny et al., 2011; Sobolewska et al., 2015). Its vegetation is closely related to the rhythm of deciduous forest life. *A. ursinum* leaves emerge approximately 60 days before tree leaves (Hiyasat et al., 2009). As reported by Sobolewska et al. (2015), in natural conditions, *A. ursinum* reproduces mainly generatively, forming dense patches and producing numerous seeds. However, as points out by Eggert (1992), most seeds remain dormant for several years; hence, vegetative reproduction is essential. In a study conducted by Rychnovská and Bednář (1998), *A. ursinum* inflorescences produced an average of 2,692 seeds per 1 m^2, and seedling emergence was estimated at 250 to 300 $pcs \cdot m^{-2}$. The plant reaches reproductive maturity only in the 4th–5th year of vegetation. Generative reproduction is the primary means of spreading bear garlic populations in the wild, but the survival rate of seedlings from emergence to the fourth year of life does not exceed 10% (Bierzychudek, 1982; Eggert, 1992).

A. ursinum bulbs are elongated and surrounded by translucent, delicate skin. In the third year of vegetation, an abundant root system develops. The roots shrink in autumn, embedding the bulb deep into the soil. The basis of vegetative reproduction is the resulting progeny bulbs (Eggert, 1992; Ernst, 1979; Oborny et al., 2011). In early spring, 2–3 long-tailed stubby leaves emerge from the bulb, with an egg-shaped, lanceolate, smooth blade 20–65 mm wide (Błażewicz-Woźniak, 2023; Błażewicz-Woźniak & Michowska, 2011). In Polish conditions, bear garlic most often begins growth in February/March and ends vegetation in June after flowering and releasing seeds. In a field study carried out by Błażewicz-Woźniak et al. (2011) in 2007–2009, the first leaves of garlic were recorded in March, and the beginning of flowering was recorded between April 17 and May 5, depending on the year. In June, the leaves dried out. Environmental factors play an essential role in the variability of morphological traits as well as the health properties of *A. ursinum* (Todorović et al., 2023). Golubkina et al. (2012) reported that sunshine caused a significant increase in the content of ascorbic acid, selenium, and flavonoids in bear garlic leaves. Amagova et al. (2022) compared the results obtained in the field cultivation of garlic with the results of the growth of this plant in the forest (natural habitat) and showed a significantly higher level of antioxidant status in the case of the environmental stress, i.e., the field conditions.

The following climate changes and increasingly frequent droughts are prompting a search for ways to support crops grown in unfavorable conditions (Mystkowska, 2018). Biostimulants offer an environmentally friendly way to meet the growing demand for food and are an excellent alternative to chemicals (Kulkarni et al., 2021). Many researchers emphasize the vital role of seaweed biopreparations in counteracting the effects of plant stressors, such as excessive sunlight, high temperature, drought, and salinity (Bulgari et al., 2019; Hassan et al., 2021; Sharma et al., 2014; Stirk et al., 2020; Truba et al., 2012). Seaweed concentrates can overcome nutritional stress in crop plants (Papenfus et al., 2013). Of these, the greatest biostimulatory properties are attributed to brown seaweeds (Kisvarga et al., 2022). These include *Ecklonia maxima*, the extract of which is used as the preparation Kelpak SL characterized by a high concentration of auxins (11 mg dm^{-3}) and cytokinins (0.031 mg dm^{-3}). On the other hand, the formulation Bio-Algeen S90 is produced from *Ascophyllum nodosum*. It is qualified for organic farming in Poland. It contains 90 groups of organic compounds (including numerous vitamins, alginic acid, and amino acids) (Khan et al., 2009; Mikiciuk & Dobromilska, 2014). The effectiveness of application of algae in crop cultivation depends not only on the species but also on the dose used and the number, frequency, and methods of carrying out the treatments (Bulgari et al., 2019; Matysiak et al., 2012; Mitura et al., 2014; Parađiković et al., 2019; Sharma et al., 2014).

Harvesting garlic from natural sites in Poland is limited by the fact that it has been under partial species protection since 2004 (Journal of Laws of 2004, No. 168, item 1,764). Studies undertaken to date on bear garlic cultivation in Poland have mainly used shade and irrigation, which significantly increases cultivation costs (Błażewicz-Woźniak et al., 2011; Kęsik et al., 2011). The purpose of the study was to evaluate the possibility of growing bear garlic in field conditions that differed significantly from those required by this plant, using unconventional treatments (phacelia intercrop, shade crop – rapeseed, biopreparations: Bio-Algeen S90 and Kelpak SL). This study is part of broader research, some of the results of which have already been published (Błażewicz-Woźniak, 2023), while the subject of this paper is to evaluate the effect of selected agrotechnical treatments on the yield and reproductive capacity of bear garlic grown in the field.

2. Material and methods

The field experiment was carried out in 2017–2020 at the Felin Experimental Farm of the University of Life Sciences in Lublin (Poland, 22°56′E, 51°23′N) on a grey loam soil made of medium silty clay (AP) (BN-178/9180-11). Before the establishment of the experiment, an average of 1.04–1.11% humus was determined in the 0–20 cm layer of the soil, and the content of macronutrients (in mg per dm^{-3} of soil) was N – 69, P – 27, K – 84, Ca – 563.5, and Mg – 66. The soil pH was in the range of 5.96–6.12 pH in KCl. After pre-sowing tillage, phacelia (intercrop) was sown in half of the field on June 23, 2017. The phacelia biomass, after crushing, was mixed with the soil on September 4, providing cultivation conditions for planting garlic bulbs. Phosphorus (superphosphate) and potassium (K_2SO_4) fertilization were applied in autumn, while nitrogen in the form of ammonium nitrate was applied in spring. Soil nutrients were brought to a level of N:P:K 120:70:200 mg dm^{-3} (Kęsik et al., 2011).

The experiment was established in 3 replicates using the completely randomized block method. The repetition consisted of 15 plants growing in a plot. *A. ursinum* bulbs were obtained from field experiments authorized by the Regional Directorate for Environmental Protection (Journal of Laws of 2012, item 81, as amended). Bulbs weighing 3.4 to 4.6 g were planted into the ground on 13.09.2017 at a depth of 10 cm, at a spacing of 30 × 30 cm. The entire soil surface was covered with a layer of pine bark in accordance with the results reported in Błażewicz-Woźniak et al. (2011, 2019). The course of weather at the time of planting the bulbs was favorable. The average decadal temperature in September 2017 was 14.0 °C, and the total precipitation was 77 mm. The factors of the experiment were intercrop (*Phacelia tanacetifolia* Benth.), shade crop (winter turnip rape *Brassica campestris* ssp. *oleifera* f. *biennis*), and biopreparations: Bio-Algeen S90 and Kelpak SL. The control was an untreated site. Bio-Algeen S90 was applied in the form of a spray at a rate of 2 l ha^{-1}, while Kelpak SL was applied in the form of a spray (first at a rate of 3 l ha^{-1} and next at a rate of 2 l ha^{-1}) and soaking before planting at a concentration of 0.3% for 5 minutes + spraying. Spraying was performed three times every seven days after garlic produced two leaves. Weeds were removed by hand, and no pesticides were applied. In the following three years of the study, the weight and number of bulbs produced from one bulb planted in 2017 were determined, as well as the weight of a single bulb, the weight of roots and their proportion, and the yield of leaves of *A. ursinum*. Garlic leaves were harvested before flowering (April 25 and May 8, 2018; April 19 and May 8, 2019; April 7 and May 7, 2020). The results obtained were statistically processed using analysis of variance (ANOVA) with a significance level of p = 0.05 determined by Tukey's test. Air temperatures and rainfall during garlic vegetation in 2018–2020 are included in Table 1.

3. Results

3.1. Number of progeny bulbs

The number of *A. ursinum* progeny bulbs increased significantly in the successive years of cultivation (Table 2). From one bulb, the bear garlic planted in autumn 2017 yielded, on average 1.34, 2.84, and 9.06 bulbs in the following years, respectively, regardless of

Table 1 Mean air temperatures and amount of precipitation during the experiment in years 2018–2020 in ES Felin.

	Year	**Month and decade**															
		III				**IV**				**V**				**VI**			
		1	**2**	**3**	**Monthly**	**1**	**2**	**3**	**Monthly**	**1**	**2**	**3**	**Monthly**	**1**	**2**	**3**	**Monthly**
Average decade temperature (°C)	2018	−4.2	0.7	1.5	−0.6	10.6	14.5	15.0	13.4	16.8	14.4	18.8	17.1	19.4	20.4	16.5	18.8
	2019	4.7	4.2	6.2	5.1	7.8	7.1	13.5	9.5	9.8	13.8	16.2	13.4	20.3	23.4	20.7	21.5
	2020	4.5	6.1	2.0	4.2	7.8	7.6	10.1	8.8	11.7	11.4	12.0	11.7	21.4	24.6	23.3	23.1
Mean monthly for 1951–2005					1.1				7.4				13.0				16.2
Amount of precipitation (mm)	2018	4.1	8.9	6.5	19.5	34.1	5.3	9.1	48.5	0.0	56.0	0.1	56.1	4.3	14.2	46.4	64.9
	2019	10.6	10.9	2.7	24.2	0.6	6.1	42.0	48.7	0.3	72.2	20.0	92.5	3.8	5.2	28.1	37.1
	2020	10.7	6.7	0.7	18.1	0.0	0.4	25.3	25.7	21.0	5.7	77.6	104.3	37.0	41.4	89.7	168.1
Mean monthly for 1951–2005					26.3				40.2				57.7				65.7

Table 2 Reproductive capacity of *Allium ursinum* bulbs depending on experience factors in years 2018–2020.

Experimental factors		Number of *A. ursinum* bulbs			
		Year			Mean
		2018	2019	2020	
Catch crop (A)	Without (A1)	1.39 ± 0.15	2.57 ± 0.39a	8.52 ± 0.87	4.16 ± 0.74
	Phacelia (A2)	1.28 ± 0.07	3.12 ± 0.31b	9.59 ± 0.51	4.66 ± 0.41
Shade plant (B)	Without (B1)	1.36 ± 0.04	2.73 ± 0.38	8.35 ± 1.38	4.15 ± 0.52
	Turnip rape (B2)	1.32 ± 0.17	2.96 ± 0.29	9.76 ± 1.21	4.68 ± 0.47
Biopreparats (C)	Without	1.31 ± 0.01	3.14 ± 0.08	9.28 ± 0.98	4.58 ± 0.65
	Bioalgeen	1.23 ± 0.08	2.91 ± 0.46	8.87 ± 1.58	4.34 ± 0.73
	Kelpak	1.27 ± 0.08	2.56 ± 0.13	8.13 ± 0.36	3.99 ± 0.27
	Kelpak 2x	1.55 ± 0.13	2.77 ± 0.25	9.95 ± 0.70	4.76 ± 0.44
Interaction	A1 × B1	1.45 ± 0.07	2.42 ± 0.67	7.93 ± 2.03b	3.93 ± 0.75b
	A1 × B2	1.34 ± 0.27	2.72 ± 0.38	9.12 ± 1.80a	4.39 ± 0.62ab
	A2 × B1	1.27 ± 0.06	3.04 ± 0.29	8.78 ± 1.05ab	4.36 ± 0.39ab
	A2 × B2	1.30 ± 0.10	3.20 ± 0.33	10.40 ± 0.90a	4.97 ± 0.37a
Control		1.34 ± 0.49	2.67 ± 0.56	5.91 ± 1.26	3.31 ± 0.75
$\bar{x}$		1.34 ± 0.11A	2.84 ± 0.31B	9.06 ± 01.13C	4.41 ± 0.25
$\bar{x}$ without control		1.35 ± 0.14	2.85 ± 0.39	9.27 ± 1.17	4.49 ± 0.26

Means marked with the same small letters within the same column between the same factors are not significantly different ($p < 0.05$). Along each line, values with the same capital letters are not significantly different ($p < 0.05$).

the factors of the experiment. The plowing of phacelia biomass had a positive effect on the number of garlic progeny bulbs in the second year of cultivation, and this trend was also discernible in the third year. The winter turnip rape applied as a shade crop slightly increased the number of *A. ursinum* progeny bulbs compared to the crop without turnip rape. This trend was recorded in 2019 and 2020. The applied biopreparations did not significantly increase the number of bulbs although, in the first and third years of cultivation, slightly more bulbs were harvested after applying Kelpak as a spray with soaking of the bulbs before planting. The analysis of the interaction of the factors of the experiment showed that the combination with the application of the phacelia catch crop and the simultaneous cultivation of the shade crop had the most favorable effect on the formation of *A. ursinum* progeny bulbs. The greatest numbers of miniature bulbs were produced by garlic in the combination without the catch crop and turnip rape. In all years of the study, the lowest number of progeny bulbs was obtained in the control object, i.e., in the cultivation without the catch crop, rapeseed, and application of biopreparations.

3.2. Weight of a single bulb

The unit weight of *A. ursinum* bulbs averaged 4.72 g over the years of the study (Table 3). The highest weight was recorded in 2019, and the lowest in the first year of cultivation. The plowing of phacelia biomass had a positive effect on the unit weight of *A. ursinum* bulbs. Statistically significant differences were noted in the first year of cultivation, and this trend was also evident in the subsequent years. The turnip rape applied as a shade crop increased the bulb weight compared to the cultivation without the turnip rape in 2018 and 2019, although these differences were not statistically confirmed. Among the applied biopreparations, the Kelpak spray proved beneficial for the unit weight of bulbs. Garlic bulbs grown in this combination had a significantly higher average weight than those grown without the biopreparations. In 2018 and 2020, a slightly higher unit weight of *A. ursinum* bulbs was recorded after the application of the Bioalgeen spray, but the differences were not significant compared to the other combinations. The analysis of the interaction of factors revealed that the weight of *A. ursinum* bulbs was most favorably affected by the combination with the application of the phacelia catch crop and the simultaneous cultivation of the shade crop or without the turnip rape. The most negligible average bulb weight was produced by

Table 3 Influence of experimental factors on the weight of 1 garlic bulb without roots 2018–2020.

Experimental factors		Weight of 1 garlic bulb without roots (g) Year 2018	2019	2020	Mean
Catch crop (A)	Without (A1)	3.91 ± 0.54a	4.95 ± 0.26	4.08 ± 0.26	4.31 ± 0.47a
	Phacelia (A2)	4.61 ± 0.69b	5.69 ± 0.29	5.05 ± 0.33	5.12 ± 0.48b
Shade plant (B)	Without (B1)	4.11 ± 0.37	5.01 ± 0.41	4.91 ± 0.18	4.67 ± 0.20
	Turnip rape (B2)	4.41 ± 0.83	5.64 ± 0.35	4.22 ± 0.38	4.76 ± 0.22
Biopreparats (C)	Without	3.92 ± 0.05a	5.44 ± 0.24	4.23 ± 0.25	4.53 ± 0.33a
	Bioalgeen	4.65 ± 0.33ab	4.80 ± 0.27	4.90 ± 0.44	4.79 ± 0.83ab
	Kelpak	5.06 ± 0.50b	5.75 ± 0.31	4.37 ± 0.68	5.06 ± 0.62b
	Kelpak 2x	3.41 ± 0.39a	5.30 ± 0.54	4.75 ± 0.28	4.49 ± 0.47a
Interaction A × B	A1 × B1	3.62 ± 0.21	4.46 ± 0.70	4.17 ± 0.39	4.08 ± 0.37b
	A1 × B2	4.20 ± 0.87	5.45 ± 0.29	4.00 ± 0.84	4.55 ± 0.46ab
	A2 × B1	4.60 ± 0.61	5.56 ± 0.52	5.65 ± 0.72	5.27 ± 0.34a
	A2 × B2	4.63 ± 0.78	5.82 ± 0.98	4.45 ± 0.63	4.97 ± 0.62a
Control		3.78 ± 1.33	4.31 ± 0.70	4.23 ± 1.24	4.11 ± 0.22
$\bar{x}$		4.26 ± 0.60A	5.32 ± 0.43B	4.56 ± 0.44AB	4.72 ± 0.21
$\bar{x}$ without control		4.37 ± 0.67	5.39 ± 0.50	4.68 ± 0.47	4.81 ± 0.19

Means marked with the same small letters within the same column between the same factors are not significantly different ($p < 0.05$). Along each line, values with the same capital letters are not significantly different ($p < 0.05$).

Table 4 Correlation coefficient for the tested yield and reproduction parameters of *Allium ursinum*.

Parameters	Number of bulbs	Weight of 1 bulb	% of roots weight	Yield of bulbs	Yield of leaves
Number of bulbs	×	−0.101	−0.808	0.926	0.981
Weight of 1 bulb	−0.101	×	−0.066	0.303	0.097
% of roots weight	−0.808	−0.066	×	−0.762	−0.833
Yield of bulbs	0.926	0.303	−0.762	×	0.933
Yield of leaves	0.981	0.097	−0.833	0.933	×

garlic in combination without the catch crop and rapeseed. However, these differences were not statistically confirmed. The unit weight of bulbs was negatively correlated with their number (Table 4).

3.3. Percentage of roots

The weight of roots produced by garlic bulbs accounted for an average of 27.89% of the bulb weight with roots (Table 5). The highest share of roots was recorded in the first year of cultivation (31.36%). In the second year, the share decreased slightly, while in the third year, it was significantly lower (23.80%). The plowing of phacelia biomass did not affect this trait. The turnip rape used as a shade crop significantly increased the proportion of roots compared to the crop without turnip rape, and this was statistically confirmed in 2018 and 2019. Of the biopreparations used, the Kelpak spray combined with bulb soaking proved beneficial for root development in 2018 and 2019 as well as the Bioalgeen spray in 2020, but these differences were not statistically confirmed. The analysis of the interaction of the factors of the experiment showed that the combination with the application of the phacelia catch crop and the simultaneous cultivation of the shade crop had the most favorable effect on the growth of *A. ursinum* roots, but turnip rape without the catch crop. However, these differences were not statistically confirmed. The lowest percentage of roots (19.83%) was recorded in 2019 in the control plot. The percentage of roots was negatively correlated with the number of progeny bulbs (Table 4).

Table 5 Influence of experimental factors on the percentage of *A. ursinum* root mass 2018–2020.

Experimental factors		Percentage of root mass (%)			
		Year			Mean
		2018	2019	2020	
Catch crop (A)	Without (A1)	31.39 ± 1.00	27.08 ± 1.98	25.35 ± 3.29	27.94 ± 2.06
	Phacelia (A2)	31.34 ± 1.89	29.94 ± 2.23	22.25 ± 0.59	27.84 ± 1.94
Shade plant (B)	Without (B1)	29.67 ± 0.86a	26.38 ± 1.23a	23.47 ± 1.87	26.51 ± 0.60a
	Turnip rape (B2)	33.06 ± 1.90b	30.64 ± 1.09b	24.13 ± 1.45	29.28 ± 0.87b
Biopreparats (C)	Without	30.85 ± 1.00	27.15 ± 3.02	23.07 ± 0.50	27.02 ± 1.44
	Bioalgeen	31.19 ± 1.49	28.89 ± 1.06	25.47 ± 2.76	28.52 ± 1.94
	Kelpak	30.14 ± 1.59	27.89 ± 0.92	24.84 ± 2.35	27.63 ± 1.76
	Kelpak 2x	33.27 ± 2.22	30.12 ± 3.48	21.83 ± 1.08	28.41 ± 2.85
Interaction A × B	A1 × B1	29.55 ± 0.61	24.78 ± 2.48	25.95 ± 3.52	26.76 ± 1.57
	A1 × B2	33.23 ± 2.54	29.38 ± 1.65	24.76 ± 4.02	29.13 ± 2.28
	A2 × B1	29.79 ± 1.47	27.98 ± 1.22	21.00 ± 1.08	26.26 ± 0.84
	A2 × B2	32.88 ± 2.49	31.90 ± 3.47	23.51 ± 1.12	29.43 ± 2.34
Control		30.62 ± 3.39	19.83 ± 2.51	25.44 ± 3.91	25.29 ± 3.65
$\bar{x}$		31.36 ± 1.70A	28.51 ± 2.12A	23.80 ± 2.04B	27.89 ± 0.57
$\bar{x}$ without control		31.53 ± 1.92	29.09 ± 1.87	24.05 ± 2.48	28.22 ± 0.37

Means marked with the same small letters within the same column between the same factors are not significantly different ($p < 0.05$). Along each line, values with the same capital letters are not significantly different ($p < 0.05$).

3.4. Yield of bulbs

The yield of *A. ursinum* bulbs from all years of the study averaged 110.02 g m^{-2} (Table 6). The yield increased significantly in the subsequent years of cultivation and was the highest in 2020 (194.33 g). The plowing of phacelia biomass had a positive effect on the yield of garlic bulbs. Statistically significant differences were recorded for the entire cultivation period, and this trend was noticeable in all study years. The turnip rape applied as a shade crop increased the bulb yield compared to the cultivation without turnip rape in all years of cultivation, although these differences were not statistically confirmed. Of the biopreparations used, the Kelpak spray combined with pre-soaking of the bulbs proved beneficial for the yield of *A. ursinum* bulbs. The analysis of the interaction of the factors of the experiment revealed that the most favorable effect on the yield of *A. ursinum* bulbs was observed in the combination with the application of the phacelia catch crop and the simultaneous cultivation of the shade crop or without turnip rape. The lowest bulb yield was obtained in the combination without the catch crop and rapeseed. However, these differences were not statistically confirmed. In all years of the study, the most negligible bulb yield was obtained in the control object, i.e., in the cultivation without the catch crop, turnip rape, and application of biopreparations. The yield of garlic bulbs was positively correlated with the number of progeny bulbs, unit bulb weight, and leaf yield and negatively correlated with root weight (Table 4).

3.5. Leaf yield

The leaf yield of *A. ursinum* from all years of the study averaged 140.93 g m^{-2} (Table 7). The yield increased significantly in the subsequent years of cultivation and was the highest in 2020 (278.26 g). The plowing of phacelia biomass had a positive effect on the yield of *A. ursinum* leaves, although there were statistically confirmed differences only in 2019. The turnip rape applied as a shade crop significantly increased the leaf yield of *A. ursinum* compared to the crop without turnip rape on average in the three years of the study. Of the biopreparations used, a slightly higher leaf yield of *A. ursinum* was harvested upon the use of the Kelpak spray combined with pre-wetting of bulbs, and the lowest without application of the biopreparation. The analysis of the interaction of the factors of the experiment showed no statistically significant

Table 6 Influence of experimental factors on the yield of *A. ursinum* bulbs 2018–2020.

Experimental factors		Yield of bulbs (g m^{-2}) Year 2018	2019	2020	Mean
Catch crop (A)	Without (A1)	32.56 ± 5.12	72.30 ± 7.51	146.33 ± 28.01	83.73 ± 10.58a
	Phacelia (A2)	37.04 ± 3.43	129.55 ± 28.47	242.33 ± 53.6	136.30 ± 27.84b
Shade plant (B)	Without (B1)	31.22 ± 1.01	95.41 ± 21.09	196.39 ± 58.05	107.67 ± 30.07
	Turnip rape (B2)	38.37 ± 5.64	106.44 ± 17.24	192.27 ± 15.51	112.36 ± 10.00
Biopreparats (C)	Without	31.75 ± 1.41	97.87 ± 29.45	184.80 ± 23.15	104.81 ± 17.86
	Bioalgeen	36.25 ± 4.45	95.15 ± 13.14	205.53 ± 15.29	112.31 ± 8.01
	Kelpak	37.99 ± 5.08	93.57 ± 13.76	127.35 ± 38.21	86.30 ± 17.81
	Kelpak 2x	33.21 ± 4.30	117.12 ± 24.70	259.64 ± 40.71	136.66 ± 21.72
Interaction A × B	A1 × B1	26.08 ± 3.02	60.78 ± 19.58b	142.13 ± 49.81	76.33 ± 22.11b
	A1 × B2	39.03 ± 5.40	83.82 ± 16.61b	150.53 ± 40.49	91.13 ± 29.45b
	A2 × B1	36.36 ± 2.53	130.05 ± 32.70a	250.65 ± 45.58	139.02 ± 38.61a
	A2 × B2	37.71 ± 6.15	129.06 ± 31.09a	234.00 ± 35.87	133.59 ± 38.33a
Control		26.30 ± 1.67	43.53 ± 8.53	152.35 ± 20.8	74.06 ± 20.12
$\bar{x}$		34.80 ± 2.32A	100.92 ± 24.46B	194.33 ± 38.26C	110.02 ± 20.70
$\bar{x}$ without control		35.36 ± 1.74	104.75 ± 23.78	197.13 ± 39.78	112.41 ± 30.33

Means marked with the same small letters within the same column between the same factors are not significantly different ($p < 0.05$). Along each line, values with the same capital letters are not significantly different ($p < 0.05$).

differences, although the application of the catch crop and the shade crop increased the leaf yield of *A. ursinum* compared to the crop without the catch crop and turnip rape. On average, during the three years, the lowest leaf yield was obtained in the control object, i.e., in the cultivation without the catch crop, rapeseed, and application of biopreparations. This trend was observed in 2018 and 2020. The leaf yield of *A. ursinum* was correlated positively with the number of progeny bulbs and bulb yield, slightly with the bulb unit weight, and negatively with the root weight (Table 4).

4. Discussion

4.1. Number of progeny bulbs

Bear garlic produces progeny bulbs. In this way, it can be propagated vegetatively. As reported by Ernst (1979), the most critical factors necessary for the reproduction of *A. ursinum* are light and phosphorus supply. In the experiment conducted, the number of progeny bulbs increased significantly in the successive years of cultivation. From one bulb of bear garlic planted in the autumn of 2017, on average 1.34, 2.84, and 9.06 bulbs were obtained regardless of the factors of the experiment in the subsequent years, respectively. As shown by Heinrichs et al. (2018), increasing the length of the growing season over time promotes the growth of juveniles and the formation of progeny bulbs of *A. ursinum*. The plowing of phacelia biomass had a beneficial effect on the number of garlic progeny bulbs in the second and third years of cultivation. Numerous studies have demonstrated the advantages of blue phacelia as a catch crop for improving soil fertility, structure, and nutrient abundance (Błażewicz-Woźniak & Konopiński, 2013; Błażewicz-Woźniak & Wach, 2012; Kęsik et al., 2002). The positive effect of intercrops on soil moisture and soil reserves, which persisted throughout the growing season, was noted by Konopiński et al. (2001). Although there was no statistically significant effect of the biopreparations on the number of *A. ursinum* progeny bulbs, slightly more bulbs were harvested in the first and third years of cultivation after applying Kelpak as a spray with soaking of the bulbs before planting. In potato cultivation, it is recommended that seed potatoes be soaked for 5 minutes in 0.2–0.4% Kelpak SL or sprayed during planting with 0.5% liquid (Mitura et al., 2014). In a study conducted by Mystkowska (2018), the biostimulants used in the experiment increased potato yields by an average of 1.6 t ha^{-1}.

Table 7 Influence of experimental factors on the yield of *A. ursinum* leaves in 2018–2020.

Experimental factors		Yield of leaves (g m^{-2}) Year 2018	2019	2020	Mean
Catch crop (A)	Without (A1)	34.94 ± 2.59	101.55 ± 7.01a	261.39 ± 43.77	132.63 ± 13.03
	Phacelia (A2)	33.04 ± 2.59	119.54 ± 8.22b	295.12 ± 25.60	149.23 ± 7.15
Shade plant (B)	Without (B1)	33.91 ± 0.69	110.37 ± 13.49	247.55a ± 38.92	130.61 ± 14.39a
	Turnip rape (B2)	34.08 ± 1.64	110.72 ± 11.07	308.96b ± 30.45	151.25 ± 5.94b
Biopreparats (C)	Without	34.94 ± 2.08	124.55 ± 5.88a	232.84 ± 30.45	130.78 ± 12.80
	Bioalgeen	33.91 ± 0.35	110.72 ± 7.96ab	254.30 ± 30.34	132.97 ± 12.92
	Kelpak	32.87 ± 0.69	96.88 ± 7.27b	292.36 ± 21.80	140.70 ± 9.46
	Kelpak 2x	34.25 ± 3.46	110.02 ± 13.15ab	333.53 ± 12.46	159.27 ± 2.19
Interaction A × B	A1 × B1	34.94 ± 4.67	103.11 ± 13.84b	206.55 ± 30.79	114.87 ± 13.15b
	A1 × B2	34.94 ± 1.04	99.99 ± 12.80b	316.23 ± 56.74	150.39 ± 14.53a
	A2 × B1	32.87 ± 3.29	117.63 ± 13.15a	288.55 ± 47.05	146.35 ± 15.63ab
	A2 × B2	33.22 ± 2.77	121.44 ± 9.34a	301.70 ± 4.84	152.12 ± 2.35a
Control		30.45 ± 1.56	112.10 ± 9.07	170.22 ± 36.12	104.26 ± 10.21
$\bar{x}$		33.99 ± 1.76A	110.54 ± 12.20B	278.26 ± 39.09C	140.93 ± 25.97
$\bar{x}$ without control		34.23 ± 1.61	110.44 ± 10.03	285.46 ± 33.68	143.38 ± 25.93

Means marked with the same small letters within the same column between the same factors are not significantly different ($p < 0.05$). Along each line, values with the same capital letters are not significantly different ($p < 0.05$).

4.2. Weight of a single bulb

The highest unit weight of *A. ursinum* bulbs was recorded in 2019, and the lowest in the first year of cultivation. As reported by Todorović et al. (2023), there is a positive correlation between bulb length and plant age. In a study conducted by Kęsik et al. (2011), the average weight of bear garlic bulbs after three years of cultivation ranged from 5.9 to 9.8 g. In the experiment conducted, the plowing of phacelia biomass and the use of rapeseed as a shade crop had a positive effect on the unit weight of *A. ursinum* bulbs, which can explain the advantages of phacelia as a catch crop. Of the biopreparations used, the Kelpak spray proved beneficial. Khan et al. (2009) believe that seaweed extracts improve nutrient uptake by roots. A result of better root system efficiency and nutrition is better plant growth. The negative correlation between the number and weight of bulbs can also explain this issue. In a study carried out by Aremu et al. (2015), phenolic compounds isolated from the seaweed *Ecklonia maxima* increased the size of *Eucomis autumnalis* bulbs. In the present experiment, a slightly higher unit weight of *A. ursinum* bulbs was recorded after the Bioalgeen spray application in 2018 and 2020. In a study conducted by Abbas et al. (2020), the application of *Ascophyllum nodosum* extract (SWE) significantly affected the bulb weight and yield of four bulb varieties. A maximum increase in the bulb weight of 5.8, 5.4, 2.4, and 2.0% was observed in Lambada, Red Bone, Phulkara, and Nasar puri cultivars, respectively, at the 0.5% concentration of the preparation (SWE). SWE at the 0.5 and 1% concentrations significantly increased bulb weight, 2% SWE had no effect, while 3% SWE caused a reduction in weight in the Lambada variety.

4.3. Percentage of roots

The weight of roots produced by the garlic bulbs accounted for an average of 27.89% of the bulb weight with roots. The roots contributed the most in the first year of cultivation and the least in the third year. As demonstrated by Eggert (1992), the development of contractile roots in *A. ursinum* occurs around the third year of vegetation, and their number is an essential indicator of the developmental stage. Of the biopreparations used, the Kelpak spray combined with bulb soaking proved beneficial for root development in 2018 and 2019 as well as the Bioalgeen spray in 2020. The negative correlation between the proportion of root mass and the number and unit weight of bulbs can explain this finding. In a study conducted by Szczepanek et al. (2017), the application of Kelpak SL at a dose of 2 + 2 + 2 dm^3 ha^{-1} had a positive effect on the length and weight of bulb roots. As suggested by Kurepin et al. (2014), the stimulation of root system growth by algal extracts is related to the action of phytohormones. In cultivation of okra (*Abelmoschus esculentus* (L.) Moench), Papenfus et al. (2013) found that seedlings treated with Kelpak® had longer shoots and produced more roots and fresh and dry matter (Papenfus et al., 2013). Khan et al. (2009) emphasize that the effect of *Ascophyllum nodosum* application on root development depends on the plant species and the concentration of the preparation. Abbas et al. (2020) reported a maximum increase in root weight of bulb in cultivars Nasar puri by 92.7%, 'Red Bone' by 73.4%, 'Phulkara' by 65.2%, and 'Lambada' by 16.6% at a concentration of 0.5% SWE compared to the control. At higher concentrations, the response of the bulb varieties varied.

4.4. Yield of bulbs

The yield of *A. ursinum* bulbs increased significantly in the successive crop years and was the highest in 2020. The plowing of phacelia biomass had a positive effect on the yield of garlic bulbs, which can be explained by the beneficial effect of the intercrop on soil moisture and structure (Błażewicz-Woźniak et al., 2022; Błażewicz-Woźniak & Konopiński, 2013). Based on the results of their study, Gordanić et al. (2022) found that *A. ursinum* grew best when grown on chernozem, although it is also possible to grow it on other soils. Of the biopreparations used, the Kelpak spray combined with pre-soaking of the bulbs proved beneficial for the yield of *A. ursinum* bulbs. Bulb losses should explain the lowest yield harvested in the combination with Kelpak spraying without soaking. In a study conducted by Szczepanek et al. (2017), the application of Kelpak SL seaweed extract had a beneficial effect on bulb growth. The most significant increase in the yield of fresh weight of bulbs and fresh weight of roots occurred after the biostimulant was applied three times at the three- or four-leaf stage. The beneficial effect of the algal biostimulant on plants can be explained by an increase in the rate of CO_2 assimilation and the rate of water use efficiency in photosynthesis (Mikiciuk & Dobromilska, 2014). Xu and Leskovar (2015) showed that, in drought-stress conditions, seaweed extracts enhanced spinach growth by improving water relations in the leaves. Osman et al. (2021) showed that spraying with *Ascophyllum nodosum* at a concentration of 1 ml l^{-1} had the best effect on the growth and yield of green garlic in reclaimed sandy soil. Foliar spraying with *A. nodosum* resulted in the highest total yield and the highest weight and diameter of garlic bulbs at harvest. In a study carried out by Abbas et al. (2020), the application of the 0.5%, 1%, 2%, and 3% concentrations of SWE resulted in a significant increase in the yield of four bulb varieties per unit area.

4.5. Leaf yield

Garlic leaves were harvested before flowering, as they become phloem-like and less palatable later. During this period, the leaves are typically harvested for consumption (Błażewicz-Woźniak, 2023). Harvesting the leaves of garlic before the flowering period is optimal for their biological value and the content of active substances (more than 0.4% of the sum of cysteine sulfoxides) (Schmitt et al., 2005). As shown by Hiyasat et al. (2009), the aboveground biomass peaks within six weeks. In the present experiment, the leaf yield of *A. ursinum* increased significantly in the successive crop years and was the highest in 2020. As reported by Todorović et al. (2023), the growth of this plant is slow in the first two years; rapid growth begins in the third year and continues until the fifth year, after which the growth slows down again. The plowing of phacelia biomass had a positive effect on the *A. ursinum* leaf yield, although statistically confirmed differences were noted only in 2019. Turnip rape applied as a shade plant significantly increased the leaf yield of *A. ursinum* compared to the crop without turnip rape on average for the three years of the study. Regardless of the year of the study, the rosettes of *A. ursinum* growing with the turnip rape were on average 2.3% higher in April, while in May, they were 5.9% higher than those growing without the seedling (Błażewicz-Woźniak, 2023). The positive effect of the shade crop on the leaf yield was particularly evident in 2020. In a study carried out by Golubkin et al. (2012), the green matter yield of *A. ursinum* was 88.8 g m^{-2} when grown in the sun and 118.2 g m^{-2} when grown in the shade. The beneficial effect of the turnip rape as a shade plant indicates the possibility of using this type of natural plant cover, as it increases biodiversity and is an alternative to shade trees used in horticulture (Błażewicz-Woźniak, 2023). In the catch cropping of *A. ursinum* and *Armoracia rusticana*, Amagova et al. (2022) recorded mutual growth stimulation of both species. The biomass of garlic increased 1.28 times, and the biomass of horseradish root increased 1.7 times. In the present experiment, among the applied biopreparations, on average for three years, a slightly higher leaf yield of *A. ursinum* was harvested using the Kelpak spray combined with pre-wetting of bulbs, and the lowest yield was recorded in the variant without the application of biopreparations. A Kelpak spray had a positive effect on onion leaf growth in a study performed by Szczepanek et al. (2017).

5. Conclusion

The plowing of phacelia biomass had a beneficial effect on the number of *A. ursinum* progeny bulbs, the unit weight of bulbs and their yield per unit area, and the leaf yield not only in the first year of cultivation but also in the follow-up. The turnip rape applied as a shade crop caused a slight increase in the unit weight of bulbs and their yield in the first and second years of cultivation and in the number of progeny bulbs in the second and third years of cultivation. The cultivation of *A. ursinum* with turnip rape increased the percentage of garlic root weight and leaf yield. There was a positive effect of the applied biopreparations on the studied traits of *A. ursinum* bulb yield and leaf yield and on the formation of progeny bulbs in relation to the control object. The analysis of the interaction of the factors of the experiment revealed that the combination with the application of the phacelia catch crop and the simultaneous cultivation of the shade crop had the most favorable effect on *A. ursinum* progeny bulb formation, bulb unit weight, root system development, and leaf yield. In all years of the study, the worst effect was obtained in the control object, i.e., in the cultivation without the catch crop, rapeseed, and application of biopreparations. The evaluation of the results of the yield and reproduction of *A. ursinum* bulbs allows us to conclude that it is possible to grow the plant in field conditions that are even significantly different from the requirements of this species if appropriate, even unconventional, agrotechnical treatments are applied.

References

Abbas, M., Anwar, J., Zafar-ul-Hye, M., Khan, R. I., Saleem, M., Rahi, A. A., Danish, S., & Datta, R. (2020). Effect of seaweed extract on productivity and quality attributes of four onion cultivars. *Horticulturae*, *6*(2), Article 28. https://doi.org/10.3390/horticulturae6020028

Amagova, Z., Matsadze, V., Kavarnakaeva, Z., Golubkina, N., Antoshkina, M., Sękara, A., Tallarita, A., & Caruso, G. (2022). Joint cultivation of *Allium ursinum* and *Armoracia rusticana* under foliar sodium selenate supply. *Plants*, *11*(20), Article 2778. https://doi.org/10.3390/plants11202778

Aremu, A. O., Masondo, N. A., Rengasamy, K. R. R., Amoo, S. O., Gruz, J., Bíba, O., Šubrtová, M., Pěnčík, A., Novák, O., Doležal, K., & van Staden, J. (2015). Physiological role of phenolic biostimulants isolated from brown seaweed *Ecklonia maxima* on plant growth and development. *Planta*, *241*, 1313–1324. https://doi.org/10.1007/s00425-015-2256-x

Bierzychudek, P. (1982). Life histories and demography of shade-tolerant temperate forest herbs: A review. *New Phytologisty*, *90*(4), 757–776. https://doi.org/10.1111/j.1469-8137.1982.tb03285.x

Błażewicz-Woźniak, M. (2023). The impact of selected agrotechnical treatments on the growth of wild garlic (*Allium ursinum* L.) leaves in field cultivation. *Acta Scientiarum Polonorum Hortorum Cultus*, *22*(3), 81–91. https://doi.org/10.24326/asphc.2023.4889

Błażewicz-Woźniak, M., Kęsik, T., & Michowska, A. (2011). Flowering of bear garlic (*Allium ursinum* L.) cultivated in the field at varied nitrogen nutrition and mulching. *Acta Scientiarum Polonorum Hortorum Cultus*, *10*(3), 133–144.

Błażewicz-Woźniak, M., & Konopiński, M. (2013). Impact of cover crops and tillage on porosity of podzolic soil. *International Agrophysics*, *27*(3), 247–255. https://doi.org/10.2478/v10247-012-0092-9

Błażewicz-Woźniak, M., & Michowska, A. (2011). The growth, flowering and chemical composition of leaves of three ecotypes of *Allium ursinum* L. *Acta Agrobotanica*, *64*(4), 171–180.

Błażewicz-Woźniak, M., & Wach, D. (2012). The fertilizer value of summer catch crops preceeding vegetables and its variation in the changing weather conditions. *Acta Scientiarum Polonorum. Hortorum Cultus*, *11*(3), 101–116.

Błażewicz-Woźniak, M., Wach, D., Najda, A., & Mucha, S. (2019). Influence of mulching and foliar nutrition on the formation of bulbs and content of some components in leaves and bulbs of Spanish bluebell (*Hyacinthoides hispanica* (Mill.) Rothm.). *Journal of Elementology*, *24*(1), 305–318. https://doi.org/10.5601/jelem.2018.23.1.1646

Błażewicz-Woźniak, M., Wach, D., & Patkowska, E. (2022). The effect of cover crops on soil moisture in ploughless and traditional tillage in the cultivation of carrot. *Acta Scientiarum Polonorum Hortorum Cultus*, *21*(1), 11–20. https://doi.org/10.24326/asphc.2022.1.2

Bulgari, R., Franzoni, G., & Ferrante, A. (2019). Biostimulants application in horticultural crops under abiotic stress conditions. *Agronomy*, *9*(6), Article 306. https://doi.org/10.3390/agronomy9060306

Chybowski, J. (1997). Badanie aktywności przeciwrobaczej wyciągów czosnkowych [Testing the anthelmintic activity of garlic extracts]. *Herba Polonica*, *43*(4), 383–387.

Djurdjevic, L., Dinic, A., Pavlovic, P., Mitrovic, M., Karadzic, B., & Tesevic, V. (2004). Allelopathic potential of *Allium ursinum* L. *Biochemical Systematics and Ecology*, *32*(6), 533–544. https://doi.org/10.1016/j.bse.2003.10.001

Eggert, A. (1992). Dry matter economy and reproduction of a temperate forest spring geophyte, *Allium ursinum*. *Ecography*, *15*(1), 45–55. https://doi.org/10.1111/j.1600-0587.1992.tb00007.x

Ernst, W. H. O. (1979). Population biology of *Allium ursinum* in northern Germany. *The Journal of Ecology*, 347–362. https://doi.org/10.2307/2259355

Fijałkowski, D., & Chojnacka-Fijałkowska, E. (2009). *Rośliny lecznicze na Lubelszczyźnie* [Medicinal plants in the Lublin region]. Lubelskie Towarzystwo Naukowe.

Голубкина [Golubkina], N. A., Кошелева [Koseleva], O. M., Savcenko [Savcenko], O. M., Соловьева [Colovieva], A. U., Козловская [Kozlovskaia], L. N., & Маланкина [Malankina], E. L. (2012). Особенности формирования урожая і аккумуляции селена в луке победном (*Allium victorialis* L.) і луке медвежьем (*Allium ursinum* L.) [Productivity and selenium accumulation in *Allium victorialis* L. and *Allium ursinum* L.]. *Известия Тимирязевской сельскохозяйственной академии* [Izvestiâ Timirâzevskoj sel'skohozâjstvennoj akademii], *6*, 80–86.

Gordanić, S., Radanović, D., Vuković, S., Kolašinac, S., Kilibarda, S., Marković, T., Moravčević, Đ., & Kostić, A. Ž. (2022). Phytochemical characterization and antioxidant potential of *Allium ursinum* L. cultivated on different soil types – A preliminary study. *Emirates Journal of Food and Agriculture*, *34*(11), 904–914. https://doi.org/10.9755/ejfa.2022.v34.i11.2958

Hæggström, C. A., Hæggström, E., Carlsson, R., & von Numers, M. (2016). *Allium ursinum* (*Alliaceae*) in Finland. *Memoranda Societatis pro Fauna et Flora Fennica*, *92*, 54–78.

Hassan, S. M., Ashour, M., Sakai, N., Zhang, L., Hassanien, H. A., Gaber, A., & Ammar, G. (2021). Impact of seaweed liquid extract biostimulant on growth, yield, and chemical composition of cucumber (*Cucumis sativus*). *Agriculture*, *11*(4), Article 320. https://doi.org/10.3390/agriculture11040320

Heinrichs, S., Dierschke, H., Kompa, T., & Schmidt, W. (2018). Effect of phenology, nutrient availability and windthrow on flowering of *Allium ursinum* – Results from long-term monitoring and experiments. *Tuexenia*, *38*, 111–134. https://doi.org/10.14471/2018.38.016

Hiyasat, B., Sabha, D., Grötzinger, K., Kempfert, J., Rauwald, J. W., Mohr, F. W., & Dhein, S. (2009). Antiplatelet activity of *Allium ursinum* and *Allium sativum*. *Pharmacology*, *83*(4), 197–204. https://doi.org/10.1159/000196811

Kęsik, T., Błażewicz-Woźniak, M., & Michowska, A. E. (2011). Influence of mulching and nitrogen nutrition on bear garlic (*Allium ursinum* L.) growth. *Acta Scientiarum Polonorum Hortorum Cultus*, *10*(3), 221–233.

Kęsik, T., Konopiński, M., Błażewicz-Woźniak, M., & Mitura, R. (2002). Residual effect of no-tillage and cover crops in vegetables cultivation on soil aggregates formation and soil structure. *Roczniki AR w Poznaniu. Ogrodnictwo*, *35*, 83–88.

Khan, W., Rayirath, U. P., Subramanian, S., Jithesh, M. N., Rayorath, P., Hodges, D. M., Critchley, A. T., Craigie, J. S., Norrie, J., & Prithiviraj, B. (2009). Seaweed extracts as biostimulants of plant growth and development. *Journal of Plant Growth Regulation*, *28*, 386–399. https://doi.org/10.1007/s00344-009-9103-x

Kisvarga, S., Farkas, D., Boronkay, G., Neményi, A., & Orlóci, L. (2022). Effects of biostimulants in horticulture, with emphasis on ornamental plant production. *Agronomy*, *12*(5), Article 1043. https://doi.org/10.3390/agronomy12051043
Konopiński, M., Kęsik, T., & Błażewicz–Woźniak, M. (2001). Wpływ mulczowania międzyplonowymi roślinami okrywowymi i uprawy zerowej na kształtowanie wilgotności i zagęszczenia gleby [Effect of cover crops mulching and no-tillage cultivation on the soil compaction and moisture]. *Acta Agrophysica*, *45*, 105–116.
Krivokapić, M., Bradić, J., Petković, A., & Popović, M. (2021). Phytochemical and pharmacological properties of *Allium ursinum*. *Serbian Journal of Experimental and Clinical Research*, *22*(4), 357–362. https://doi.org/10.2478/sjecr-2018-0003
Kulkarni, M. G., Gupta, S., Ngoroyemoto, N., Stirk, W. A., & van Staden, J. (2021). Smoke, seaweed extracts, and vermicompost leachates – Classical natural plant biostimulants. In S. Gupta & J. van Staden (Eds.), *Biostimulants for crops from seed germination to plant development* (pp. 73–85). Academic Press. https://doi.org/10.1016/B978-0-12-823048-0.00011-3
Kurepin, L. V., Zaman, M., & Pharis, R. P. (2014). Phytohormonal basis for the plant growth promoting action of naturally occurring biostimulators. *Journal of the Science of Food and Agriculture*, *94*(9), 1715–1722. https://doi.org/10.1002/jsfa.6545
Matysiak, K., Kaczmarek, S., & Kierzek, R. (2012). Wpływ wyciągu z alg morskich *Ecklonia maxima* (Kelpak SL) na rośliny rzepaku ozimego [Effect of algae *Ecklonia maxima* (Kelpak SL) on winter oilseed rape]. *Rośliny Oleiste-Oilseed Crops*, *33*(1), 81–88. https://doi.org/10.5604/12338273.1058592
Mikiciuk, M., & Dobromilska, R. (2014). Assessment of yield and physiological indices of small-sized tomato cv 'Bianka F1' under the influence of biostimulators of marine algae orgin. *Acta Scientiarum Polonorum. Hortorum Cultus*, *13*(1), 31–41.
Mitura, K., Lipińska, K. J., Świtkowski, M., & Spychaj-Fabisiak, E. (2014). Bioregulator Kelpak – charakterystyka oraz zastosowanie [Kelpak bioregulator — Characteristics and applications]. In J. Flizikowski (Ed.), *Nauka niejedno ma imię. Część II. Nauki przyrodnicze* (pp. 125–134). Wydawnictwa Uczelniane Uniwersytetu Technologiczno-Przyrodniczego.
Mystkowska, I. T. (2018). Biostimulators as a factor affecting the yield of edible potato. *Acta Agrophysica*, *25*(3), 307–315. https://doi.org/10.31545/aagr/95109
Najgebauer-Lejko, D., Pluta-Kubica, A., Domagała, J., Turek, K., Duda, I., & Golian, J. (2022). Effect of bear garlic addition on the chemical composition, microbiological quality, antioxidant capacity, and degree of proteolysis in soft rennet cheeses produced from milk of polish red and polish holstein-friesian cows. *Molecules*, *27*(24), Article 8930. https://doi.org/10.3390/molecules27248930
Oborny, B., Botta-Dukat, Z., Rudolf, K., & Morschhauser, T. (2011). Population ecology of *Allium ursinum*, a space-monopolizing clonal plant. *Acta Botanica Hungarica*, *53*(3–4), 371–388. https://doi.org/10.1556/ABot.53.2011.3-4.18
Osman, Y. M., Rizk, S. M., & Mounir, A. M. (2021). Response of green garlic to plant density and spraying with algae extract. *Journal of Applied Horticulture*, *23*(3), 278–285. https://doi.org/10.37855/jah.2021.v23i03.49
Papenfus, H. B., Kulkarni, M. G., Stirk, W. A., Finnie, J. F., & van Staden, J. (2013). Effect of a commercial seaweed extract (Kelpak®) and polyamines on nutrient-deprived (N, P and K) okra seedlings. *Scientia Horticulturae*, *151*, 142–146. https://doi.org/10.1016/j.scienta.2012.12.022
Parađković, N., Teklić, T., Zeljković, S., Lisjak, M., & Špoljarević, M. (2019). Biostimulants research in some horticultural plant species — A review. *Food and Energy Security*, *8*(2), Article e00162. https://doi.org/10.1002/fes3.162
Rola, K. (2012). Taxonomy and distribution of *Allium ursinum* (*Liliaceae*) in Poland and adjacent countries. *Biologia*, *67*(6), 1080–1087. https://doi.org/10.2478/s11756-012-0101-2
Rychnovská, M., & Bednář, V. (1998). Floodplain forest: Herb layer as indicator of its ecological status. *Acta Universitatis Palackianae Olomucensis Facultas Rerum Naturalium. Biologica*, *36*, 7–15.
Schmitt, B., Schulz, H., Storsberg, J., & Keusgen, M. (2005). Chemical characterization of *Allium ursinum* L. depending on harvesting time. *Journal of Agricultural and Food Chemistry*, *53*(18), 7288–7294. https://doi.org/10.1021/jf0504768
Sharma, S. H. S., Fleming, C., Selby, C., Rao, J. R., & Trevor, M. (2014). Plant biostimulants: A review on the processing of macroalgae and use of extracts for crop management to reduce abiotic and biotic stresses. *Journal of Applied Phycology*, *26*, 465–490. https://doi.org/10.1007/s10811-013-0101-9
Sobolewska, D. (2018). *Czosnek niedźwiedzi Allium ursinum: wielki powrót* [Wild garlic *Allium ursinum*: A great comeback]. OSDW Azymut.

Sobolewska, D., Podolak, I., & Makowska-Wąs, J. (2015). *Allium ursinum*: Botanical, phytochemical and pharmacological overview. *Phytochemistry Reviews*, *14*(1), 81–97. https://doi.org/10.1007/s11101-013-9334-0

Stirk, W. A., Rengasamy, K. R., Kulkarni, M. G., & van Staden, J. (2020). Plant biostimulants from seaweed: An overview. *The Chemical Biology of Plant Biostimulants*, 31–55. https://doi.org/10.1002/9781119357254.ch2

Szczepanek, M., Wszelaczyńska, E., Pobereżny, J., & Ochmian, I. (2017). Response of onion (*Allium cepa* L.) to the method of seaweed biostimulant application. *Acta Scientiarum Polonorum Hortorum Cultus*, *16*(2), 113–122.

Teklić, T., Parađković, N., Špoljarević, M., Zeljković, S., Lončarić, Z., & Lisjak, M. (2021). Linking abiotic stress, plant metabolites, biostimulants and functional food. *Annals of Applied Biology*, *178*(2), 169–191. https://doi.org/10.1111/aab.12651

Todorović, V., Đekić, N., Antić, M., Bosančić, B., Gidas, J. D., & Murtić, S. (2023). Morphological characteristics and antioxidant properties of *Allium ursinum* L. wild growing in the northwestern part of the Republic of Srpska (Bosnia and Herzegovina). *Journal of Applied Botany and Food Quality*, *96*, 48–54. https://doi.org/10.5073/JABFQ.2023.096.006

Truba, M., Jankowski, K., & Sosnowski, J. (2012). Reakcja roślin na stosowanie preparatów biologicznych [The plants reaction on biological preparations treatment]. *Ochrona Środowiska i Zasobów Naturalnych*, *53*, 41–52.

Voća, S., Šic Žlabur, J., Fabek Uher, S., Peša, M., Opačić, N., & Radman, S. (2021). Neglected potential of wild garlic (*Allium ursinum* L.) — Specialized metabolites content and antioxidant capacity of wild populations in relation to location and plant phenophase. *Horticulturae*, *8*(1), Article 24. https://doi.org/10.3390/horticulturae801002

Xu, C., & Leskovar, D. I. (2015). Effects of A. *nodosum* seaweed extracts on spinach growth, physiology and nutrition value under drought stress. *Scientia Horticulturae*, *183*, 39–47. https://doi.org/10.1016/j.scienta.2014.12.004

Znamirowska, A., Rożek, P., Buniowska, M., Kalicka, D., & Kuźniar, P. (2018). Zastosowanie czosnku niedźwiedziego (*Allium ursinum* L.) do produkcji mleka fermentowanego przez *Bifidobacterium animalis* ssp. *lactis* BB-12 [Using wild garlic (*Allium ursinum* l.) in production of milk fermented with *Bifidobacterium animalis* ssp. lactis BB-12]. *Żywność Nauka Technologia Jakość*, *25*(1), 126–136. https://doi.org/10.15193/zntj/2018/114/225