

# MORPHOPHYSIOLOGICAL PARAMETERS AND LEEK SEED PRODUCTION DEPENDING ON FULVOHUMIN TREATMENT AND DATE OF PLANTING SEEDLINGS

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## ABSTRACT

Producing leek seeds without replanting one-year-old plants is cheaper and more practical, but can be risky in climates with cold winters. This research aimed to assess whether accelerating the planting of seedlings and using Fulvohumin fertilizer, containing, among others, humic acids can make such production less risky. Three dates were used for planting leek seedlings: April 10, April 25, and May 10. Fulvohumin was used presowing, foliarly, and both. Both factors significantly improved seed production. The best results were obtained at the earliest planting date, as the plants were strong and best prepared for the generative phase and the frost period. Fulvohumin significantly improved growth and development parameters, mainly when used before sowing and as foliar application. In the best combination, with two applications of fertilizers, the seed yield increased by 39%, compared to the control (without Fulvohumin fertilization), and the seed yield of plants planted on April 10 was 17% higher compared to plants planted on April 25 (considered as standard) and 39% higher than those planted on May 10. Seed yield varied in the three subsequent years of the study, but each year, the planting date and Fulvohumin had a similar effect on seed yield.

**Key words:** seed yield, planting date, production of leek seeds without replanting mother plants, humic acid fertilizer, overwintering

## INTRODUCTION

Developing the vegetable growing industry requires ecologically safe and cost-effective methods of growing seeds of vegetable plants. Genetic variability and low seed yield still require improvement in the vegetable growing industry (Brar et al. 2019; Slobodianyuk & Ternavskiy 2020). Seed production requires knowledge of the physiology of vegetable plants under specific agroecological conditions (Khokhar 2014). Plant adaptation to dry summer and winter resistance influence the yield of leek seeds. The high need for leeks in nutrients requires programming of fertilization conditions. The use of various biostimulants has a positive effect on the resistance of plants to biotic and abiotic stresses (Bulygin et al. 2019; Doctor et al. 2019; Yatsenko et al. 2019; Zaiets & Kysil 2019; Bahmat et al. 2020; Kisvarga et al. 2022; Prysiazhniuk et al. 2022; Kondratenko et al. 2023; Kuts et al. 2023).

Presowing seed treatment with preparations containing easily absorbed micro- and macroelements increases the adaptive potential of plants in the initial phase of their growth. Humic substances and fulvic acids are common in modern agricultural technologies. These substances are ecological and characterized by high production and economic efficiency. Humic and fulvic acids have a positive effect on the growth and development potential of onions (Canellas et al. 2015). The greatest effectiveness of complex fertilizers and microbiological preparations was achieved after their combined use: seed treatment, soil and foliar fertilization (Myalkovsky 2018; Karpenko et al. 2020; Marenych et al. 2020). Fulvic acid improves the physical and chemical condition of the soil and the availability of phosphorus (Yang et al. 2013). The additional use of fulvic acid increases the content of available iron, calcium, copper, zinc, and magnesium cations (Malan 2015; Moradi et al. 2017).

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Increasing the content of humic substances in the soil improves the growth and development of plants (Lotfi et al. 2015). There are reports of a positive effect of fulvic acid on the functioning of the root system (Schmidt et al. 2005; Slobodianyuk et al. 2022), the formation of plant mass, limiting the development of pathogens, increasing the activity of soil microorganisms (Kamel et al. 2014), and increasing the total yield (Suh et al. 2014; Moradi et al. 2017). After applying  $6 \text{ L} \cdot \text{ha}^{-1}$  of fulvic acid to onion crops, plants height, pseudostem diameter, and bulb weight were significantly higher (Mahmoud et al. 2019). Treatment of onions with fulvic acid improved protein synthesis, photosynthesis, and mineral absorption. Such onions contained more ascorbic acid, protein, and total polyphenols and had higher antioxidant activity. The highest biomass and nutrient content in marketable bulbs was obtained after fertilizing the onions with humic preparations (Bettoni et al. 2016). The highest onion yield was obtained with the highest doses of humic fertilizers, and the content of soluble sugars increased to  $149 \text{ mg} \cdot \text{g}^{-1}$ . Top dressing foliar fertilizer with humates also significantly increased bulb weight and dry matter concentration. Foliar top dressing of onions with fulvic acid increased the fresh and dry weight of leaves, and the content of carbohydrates and protein (Gemini et al. 2022).

The development of leeks is also significantly influenced by the dates and methods of cultivation. For sowing leeks without replanting in the temperate continental climate zone, only winter and frost-resistant genotypes should be selected. The selection and seed production of vegetable plants depends on climatic conditions, sales structure, and consumption (Rasco 2009; Bitá & Gerats 2013). Late-ripening types of leeks of the Northern European group, common in Northern European countries, are recommended for seed production without replanting because they have higher cold and frost resistance. Optimal conditions for the formation of seedlings and the development of leek mother plants contribute to obtaining high-quality seeds. Climatic conditions significantly influence seeds during the vernalization period (Askari-Khorasgani & Pessarakli 2019). The reproductive capacity of seeds of individual leek cultivars is only 31–33%, which depends on the biometric indicators of annual plants.

For most vegetable plants, presowing seed treatment is recommended, especially with fulvic acid at a concentration of  $80 \text{ mg} \cdot \text{L}^{-1}$  (Zhang et al. 2021). This treatment eliminates the adverse effects of biotic stress (Al-Haidary & Al-Zubaidy 2020). The cultivation dates of mother plants of two-year-old vegetable plants depend on the length of their rest period (Askari-Khorasgani & Pessarakli 2019). It is recommended to sow onions 15–20 days before they become mother leek plants, so that the plants have more than seven leaves before the induction of the flower buds. The initiation of flowering of leeks grown using the seedling and seedless methods begins only after the juvenile phase, when the plant, depending on the cultivar, has from 4 to 14 leaves (Kisvarga et al. 2022). An earlier sowing date reduces the risk of onion damage by flies (Hermize 2015). At optimal planting dates, onion mother plants are 5–6% less susceptible to diseases (Lamani & Deshpande 2017).

This study provides new information on leek seed production in a system without replanting annual plants. It also determines the influence of the dates of planting seedlings and the use of Fulvohumin on the growth of mother plants and the productivity of seed plants in forest-steppe conditions in Ukraine.

## MATERIALS AND METHODS

### Soil and climatic conditions

The experiment was carried out at the Department of Vegetable Growing of the Uman National University of Horticulture in 2019–2022. The soil in the experimental plots is podzolic, heavy, clayey black soil with a humus content of 1.9% (according to SSTU 4289:2004) and pH 6.3 (according to the Kappen method). The nitrogen content in the arable soil layer is  $103 \text{ mg} \cdot \text{kg}^{-1}$  (according to the Cornfield method), mobile phosphorus and potassium compounds (according to the Chirikov method) are  $122 \text{ mg} \cdot \text{kg}^{-1}$  and  $135 \text{ mg} \cdot \text{kg}^{-1}$ . The region's climate is temperate continental with unstable precipitation.

Less favorable weather conditions for the rooting of leek seedlings were in April 2020 and May 2019. In the second half of the growing season of the mother plants, there were periods of lack of precipitation and extremely high temperatures. In 2020 and 2022, the sum of active temperatures (above  $+10^\circ\text{C}$ )

significantly exceeded the statistical average for the forest-steppe zone of Ukraine – 3005–3272 °C. The summer of 2021 was relatively rainy, and the sum of active temperatures during the growing season of annual leek plants was 2551.6–2672.6 °C, depending on the planting date. Extremely low winter temperatures are a limiting factor for in leek production without replanting. During the research years, the winter of 2019–2020 was the warmest. The sum of effective temperatures above 0 °C in the winter of 2019–2020 was 161 °C, in 2020 – 21–42, in 2021 – 22–92 °C, and the sum of precipitation was 109 mm, 135.5 mm, and 122.3 mm, respectively. The lowest temperature was recorded in January–February 2021, with frosts below –15 °C. For the development of nonreplanted seed plants in early spring, the sum of effective temperatures above +5 °C is crucial. In the period March–April, the sum of the temperatures above +5 °C in 2020 and 2022 was 170 °C and 134 °C, respectively. In 2021 it was only 72 °C. In 2022, inflorescences developed according to the indicators (hydrothermal coefficient) at severe and moderate levels of drought. In 2020, leek seed ripened in the driest conditions. The sum of active temperatures above +15 °C in the growing season of leek seed plants in 2020 was 1930 °C, while in 2021–2022 it was 2057–2059 °C.

### Research methodology

In the experiment, the productivity of ‘Bartek’ leek seeds was evaluated. The experimental variants were as follows: A – application of Fulvohumin – presowing seed treatment with a 1.25% solution, foliar top dressing with a 0.25% solution, combined presowing seed treatment with foliar top dressing, water as a control and B – seedling planting dates – April 10, April 25 (common control date), and May 10. There were four repetitions of plots, the planting scheme was 70 × 10 cm, the area of each experimental plot was 20 m<sup>2</sup>, and each plot included 290 plants.

The experiment used Fulvohumin, a humic-fulvic fertilizer with trace elements in chelated form (LL company Park). It is known for its unique properties as a plant bioregulator and an anti-stress agent against biotic and abiotic factors. It is produced from ecologically clean raw materials – a mixture of organic complexes such as peat, coal, and other organic substances. Active substances in Fulvo-

humin include: N – 3.0%, P<sub>2</sub>O<sub>5</sub> – 2.5%, K<sub>2</sub>O – 4.0%, total carbon – 16.0%, humic acid – 4.0%, fulvic acid carbon – 15.0%, and organic matter – 40.0%. Fulvohumin working solutions were prepared in accordance with the producer’s instructions, and the presowing treatment consisted of soaking the seeds in water (control) or in a 1.25% solution. Foliar top dressing was made with a 0.25% Fulvohumin solution twice – 30 and 60 days after planting seedlings in the field, using 3 L solution per 100 m<sup>2</sup> with the addition of Liposam adhesive.

Leaf surface area was recorded and photosynthetic potential during the leek vegetation period was calculated. The leek leaf surface area (cm<sup>2</sup>) was calculated according to the formula:  $S = D \times L/2$ , where D is the length of the leaf from the tip to the base (cm), L is the leaf width (cm), with further recalculation (m<sup>2</sup> per 1 ha) (Bondarenko & Yakovenko 2001). The formula was used to determine the net photosynthetic productivity:  $NPP = 2(B_2 - B_1) / [T(L_1 + L_2)]$ , where NPP is the net photosynthetic productivity (g per m<sup>2</sup> per day); B<sub>1</sub>, B<sub>2</sub> is the dry weight of plants (two plants per m<sup>2</sup>) at the beginning and end of the counting period (g); (B<sub>2</sub>–B<sub>1</sub>) – dry matter increase within T days (g); L<sub>1</sub> and L<sub>2</sub> – leaf area at the beginning and end of the counting period. The initial count was made one month after seedling emergence, on August 20 and finally on October 20. Winter resistance in the plots of each treatment was calculated according to the formula:  $M = a \times 100/b$ , where a is the number of live plants in the spring of the following year (pcs), and b is the number of annual plants in autumn (pcs).

The instructions for approving the cultivation of vegetable and melon seeds were followed (Yakovenko et al. 1999). Approval in the first year of growing mother plants was in autumn, when the plants showed clear signs, the typical leaf apparatus was fully formed. Two-year-old leek plants in the flowering phase were tested. Underdeveloped plants were removed. Leeks are characterized by long and uneven ripening seeds. Therefore, flowering stems with inflorescences were cut before the first pods burst. They were dried and then threshed and the seed yield of was recorded. The varietal purity of reproductive seeds must be at least 97%, germination above 70%, and humidity up to 11%. The weight of the average sample was 5 g.

### Statistical analysis

Data are expressed as mean and standard deviation ( $\pm$ SD). Mean data were analyzed using two-way analysis of variance (ANOVA) in Excel 2016 and additional data analysis. The obtained mean values were compared using the Tukey's test, calculated using Statistica (version 10.0). Direct correlation throughout the experiment was determined by comparing average annual values. The graphs show the average long-term values of the variables throughout the experiment and the standard deviation.

## RESULTS AND DISCUSSION

The technology of growing seed plants significantly affects the seed yield. The date of onion cultivation determined the intensity of flowering of the shoots and the quality of the seeds (Khokhar 2008; Khodadadi 2012; Asaduzzaman et al. 2015). The yield of onion seeds depends on the size of the phytomass of annual plants. With a larger number of leaves and height of onion plants, the seed yield

was higher (Lamani & Deshpande 2017). Treatment of leeks with the biostimulant 'Aveikan' had a positive effect on reproductive characteristics, the average weight of plants was 20–34% higher (Masheva et al. 2012). In our experiment, the total weight of leek mother plants untreated with Fulvohumin was 165 g. However, after presowing treatment, the weight increased by 7–9%, depending on the planting date (Table 1). Foliar fertilization with Fulvohumin increased the weight of mother plants by 3–6% compared to the control, while seed and foliar treatments increased the weight of seed plants by 15–19%. Presowing seed treatment with Fulvohumin stimulated the morphogenesis and metabolism of seedlings, which turned out to be more effective than foliar top dressing.

The choice of the date of planting seedlings is a crucial factor that has a significant influence on the weight of mother and seed plants. Specifically, seedlings planted on April 25 produced 20% less total weight, and seedlings planted on May 10 produced 79% less than those planted on April 10 (Table 1).

Table 1. Total weight and net photosynthetic productivity (NPP, g per m<sup>2</sup> per day) of leek mother plants depending on the Fulvohumin (FH) treatment and the date of planting seedlings (as of October 20, means  $\pm$  SD for 2019–2021)

Treatments	Seedling planting date	Total weight (g per plant)	NPP (whole compared with growing season)	NPP (August 20 – October 20)
Water (control)	April 10	210 <sup>cd</sup> $\pm$ 6	3.98 <sup>d</sup> $\pm$ 0.12	3.36 <sup>de</sup> $\pm$ 0.12
	April 25	169 <sup>f</sup> $\pm$ 6	4.65 <sup>c</sup> $\pm$ 0.17	3.59 <sup>d</sup> $\pm$ 0.16
	May 10	117 <sup>h</sup> $\pm$ 4	5.84 <sup>b</sup> $\pm$ 0.11	4.07 <sup>c</sup> $\pm$ 0.21
	mean	165 <sup>C</sup> $\pm$ 14	4.82 <sup>B</sup> $\pm$ 0.81	3.67 <sup>A</sup> $\pm$ 0.34
Presowing seed treatment 1.25% FH	April 10	229 <sup>ab</sup> $\pm$ 15	3.10 <sup>fg</sup> $\pm$ 0.12	2.78 <sup>f</sup> $\pm$ 0.06
	April 25	183 <sup>ef</sup> $\pm$ 6	3.55 <sup>c</sup> $\pm$ 0.07	2.83 <sup>f</sup> $\pm$ 0.08
	May 10	125 <sup>gh</sup> $\pm$ 5	6.05 <sup>b</sup> $\pm$ 0.23	4.38 <sup>bc</sup> $\pm$ 0.07
	mean	179 <sup>B</sup> $\pm$ 15	4.23 <sup>C</sup> $\pm$ 1.36	3.33 <sup>B</sup> $\pm$ 0.78
Foliar application 0.25% FH	April 10	223 <sup>bc</sup> $\pm$ 7	3.47 <sup>ef</sup> $\pm$ 0.22	2.90 <sup>f</sup> $\pm$ 0.07
	April 25	175 <sup>f</sup> $\pm$ 6	4.13 <sup>d</sup> $\pm$ 0.13	3.02 <sup>ef</sup> $\pm$ 0.18
	May 10	120 <sup>h</sup> $\pm$ 3	7.00 <sup>a</sup> $\pm$ 0.33	4.97 <sup>a</sup> $\pm$ 0.16
	mean	173 <sup>BC</sup> $\pm$ 14	4.87 <sup>A</sup> $\pm$ 1.62	3.63 <sup>A</sup> $\pm$ 1.00
Presowing seed treatment + foliar application	April 10	243 <sup>a</sup> $\pm$ 10	2.97 <sup>g</sup> $\pm$ 0.07	2.71 <sup>f</sup> $\pm$ 0.13
	April 25	198 <sup>de</sup> $\pm$ 5	3.25 <sup>efg</sup> $\pm$ 0.08	2.79 <sup>f</sup> $\pm$ 0.18
	May 10	140 <sup>g</sup> $\pm$ 4	6.22 <sup>b</sup> $\pm$ 0.21	4.57 <sup>b</sup> $\pm$ 0.23
	Mean	194 <sup>A</sup> $\pm$ 15	4.15 <sup>C</sup> $\pm$ 1.54	3.36 <sup>B</sup> $\pm$ 0.91
Seedling planting date				
	April 10	226 <sup>A</sup> $\pm$ 15	3.38 <sup>C</sup> $\pm$ 0.42	2.94 <sup>B</sup> $\pm$ 0.28
	April 25 (control)	181 <sup>B</sup> $\pm$ 12	3.90 <sup>B</sup> $\pm$ 0.57	3.06 <sup>B</sup> $\pm$ 0.36
	May 10	126 <sup>C</sup> $\pm$ 10	6.28 <sup>A</sup> $\pm$ 0.50	4.50 <sup>A</sup> $\pm$ 0.37

Means  $\pm$  standard deviation followed by different letters are significantly different according to Tukey's test ( $p = 0.05$ )

The most effective combination was early planting – on April 10 with complex Fulvohumin treatment, resulting in seed weight 1.4 times higher than the control, which emphasized the importance of this factor in plant productivity.

The intensity of photosynthesis and respiration is a polygenic feature inherited by plants. Synchronized with physiological and biochemical processes, net photosynthetic productivity is higher in areas where the share of assimilating leaves is greater in relation to the intensity of dry biomass accumulation. In the first growing season, net photosynthetic productivity of mother plants was the highest in the control. Low values of this parameter with a larger leaf surface area are attributed to the shading of the leaves of the lower levels due to excessive plant density. However, the unproductive use of assimilation products is limited by the total amount of photosynthesis products.

In both recording periods, August 20 to October 20, and throughout the growing season, the highest net photosynthetic productivity (NPP) rates were recorded when leeks were planted on May 10 compared to earlier planting dates. Some publications state that the rate of leaf photosynthesis is not strictly related to productivity and depends on the type of agricultural crop (Long et al. 2006).

The relationship between individual biometric indicators of leek mother plants was calculated using correlation-regression analysis and presented graphically (Fig. 1). The relationship between the total weight of annual plants and the area of their

leaf surface was  $r = 0.89$ . Changes in leaf area can explain 79% of the variation in plant weight.

The winter resistance of plants limits the production of leek seeds in the system without replanting. During the winter, leeks undergo phased processes necessary for the normal development of seed plants. Leeks grown in the system with replanting have lower winter hardiness than those grown without replanting. Late ripening leek cultivars with a large supply of sugars tolerate winter better (De Clercq et al. 1999). Planting density, soil moisture, and snow cover affect the winter resistance of plants (Fowler et al. 1981; Siwek et al. 2013). Plant adaptation to low temperatures is divided into three phases. The first is cold acclimatization (prehardening), which occurs at a minimum positive temperature. The second stage is the full degree of cold resistance at minus temperatures. The final phase is the recovery of plants after winter (Li et al. 2008). The effectiveness of acclimatization of overwintering plants is influenced by the level of amino acids and micro- and macroelements that can be provided by fertilizers containing biostimulants (Dörffling et al. 2009; Jakienė 2013). Biostimulants, which contained amino acids and micro- and macroelements, had a positive effect on the autumn growth of plants, their overwintering and vegetation renewal (Gavelienė et al. 2018). The latest research involves searching for means to increase the frost resistance of plants (Zhang et al. 2004; Szalai et al. 2009). Fulvohumin is a complex preparation that requires testing for its effect on the frost resistance of nonreplanted leek plants.

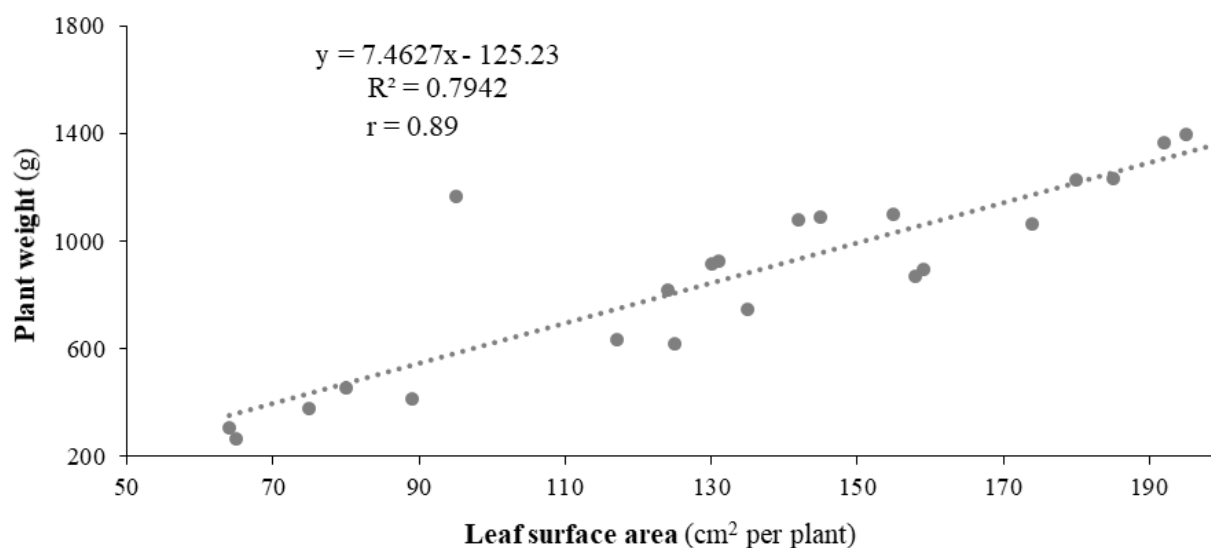


Figure 1. Correlation model of the relationship between leaf surface area (x) and the total weight of annual leek plants (y)

On average, over the course of three years, the highest winter resistance (88%) of nonreplanted leeks was observed in plots planted the earliest – on April 10 (Fig. 2). At later planting dates, leek winter resistance decreased by 6% (April 25) and 13% (May 10). After using Fulvohumin, the winter resistance of leeks is higher in all cultivation periods. All FH treatments increased winter resistance. The highest result was obtained after complex application of Fulvohumin – 16% more compared to the control.

Al-Haidary and Al-Zubaidy (2020) found that foliar application of fulvic acid significantly improves the vegetative parameters of bread wheat and its resistance to unfavorable conditions. Fulvohumin and early planting significantly increased the winter resistance of leeks.

The cultivation date had a significant effect on the leaf surface area of seed plants (Fig. 3). The leaf surface area of seed plants decreased with the delay in planting seedlings. The three-year average was 831 cm<sup>2</sup>, 620 cm<sup>2</sup>, and 278 cm<sup>2</sup> per plant on April 10, April 25, and May 10, respectively. The largest leaf surface area – 1.6 times larger than the control, was obtained on plots planted from April 10 after seed treatment and foliar top dressing with Fulvohumin. This is partly due to the largest total weight of these plants.

The smallest leaf surface area was produced by seed plants obtained from seedlings planted on May 10. Their leaf surface area at flowering was 19% less than that their first-year counterparts. In plots where seedlings were planted on April 10 and 25, this difference was 27%. Seed plants on which Fulvohumin was applied in the first year were arranged in the following order of increase in the average leaf surface area: foliar top dressing variant – 565 cm<sup>2</sup>, presowing treatment variant – 589 cm<sup>2</sup>, and combined treatment variant – 621 cm<sup>2</sup> per plant. These results, consisted with the findings of Slobodianyuk and Ternavskiy (2020), highlights progress and advances in understanding the effects of treatments on leaf surface area.

An early planting date extends the growing season and ensures the formation of larger leek mother plants. Therefore, seed plants were characterized by the highest biometric parameters, which had a positive effect on seed productivity. The highest yield of onion seeds was obtained from large bulbs planted earlier than from small bulbs planted very late (Ashagrie et al. 2014). Due to the larger size of the mother plants, the germination increases by 13%.

Larger mother bulbs formed more pods, resulting in higher seed yields (Reghin et al. 2005). However, in the study by Morozowska and Hołubowicz (2009), the size of onion mother bulbs had no effect on the weight of 1,000 seeds, their vigor or germination ability. Small mother bulbs form low-flowering stems with smaller inflorescences. The level of flowering stem formation increases linearly with the size of the mother bulbs (Khokhar et al. 2007; Khokhar 2009). ‘Purple Rain’ decorative onion did not form a flower stem if the mother bulb weighed less than 5 g. In the 6–15 g fraction, 30% of bulbs formed flower stems, while in the 15–30 g fraction, almost 100% of the bulbs flowered (Roşca et al. 2016).

Temperature and air humidity significantly influence the flowering of leek seed plants. In the conditions of the forest-steppe of Ukraine, leeks flower from July to August. As a result of uneven flowering, seed plants with more flowers have a longer seed maturation period. In the plant life cycle, flowering is determined by the corresponding gene loci, the effect of which is temperature-dependent (Dalvi et al. 2016). Late planting of mother plants and very low temperatures significantly inhibit the generative shooting of some types of onions (Dong et al. 2013). A longer photoperiod (over 14 hours a day) accelerates the development of seed plants and the flowering of leeks (Khokhar et al. 2007). Onion inflorescences have fewer flowers and low seed productivity if the temperature during vernalization is high (23–24°C), as in the case of late planting of mother bulbs (Lamani & Deshpande 2017). In this study, late planting of seedlings had a negative effect on the intensity of leek flowering, pollination, and ripening of pods. On average, only 72% of pods ripened when seedlings were planted on May 10, compared with 84 and 89% on April 10 and 25 (Table 2).

Our research has shown that the planting date and application of Fulvohumin significantly affect the production of pods. Seedlings planted on April 10 produced 476 pods per inflorescence, while those planted on April 25 produced only 447 (Table 2). The use of Fulvohumin additionally enhanced this parameter, and compared to the control, the greatest increase (18%) was observed when the preparation was applied on seeds and foliarly. The percentage of ripened pods was notably higher on plants from the earliest planting and on plants that received the complex Fulvohumin treatment.

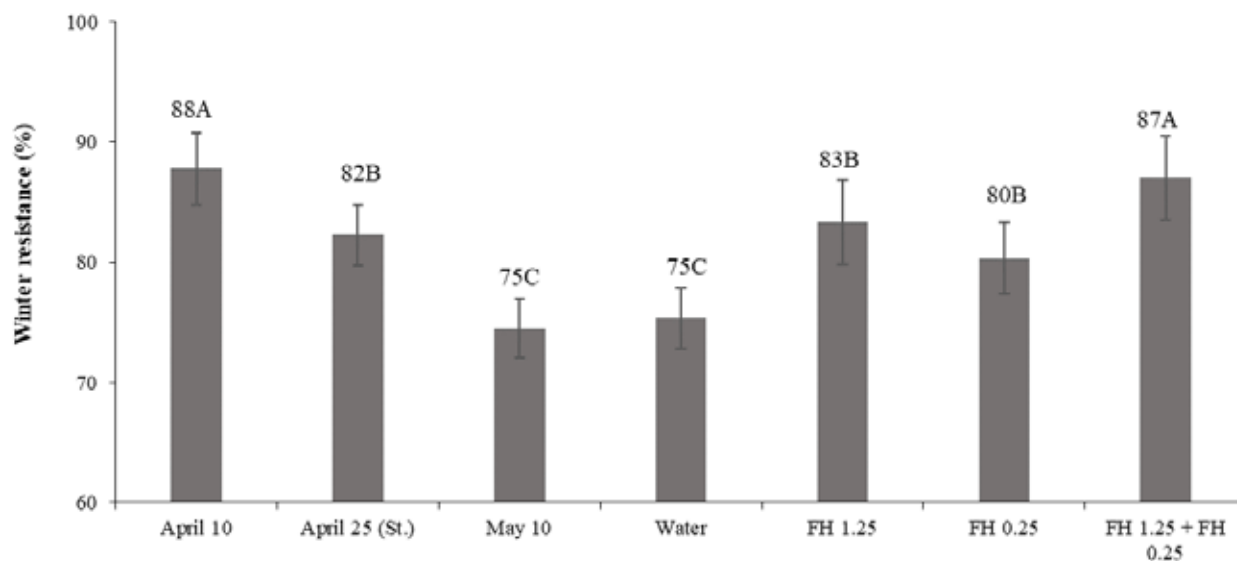


Figure 2. Winter resistance (averages of three years) of nonreplanted mother leeks plants depending on the Fulvohumin (FH) treatment and the date of planting the seedlings

FH 1.25 – presowing seed treatment (1.25% FH), foliar application FH 0.25, FH 1.25 + FH 0.25 – presowing seed treatment + foliar fertilization; Means followed by different letters are statistically significantly different at Tukey's test ( $p = 0.05$ )

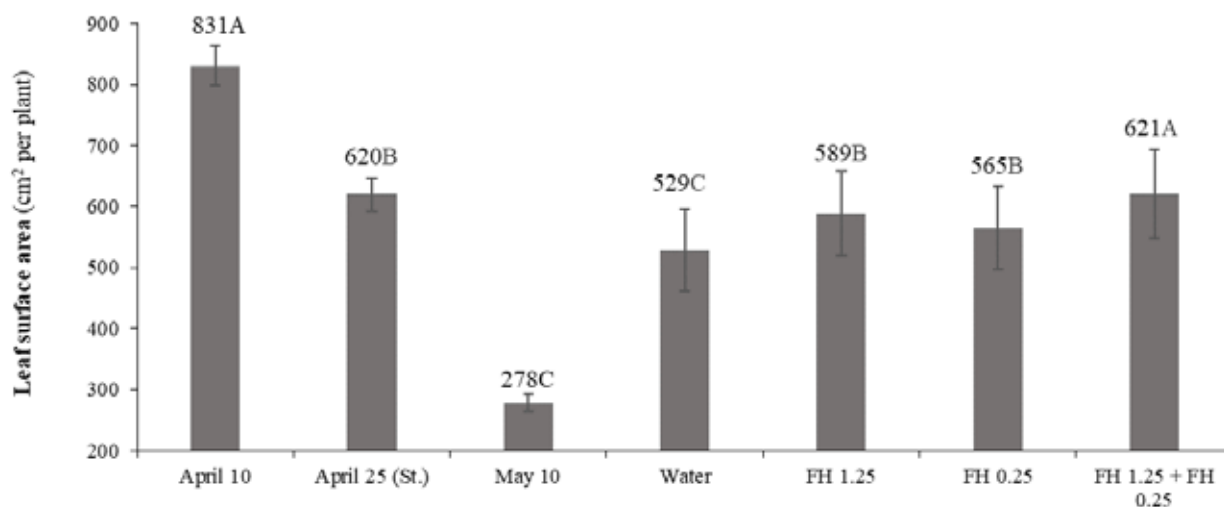


Figure 3. Average leek leaf surface area at the beginning of the flowering phase in 2020–2022 depending on the Fulvohumin (FH) treatment and the date of planting seedlings

Note: see explanation in Figure 2

The percentage of ripened pods in the total number in the inflorescence after Fulvohumin treatment was 82–84%, while in the untreated control it was on average 77%. Early planting and Fulvohumin treatments resulted in high-quality mother and seed plants, characterized by the best pod rip-

ening. Delayed planting by 15 and 30 days resulted in reduced pod ripening by 4–6% and 15%, respectively. The complex application of Fulvohumin increased the percentage of ripe pods by 8%. In terms of seed quality, the weight of 1,000 seeds did not differ significantly (Table 2).

Table 2. Leek seed productivity depending on the Fulvohumin (FH) treatment and cultivation date (means  $\pm$  SD for 2020–2022)

Treatments	Seedling planting date	Number of pods per inflorescence (pcs)	Percentage of ripe pods* (%)	Seed weight (g per plant)	Weight of 1,000 seeds (g)
Water (control)	April 10	440 <sup>c</sup> $\pm$ 17	86 <sup>ab</sup> $\pm$ 3	3.60 <sup>cde</sup> $\pm$ 0.17	3.08 <sup>abc</sup> $\pm$ 0.06
	April 25	417 <sup>cd</sup> $\pm$ 17	80 <sup>bc</sup> $\pm$ 1	3.14 <sup>fg</sup> $\pm$ 0.10	3.01 <sup>abc</sup> $\pm$ 0.05
	May 10	389 <sup>d</sup> $\pm$ 9	65 <sup>d</sup> $\pm$ 3	2.71 <sup>h</sup> $\pm$ 0.07	2.92 <sup>c</sup> $\pm$ 0.05
	Mean	415 <sup>C</sup> $\pm$ 20	77 <sup>B</sup> $\pm$ 9	3.15 <sup>C</sup> $\pm$ 0.40	3.00 <sup>A</sup> $\pm$ 0.06
Presowing seed treatment 1.25% FH	April 10	489 <sup>ab</sup> $\pm$ 35	89 <sup>a</sup> $\pm$ 4	3.98 <sup>b</sup> $\pm$ 0.14	3.12 <sup>ab</sup> $\pm$ 0.07
	April 25	450 <sup>bc</sup> $\pm$ 15	85 <sup>ab</sup> $\pm$ 4	3.46 <sup>def</sup> $\pm$ 0.12	3.05 <sup>abc</sup> $\pm$ 0.08
	May 10	408 <sup>cd</sup> $\pm$ 10	74 <sup>c</sup> $\pm$ 1	2.95 <sup>gh</sup> $\pm$ 0.10	2.96 <sup>bc</sup> $\pm$ 0.17
	Mean	449 <sup>B</sup> $\pm$ 22	83 <sup>A</sup> $\pm$ 7	3.46 <sup>B</sup> $\pm$ 0.45	3.00 <sup>A</sup> $\pm$ 0.11
Foliar application 0.25% FH	April 10	453 <sup>bc</sup> $\pm$ 18	89 <sup>a</sup> $\pm$ 3	3.66 <sup>bcd</sup> $\pm$ 0.13	3.10 <sup>abc</sup> $\pm$ 0.16
	April 25	425 <sup>cd</sup> $\pm$ 21	85 <sup>ab</sup> $\pm$ 3	3.26 <sup>fg</sup> $\pm$ 0.12	3.05 <sup>abc</sup> $\pm$ 0.10
	May 10	382 <sup>d</sup> $\pm$ 17	73 <sup>c</sup> $\pm$ 2	2.77 <sup>h</sup> $\pm$ 0.10	2.98 <sup>bc</sup> $\pm$ 0.09
	Mean	420 <sup>C</sup> $\pm$ 21	82 <sup>A</sup> $\pm$ 8	3.23 <sup>C</sup> $\pm$ 0.40	3.04 <sup>A</sup> $\pm$ 0.11
Presowing seed treatment + foliar application	April 10	521 <sup>a</sup> $\pm$ 19	91 <sup>a</sup> $\pm$ 5	4.36 <sup>a</sup> $\pm$ 0.18	3.18 <sup>a</sup> $\pm$ 0.13
	April 25	497 <sup>ab</sup> $\pm$ 15	86 <sup>ab</sup> $\pm$ 4	3.87 <sup>bc</sup> $\pm$ 0.23	3.09 <sup>abc</sup> $\pm$ 0.05
	May 10	454 <sup>bc</sup> $\pm$ 27	76 <sup>c</sup> $\pm$ 3	3.27 <sup>efg</sup> $\pm$ 0.06	3.00 <sup>abc</sup> $\pm$ 0.05
	Mean	491 <sup>A</sup> $\pm$ 24	84 <sup>A</sup> $\pm$ 8	3.83 <sup>A</sup> $\pm$ 0.49	3.09 <sup>A</sup> $\pm$ 0.12
Seedling planting date					
	April 10	476 <sup>A</sup> $\pm$ 23	89 <sup>A</sup> $\pm$ 4	3.90 <sup>A</sup> $\pm$ 0.34	3.12 <sup>A</sup> $\pm$ 0.12
	April 25 (control)	447 <sup>B</sup> $\pm$ 22	84 <sup>B</sup> $\pm$ 4	3.43 <sup>B</sup> $\pm$ 0.31	3.05 <sup>AB</sup> $\pm$ 0.08
	May 10	408 <sup>C</sup> $\pm$ 11	72 <sup>C</sup> $\pm$ 4	2.93 <sup>C</sup> $\pm$ 0.31	2.96 <sup>AB</sup> $\pm$ 0.12

\*from the total number of flowers in the inflorescence

Note: see Table 1

The correlation analysis shows that the average dependence of leek seed yield on the leaf surface area of seed plants at the beginning of the flowering phase is  $r = 0.69$  (Fig. 4). The leaf surface area of seed plants determines 48% of the variation in leek seed yield. Other researchers have found that inflorescence diameter, seed number, and seed weight per inflorescence are positively and significantly correlated with seed yield per hectare (Lamani & Deshpande 2017).

The highest seed weight was obtained after the combined treatment with Fulvohumin and planting on April 10, where this parameter was 17.5% higher than in the control. Seed yield varied depending on the years of research, but the response to planting and application of Fulvohumin was always the same (Table 3). The seed yield of plants (seedlings planted on April 10) was higher than the control (planted on April 25) by 21% and by 36% of those

planted on May 10 (Table 3). The highest yield of leek seeds was obtained in 2020, lower (by 36%) in 2021. The lowest seed yield in 2021 was the result of less developed mother plants and their freezing.

Over three years, depending on the use of the preparation, the seed yield of the variants of combined use of Fulvohumin (presowing seed treatment 1.25% FH + foliar fertilization 0.25% FH) was on average higher than the control by 39%, presowing seed treatment by 21%, and foliar fertilization by 9%. Without Fulvohumin, the average seed yield was 347 kg·ha<sup>-1</sup>. Depending on the growing period, the seed yield with Fulvohumin foliar fertilization was higher than the control by 19–37 kg·ha<sup>-1</sup>. Over the years of research, the average, highest yield was obtained from planting on April 10 in the variants of presowing seed treatment with Fulvohumin and its combined use (presowing seed treatment 1.25% FH + foliar fertilization 0.25% FH) – 522–587 kg·ha<sup>-1</sup>.

The yield of the above variants of Fulvohumin application on plots of plants planted on April 25 was 20–40% higher compared to the con-

trol. When plants were planted on May 10, the seed yield was 316 kg·ha<sup>-1</sup>, 29% less than the control.

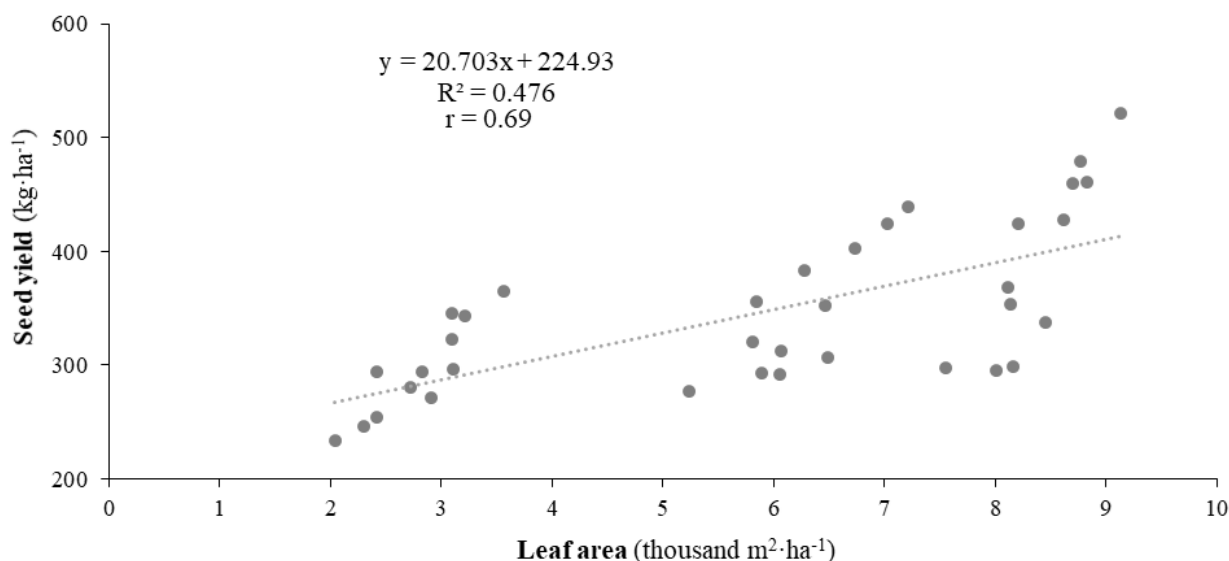


Figure 4. Correlation dependence of leek seed yield indicators (y) and leaf surface are in the budding phase (x)

Table 3. Leek seed yield depending on Fulvohumin (FH) treatment and growing periods in 2020–2022

Treatments (factor A)	Seedling planting date (factor B)	Leek seed yield (kg·ha <sup>-1</sup> )			
		2020	2021	2022	average
Water (control)	April 10	523 <sup>de</sup> ±25	295 <sup>d</sup> ±10	432 <sup>cd</sup> ±25	417 <sup>e</sup> ±8
	April 25	443 <sup>fg</sup> ±9	219 <sup>e</sup> ±8	380 <sup>def</sup> ±15	347 <sup>g</sup> ±7
	May 10	325 <sup>i</sup> ±16	165 <sup>f</sup> ±4	341 <sup>gh</sup> ±11	277 <sup>i</sup> ±5
	mean	430 <sup>D</sup> ±86	226 <sup>D</sup> ±56	384 <sup>C</sup> ±42	347 <sup>D</sup> ±60
Presowing seed treatment 1.25% FH	April 10	650 <sup>b</sup> ±44	359 <sup>bc</sup> ±20	557 <sup>ab</sup> ±39	522 <sup>b</sup> ±9
	April 25	525 <sup>de</sup> ±3	318 <sup>d</sup> ±13	414 <sup>cde</sup> ±8	419 <sup>e</sup> ±15
	May 10	398 <sup>gh</sup> ±16	230 <sup>e</sup> ±7	327 <sup>gh</sup> ±10	318 <sup>h</sup> ±5
	mean	524 <sup>B</sup> ±110	302 <sup>B</sup> ±58	433 <sup>B</sup> ±91	420 <sup>B</sup> ±87
Foliar application 0.25% FH	April 10	598 <sup>bc</sup> ±5	325 <sup>cd</sup> ±9	440 <sup>c</sup> ±7	454 <sup>d</sup> ±6
	April 25	488 <sup>ef</sup> ±18	290 <sup>d</sup> ±15	367 <sup>efg</sup> ±12	382 <sup>f</sup> ±9
	May 10	370 <sup>hi</sup> ±7	223 <sup>e</sup> ±11	295 <sup>h</sup> ±21	296 <sup>i</sup> ±4
	mean	485 <sup>C</sup> ±98	279 <sup>C</sup> ±46	367 <sup>C</sup> ±63	377 <sup>C</sup> ±68
Presowing seed treatment + foliar application	April 10	714 <sup>a</sup> ±45	441 <sup>a</sup> ±33	605 <sup>a</sup> ±20	587 <sup>a</sup> ±6
	April 25	578 <sup>cd</sup> ±16	365 <sup>b</sup> ±16	522 <sup>b</sup> ±37	488 <sup>c</sup> ±6
	May 10	434 <sup>fg</sup> ±13	289 <sup>d</sup> ±13	392 <sup>def</sup> ±21	371 <sup>f</sup> ±5
	mean	575 <sup>A</sup> ±122	365 <sup>A</sup> ±68	506 <sup>A</sup> ±95	482 <sup>A</sup> ±92
Seedling planting date					
April 10		621 <sup>A</sup> ±78	355 <sup>A</sup> ±59	509 <sup>A</sup> ±80	495 <sup>A</sup> ±68
April 25 (control)		509 <sup>B</sup> ±52	298 <sup>B</sup> ±56	421 <sup>B</sup> ±66	409 <sup>B</sup> ±54
May 10		382 <sup>C</sup> ±43	227 <sup>C</sup> ±47	339 <sup>C</sup> ±39	316 <sup>C</sup> ±34

Note: see Table 1

The highest quality of seeds was obtained by combining the Fulvohumin treatment with the planting date of April 10 – the weight of 1,000 seeds was 3.18 g. When using only Fulvohumin, the weight of 1,000 seeds was lower – 3.10–3.12 g, but the means did not differ significantly. The coefficient of variation of the weight of 1,000 seeds in this experiment was on average 3%, while in the study of De Clercq et al. (2003) it was 13–22%. In experiments with wheat, the highest values of the weight of 1,000 grains (33.6 g) were found after the use of fulvic acid (Al-Haidary & Al-Zubaidy 2020).

Our three-year study revealed an interesting finding – the effect of Fulvohumin treatment on seed yield was less significant than the planting date. This suggests that farmers and researchers should pay more attention to the optimal planting date to obtain maximum seed yield. The coefficient of variation of 26% further indicates the instability of seed productivity of nonreplanted seed plants. The correlation analysis also showed that the weight of 1,000 seeds and the yield of leek seeds under the studied conditions dependent the least on the number of seeds in pods ( $r = 0.60$  and  $r = 0.82$ ). It was found that the weight of a 1,000 leek seeds depends on the genotype, and the optimal weight is 2.5–3.0 g (De Clercq et al. 2003).

The productivity of leek seeds depends on many factors, including: the photosynthetic potential of plants in the first and second year of vegetation, winter resistance, and conditions of generative development. Our study indicates the importance of using Fulvohumin on the leeks and planting seedlings on April 10, which allows obtaining higher biometric parameters of one- and two-year-old plants, and thus increases the yield and quality of seeds.

## CONCLUSION

The date of planting leek seedlings and applying Fulvohumin affects all parameters of plant growth, seed development, and yield. The most effective method is early planting – on April 10, which allows the production of the most robust mother plants that have survived winter conditions in the highest percentage. This factor also increases the quality of seed plants, flowering, and seed yield. The second factor – double application of Fulvo-

humin on seeds and foliar in the first year of cultivation, enhanced all parameters, which led to the highest seed yield. Although there were significant differences in seed yield depending on the weather in a given year, the date of planting seedlings and Fulvohumin helped to obtain higher seed yield.

## Conflict of interest

The authors declare no conflict of interest.

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