



CARROT (*DAUCUS CAROTA* L.) RESPONSE TO COMPLEX BIOLOGICAL PREPARATIONS THROUGH SEED QUALITY AND YIELD TRAITS IN SOUTHEASTERN KAZAKHSTAN

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SUMMARY

Carrot (*Daucus carota* L.) is an important food crop; however, its productivity reaps considerable effects from poor seed germination and challenging climatic conditions. Although pre-sowing seed treatment with biological stimulants has proven effective, this approach has not yet reached studies in Kazakhstan, highlighting the relevance of this research. The concerned study aimed to determine the effect of hydropriming with complex biological preparations on seed germination energy and rate, resistance to fungal pathogens (*Alternaria dauci* and *Fusarium oxysporum f.sp. Carotae*), biochemical characteristics, plant morphometric parameters, and carrot root yield. The study comprised six treatments, including the control with four replications, carried out during 2024–2025. The results revealed the pre-sowing treatment of carrot seeds with complex biological preparations accelerates plant growth and development through the formation of uniform and viable seedlings. Likewise, pre-sowing treatment enhances resistance to both abiotic and biotic stresses and contributes to a 1.5–2-fold reduction in using plant protection products. Improvements in laboratory and field parameters manifested with an increase in germination (6.3%–15.15%) and proportion of healthy seedlings (11.71%–20.61%), along with a simultaneous increase in productivity (18.34%–30.55%) and improved quality indicators compared with the control.

Keywords: Carrot (*D. carota* L.), hydropriming, complex biopreparations, germination, fungal diseases, plant morphological traits, productivity, quality, Southeastern Kazakhstan

Key findings: Carrot (*D. carota* L.) seed treatment with complex biological preparations considerably increased the germination and germination energy, enhanced resistance to fungal pathogens, accelerated plant growth and development, and improved productivity and root quality.

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INTRODUCTION

The organic agriculture development critically requires the creation of new biologically based agrotechnological and innovative solutions in Kazakhstan. A key aspect is seed quality, as uniform seed germination and high viability of seed material determine sustainable establishment of plants, their vegetative growth—including phytosanitary status—and ultimately, the highest productivity. Seed germination begins with water uptake, followed by the activation of seeds' internal physiological processes. This process progressed in the formation of the primary root (Tuan *et al.*, 2019); however, the crucial growth phases had internal and external factors influencing these (Makhaye *et al.*, 2021).

With abiotic stress conditions, it is typical that seeds struggle to germinate and produce the full and uniform seedlings. For this reason, pre-sowing seed treatment is an essential tool to enhance their resistance to adverse environmental conditions. The improvement of seed quality enables the technology known as pre-sowing seed treatment for effective application. By treating seeds with growth-regulating compounds, significant improvements in seed quality have been evident in different crop plants (Jatana *et al.*, 2024).

In the present era, research pays considerable attention to applying biostimulants, depending on their composition and function, classifying these into humic substances, micro- and macro-elements, hydrolyzed proteins, seaweed extracts, phytohormones, and various microorganisms. Pre-sowing carrot (*Daucus carota* L.) seeds with treatment of humic preparations reduces the negative effect of seed trauma and considerably decreases infection caused by fungal pathogens arising from internal seed infections (Alhariri and Boras, 2020).

Carrot (*D. carota* L.) is a crop characterized by a significantly low seed-germination rate and slow sprouting. With favorable conditions, seeds usually germinate within 10–15 days, whereas at the extremely low and high temperatures, this process may

take 25–30 days (Aitbayeva *et al.*, 2024). The reproductive biology of carrots complicates seed germination and the formation of uniform seedlings. The untreated carrot seeds with slow germination showed an association with the presence of inhibitors in the seed coat. It is common for the carrot seed to have a dense seed coat containing 0.5%–1.0% essential oils and the growth inhibitor carotol, which hinders moisture access to the embryo, delaying seed swelling and, eventually, germination. For this reason, the pre-sowing seed treatment is one of the most crucial elements of carrot cultivation technology. Studies have shown that soaking seeds in specialized solutions can accelerate seedling emergence by 3–5 days (Alhariri and Boras, 2020; Jatana *et al.*, 2024).

Carrot is recognizably one of the most important vegetable crops, representing high consumer interest due to the elevated content of provitamin A, carotene, vitamins B, C, K, and PP, and minerals in the roots. According to past studies, poor seed germination is one of the causes of the reduction in carrot cultivation area and productivity (Ghafoor *et al.*, 2020). Therefore, for achieving maximum carrot productivity, along with obtaining high-quality roots, one of the viable factors is the formation of uniform and vigorous seedlings, which requires a considerable increase in seed germination energy.

Recent studies confirmed the pre-sowing treatment of carrot seeds with biostimulants accelerates germination, improves seedling vigor, and enhances plant resistance to stressful conditions (Muhie *et al.*, 2021). Research has shown that high air temperatures during seed germination can reduce carrot productivity by up to 47% due to irreversible damage to cell membranes. In this regard, the exogenous application of growth-stimulating agents significantly improves plant growth and development by mitigating the harmful effects of abiotic stress conditions. Moreover, recent past findings revealed carrot seeds' treatment also boosts germination and seedling viability by up to 35% under salinity stress and up to 28% under drought stress conditions (Nowicki *et al.*, 2025).

Other studies confirmed the effectiveness of microbial biostimulants on

carrot plants during the vegetative period (Zhu et al., 2024). Reliable previous findings exhibited that the combined application of biological stimulants with organic fertilizers enhances carrot productivity and root quality (Girhepunje et al., 2025), confirming the necessity of conducting such studies under the existing conditions of the Kazakhstan region.

Carrot is a staple food product listed as a socially significant food commodity in Kazakhstan. The industrial carrot cultivation area in the country covers approximately 13,000 hectares. The main production zones have their concentration in the northeastern region (36.2% of the total area), as well as in the Zhambyl (18.8%), Turkestan (15.0%), and Almaty (10.7%) regions (AB-Center, 2024). The western, southwestern, and northern regions are traditionally the less favorable for commercial carrot production (Amirov, 2019). According to 2025 data, the gross carrot yield in Kazakhstan amounted to approximately 446,300 tons; however, production has shown a decline compared with relatively higher levels in previous years. Against this background, by the beginning of 2026, carrots became the fastest-rising food product among socially significant commodities, with a 25.8% year-on-year price increase, highlighting their vital role in ensuring national food security (Alto Consulting Group, 2025). In Kazakhstan, carrots undergo cultivation during the summer, while year-round consumption relies on stored root crops kept under long-term storage conditions of five to seven months or more. In ensuring better preservation during storage, it is necessary to implement integrated preventive measures at early stages of cultivation, which can limit pathogen development and improve storage stability. Previous studies have shown postharvest losses of carrots due to infectious diseases can reach 25%–40% on average (Poberezny et al., 2020). Therefore, the production of healthy root crops largely depends on the quality of seed material. Vegetable crops often receive adverse impacts from fungal pathogens, which are present both on the surface and inside the seeds. Carrots are susceptible to viral, bacterial, and fungal diseases, with fungal

infections being among the main biotic factors affecting yield and postharvest quality.

Kazakhstan possesses significant land resources and strong agricultural production potential, allowing it to be a promising producer and supplier of agricultural products while also ensuring domestic market demand. Principles of sustainable agriculture, focused on environmental safety and high productivity, require the introduction of modern cultivation technologies aimed at biological intensification of agroproduction. In this context, pre-sowing seed treatment with growth-stimulating agents is an effective tool for improving seed quality, accelerating germination, and enhancing plant stress resistance. Studies related to seed hydropriming of carrots using complex biological preparations had not previously taken place under Kazakhstan conditions, which emphasized their relevance and high practical significance and served as the basis for the consequent study.

MATERIALS AND METHODS

Experimental site and procedure

The timely study on carrot (*D. carota* L.) transpired in 2024–2025 at the Regional Branch 'Kainar' of the LLP - Kazakh Research Institute of Fruit and Vegetable Growing, located in the Trans-Ili Alatau, Southeastern Kazakhstan (1000–1050 m above sea level). The climate is sharply continental, with average air temperatures of 24 °C–26 °C in July and from –8 °C to –12 °C in January, and annual precipitation of 350–600 mm. The soil is dark chestnut, medium loamy, slightly alkaline (pH 8.36–8.37), with a humus content of 2.27%.

In the experiments, the study used the mid-season carrot cultivar Alau, officially recommended for cultivation in this zone. The seeding rate was 3.5 kg ha⁻¹. Sowing commenced on April 29 and 30 during the 2024 and 2025 growing seasons, respectively. The established experiment had a randomized design with four replications, and the plot area was 25 m². Seed sowing was in a three-row pattern with a 70-cm spacing. The preceding

crop was potatoes. Mineral fertilizers applied had the rate of $N_{90}P_{90}K_{60}$, carrying out irrigation five times at a $500\text{--}550\text{ m}^3\text{ ha}^{-1}$ rate. Agronomic practices included autumn plowing (27–29 cm), spring soil preparation, double harrowing, inter-row cultivation, hilling, irrigation, and plant protection measures against pests, diseases, and weeds.

Experimental design

The experimental design included six treatments (T1–T6). These comprised the control (soaking in water for 1 h) (T1); Fitolaza (1.0 mL/L) + Fitosporin (2.0 g/L for 1 h), based on enzymes and elicitors combined with a microbiological bactericide (T2); Celobacirin (1.0 mL/L) + Phosphobacirin (1.5 mL/L for 1 h), based on microbial inoculants (T3); Scudo (1.5 mL/L for 45 min), based on water-soluble copper compounds, amino acids, and organic substances (T4); Calcium Humate (0.5% for 1 h) + Fitolavin (2.0 mL/L for 45 min), based on phytohormone and organic compounds and a natural antibiotic (T5); and Biosok Energy+ (10 mL/L for 1 h) + Koppert (5.0 g/L for 45 min), based on vermicompost, beneficial microorganisms, and copper (T6). The selected scheme includes a wide range of preparations from biostimulants and microbial inoculants to fungicidal agents with a biologized composition—allowing for a comprehensive assessment of their effects on laboratory and sowing parameters of carrot seeds. Pre-sowing treatment of carrot seeds occurred at the BBCH 00 stage.

Traits measurement

The evaluated seed parameters included germination (%), germination energy (%), and phytosanitary status (infection by pathogenic microflora, %). The determination of germination energy and seed germination had four samples of 100 seeds each taken and germinated in pre-prepared containers in a forced-air thermostat at a controlled temperature ($0\text{ }^{\circ}\text{C}$ – $28\text{ }^{\circ}\text{C}$). Monitoring of germination and seed moisture continued as needed. Growth parameters and germination energy underwent recording on day 7 and final

germination on day 14, in accordance with GOST 12038-84.

Phytosanitary analysis proceeded using the seed plating method on nutrient media in Petri dishes (Czapek agar) in four replications, with 10 seeds per dish. Incubation ensued in a thermostat at a temperature of $25\text{ }^{\circ}\text{C} \pm 1\text{ }^{\circ}\text{C}$ for 5–7 days under conditions close to darkness, while maintaining optimal medium humidity. Seed infection assessment daily started from the third day, with registration of mycelial growth and sporulation of phytopathogenic fungi. The species composition of pathogens, as determined by the study, used microscopy at $\times 100$ and $\times 400$ magnifications. Samples entailed examination for the presence of mycelium, spores, and conidia of fungal pathogens. Recording the number of infected seeds continued by counting affected seedlings in each replication in accordance with GOST 12044–93.

Under field conditions, the phenological and biometric observations of carrot plants took place at the following growth stages: emergence (BBCH 10–15); full emergence (BBCH 19–24); formation of 3–5 true leaves (BBCH 32–39); beginning of root formation (BBCH 52–58); intensive root growth (BBCH 75–81); and technical maturity of roots (BBCH 109–118) (Meier, 2018).

Morphological parameters of carrot plants reached assessment at two key stages: a) intensive root growth and b) technical maturity. For this purpose, 10 model plants received random selection from each treatment. At each stage, plant weight, the number of leaves, and the length of the longest leaf attained recording. Additionally, during the harvest formation phase, the marketable root weight, root length, and diameter garnered measurements (Dospekhov, 1980; Litvinov, 2011). Yield accounting occurred for each treatment in four replications. Total marketable root yield entailed calculation and expression in t/ha. Based on these data, determining yield increase and percentage gain relative to the control (T1) succeeded.

The determination of total soluble solids used a refractometric method in accordance with GOST 28562-90. Total sugar

content sustained analysis according to GOST 8756.13-87; vitamin C content according to GOST 24556-89; carotene content by spectrophotometry according to GOST ISO 6558-2:2019; and nitrate content in the carrot roots by a potentiometric method in accordance with GOST 29270-95.

Statistical analysis

The comparison of mean values among the six treatments (T1–T6) for each measured trait employed the one-way analysis of variance (ANOVA). For significant ($p \leq 0.05$) mean differences, post-hoc comparisons performed utilized Tukey's honestly significant difference (HSD) test. The analysis and data visualization proceeded using R software (version 4.2.1) and STATISTICA 10. Additionally, the least significant difference ($LSD_{0.05}$) values' calculation sought to support the interpretation of treatment effects.

RESULTS AND DISCUSSION

Pre-sowing seed soaking proved particularly effective for small-seeded crops, such as carrots (*D. carota* L.), as it ensures rapid and

uniform seedling emergence. Seed priming is a widely used method across various crops worldwide; however, such studies on carrot crops have not previously existed in Kazakhstan. In this context, laboratory experiments took place to hydrate carrot seeds using different growth-stimulating solutions. The greatest positive effect resulted in treatments T2, T3, and T5, which significantly ($p \leq 0.05$) exceeded the control (T1) for germination energy and germination percentage. In the control treatment, germination energy was 66.0%, and laboratory germination was 77.9%. For treatment T2, these indicators increased to 75.4% and 89.7%, respectively, indicating a pronounced stimulating effect of the applied biopreparations. In treatments T3 and T5, a notable improvement in seed sowing quality was also evident: the increase in germination energy ranged from 10.76% to 13.33%, while laboratory germination increased by 9.63%–15.15% compared with the control. Treatments T4 and T6 showed a tendency toward improvement in studied parameters; however, the differences compared with the control were not statistically significant ($p \geq 0.05$) (Table 1).

Table 1. Effect of hydropriming with complex biological preparations on germination energy and germination rate of carrot seeds.

Experimental variants	Years of study	Seed germination energy (7th Day)					Seed germination rate (14th Day)				
		1	2	3	4	Means	1	2	3	4	Means
T1	2024	68.5	71.1	62.3	66.9	67.2	80.3	77.2	78.1	78.4	78.5
	2025	62.5	67.3	63.8	66.0	64.9	75.1	79.5	76.7	77.9	77.3
	Average	65.5	69.2	63.0	66.4	66.0	77.7	78.3	77.4	78.1	77.9
T2	2024	76.1	80.3	77.8	72.6	76.7	90.9	92.7	89.0	91.4	91.0
	2025	72.0	76.4	73.5	74.5	74.1	86.0	90.9	87.5	89.2	88.4
	Average	74.0	78.3	75.6	73.5	75.4	88.4	91.8	88.2	90.3	89.7
T3	2024	75.3	72.9	74.4	80.6	75.8	89.2	86.5	88.7	90.4	88.7
	2025	74.7	71.9	73.0	76.2	73.9	88.7	83.4	86.6	90.1	87.2
	Average	75.0	72.4	73.7	78.4	74.8	88.9	84.9	87.6	90.2	87.9
T4	2024	73.3	68.9	75.2	70.6	72.0	84.6	79.7	87.2	80.5	83.0
	2025	68.2	73.0	69.7	72.3	70.8	80.8	85.0	81.1	83.5	82.6
	Average	70.7	70.9	72.4	71.4	71.4	82.7	82.3	84.1	82.0	82.8
T5	2024	77.6	71.8	73.5	73.1	74.0	90.2	83.3	86.5	86.0	86.5
	2025	70.0	74.5	71.9	72.5	72.2	81.3	87.6	84.0	84.7	84.4
	Average	73.8	73.1	72.7	72.8	73.1	85.7	85.4	85.2	85.3	85.4
T6	2024	73.6	70.2	68.5	70.9	70.8	85.6	80.9	78.8	82.3	81.9
	2025	70.5	74.8	71.5	73.7	72.6	82.7	88.0	83.3	85.9	85.0
	Average	72.0	72.5	70.0	72.3	71.7	84.1	84.4	81.0	84.1	83.4
Experiment precision (m%)						1.29					
$LSD_{0.05}$						2.89					

The effectiveness of pre-sowing hydration of carrot seeds using organic extracts revealed that stimulants based on algae and humic substances appeared to be particularly effective (Muhie and Demir, 2023). Similar results came from studies by Mukhina *et al.* (2022), who reported a considerable increase in carrot seed germination by 12.2%–13.6% when treated with Epin-Extra and Ecopin (TPS). Other studies (Yanchenko *et al.*, 2024) also showed soaking carrot seeds in preparations based on amino acids and nitrogen-fixing bacteria enhanced the seeds' germination energy from 46% (control) to 64% and 80%, respectively.

Pathogens, such as *Alternaria dauci* and *Fusarium oxysporum* f. sp. *Carotae* (carrot root diseases) can be seed-borne and negatively affect the vegetative productivity potential of the carrot crop. The *Alternaria* pathogen also causes damping-off in seedlings (black leg). During carrot storage, losses due to alternariosis can reach 30%–60%, leading to decay of the growing point and up to a 40% reduction in seed productivity. According to Porsev *et al.* (2023), phytosanitary assessment showed seed treatment with biofungicides (*Trichoderma viride* 471 and Fitosporin-M) and biostimulants (Kornevin and Epin-Extra) reduced carrot seed infection with *Alternaria* to 2%–3%, depending on the cultivars. Zhang *et al.* (2020) reported that, on average, the germination of healthy seeds was 28.7% higher than that of the seeds infected with fungal pathogens.

The laboratory studies revealed that the control treatment (T1) had the lowest proportion of healthy seedlings (73.25%) and the highest incidence of *Alternaria* and *Fusarium* infections (Figure 1), as well as the highest percentage of non-germinated seeds (10.3%). Seed priming with biological preparations enhanced the proportion of healthy seedlings (81.85%–88.35%) and considerably reduced the level of infection (0.95%–1.50%). The most effective treatment was T2, which ensured minimal losses from fungal diseases, followed by T3 and T5 (Figure 2). Soaking of carrot seeds increases radicle emergence by 35%–65% and accelerates the germination rate (Emeghara *et al.*, 2025).

Muhie *et al.* (2024) reported the enhanced enzymatic activity and mobilization of seed reserves induced by biostimulants promote faster transition of plants to subsequent developmental stages. A report has also stated that hydropriming ensures a faster and more uniform seedling emergence, accelerating phenological traits' development.

The phenological observations were consistent with these findings and revealed a significant acceleration in the progression of key ontogenetic stages compared with the control. This is likely due to the improvement in seed sowing quality and, consequently, the formation of an earlier harvest. The duration from sowing to physiological maturity ranged from 108 days (T2) to 116 days (T1). Thus, the study established that the combined use of biological preparations in seed treatment accelerated the onset of individual phenological stages of carrots by 6–9 days versus the control (Figure 3). By assessing the hydropriming effect with a complex of biostimulants on carrot growth parameters, remarkable differences were noteworthy among the treatments. Mbuyisa *et al.* (2023) also reported the positive effects of biological fertilizers and phytohormones (auxins, gibberellins, and cytokinins), which stimulate cell division and elongation, leading to enhanced plant biomass. Previous studies exhibited that hydropriming promotes elongation of carrot seedling roots from 4.31 to 4.89 cm, positively affecting plant growth and development during the vegetative period (Sanches *et al.*, 2021).

The analysis of biometric parameters of carrots during 2024–2025 showed that during the intensive root growth phase, the highest plant weight, the number of leaves, and the length of the longest leaf resulted in treatment T2 (246.9 g, 15.25 leaves, and 59.16 cm, respectively). Treatment T3 also demonstrated the highest values; however, it was slightly lower in performance than T2. The remaining treatments (T4–T6) displayed intermediate values, while the control (T1) had the lowest measurements (165.45 g, 12.66 leaves, and 49.96 cm). These results confirmed the maximum effectiveness of the pre-sowing treatment applied in T2 (Table 2).

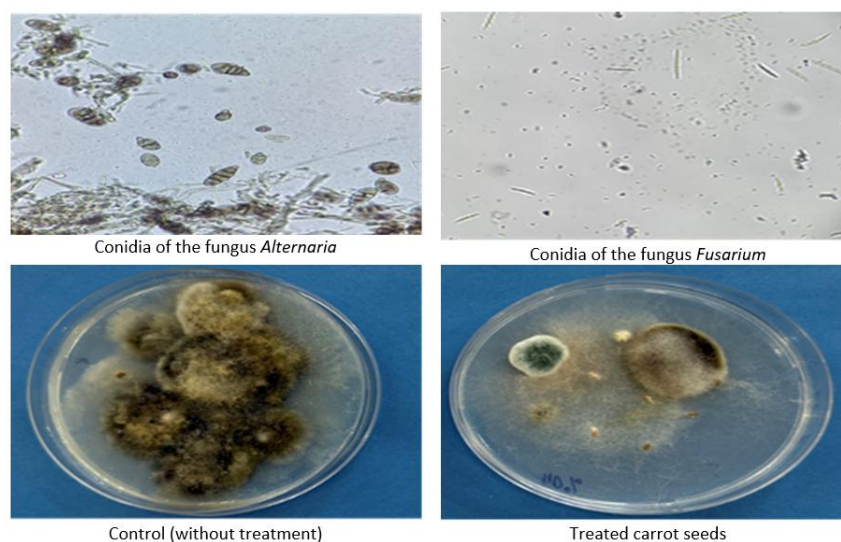


Figure 1. Laboratory studies showing incidence of *Alternaria* and *Fusarium* infections.

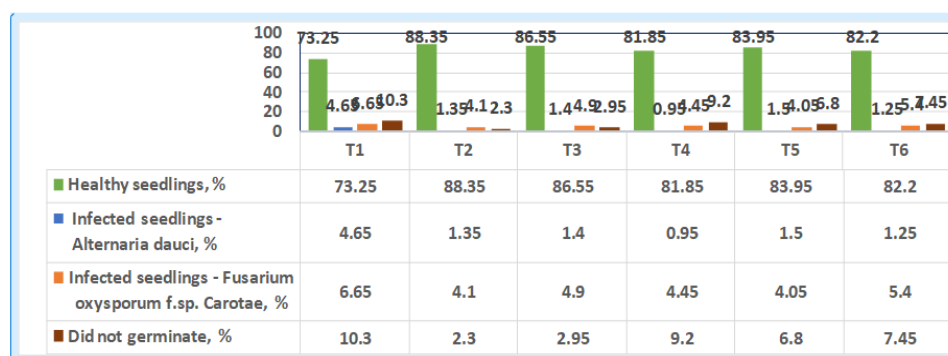


Figure 2. Effect of hydropriming with complex biological preparations on phytopathological parameters of carrot seeds.

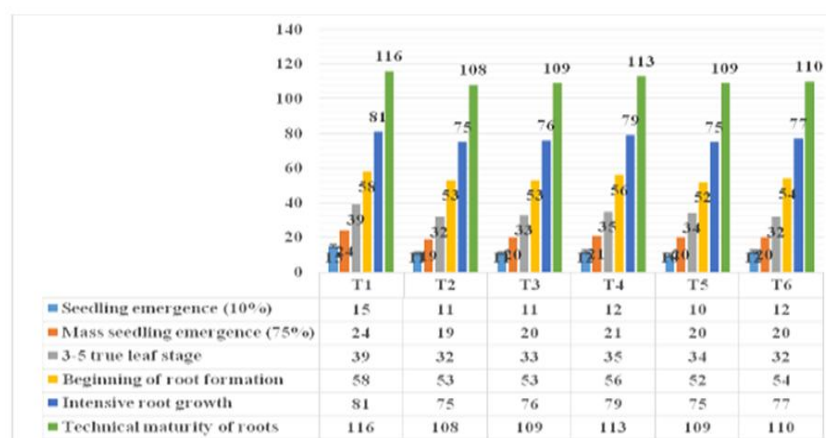


Figure 3. Effect of priming with complex preparations on the dynamics of carrot phenological development.

Table 2. Effect of hydropriming with complex preparations on biometric parameters of carrot plants (phase - intensive root growth).

Experimental variants	Years of study	Plant weight (g)	Means	Number of leaves	Means	Longest leaf length (cm)	Means
T1	2024	164.38±2.28	165.45	12.53±0.15	12.66	49.18±0.81	49.96
	2025	166.53±2.76		12.80±0.31		50.75±1.29	
T2	2024	242.95±1.67	246.90	15.13±0.12	15.25	58.48±0.37	59.16
	2025	250.85±4.30		15.38±0.18		59.85±1.83	
T3	2024	236.05±1.39	236.26	14.98±0.13	15.04	57.63±0.33	56.84
	2025	236.48±1.42		15.10±0.25		56.05±1.15	
T4	2024	212.08±1.60	213.41	13.60±0.18	13.50	54.08±0.19	53.84
	2025	214.75±1.87		13.40±0.20		53.60±0.60	
T5	2024	221.45±0.85	222.35	14.25±0.13	14.05	55.88±0.25	56.44
	2025	223.25±1.38		13.85±0.31		57.00±1.28	
T6	2024	214.05±1.82	217.15	13.63±0.18	13.71	55.18±0.34	54.05
	2025	220.25±4.10		13.80±0.11		52.93±1.03	
Experiment precision (m%)			1,6		2,7		2,5
LSD _{0.05}			3,8		0,42		1,35

Our previous studies demonstrated a close relationship between the development of vegetative biomass and the yield components in solanaceous crops (Aitbayeva *et al.*, 2025). In this present study, pre-sowing seed treatment with biostimulants significantly increased the marketable root weight, length, and diameter. However, the most pronounced effects emerged in T2, where the average root weight reached 200.05 g, length (15.9 cm), and diameter (3.2 cm)—almost 1.5 times that of the control. Treatments T3 and T5 also gave high values for the studied parameters. In these variants, root weight increased by 40–47.15 g, root length exceeded the control (T1) by 4.3–5.25 cm, and root diameter by 0.25–0.30 cm. The obtained results are consistent with previously published data, according to which leaf area and biomass directly influence photosynthetic processes and assimilate distribution (Reid, 2019), thereby determining root weight and size (Table 3).

Treatments T4 and T6 provided a more moderate improvement in the studied morphometric traits, which may refer to differences in their composition and mode of action compared with T2, T3, and T5. The latter treatments exhibited a more pronounced stimulatory effect due to their enzymatic and microbiological components. In this regard, their use may be more appropriate and economically advantageous during the growing

season as foliar fertilizers for carrot plants. It has also been noticeable that pre-sowing seed treatment enhanced the resistance to abiotic and biotic stress factors, thereby positively affecting both the yield and product quality. The use of low-quality carrot seeds can considerably reduce productivity by up to 27% (Chipenete *et al.*, 2021).

A comparative analysis of yield revealed a significant increase in root productivity by treating carrot seeds with hydropriming compared with the control. In the control (T1), the average yield was 22.52 t/ha (21.6–23.5 t/ha across replications). In the treated variants (T2–T6), the yield rose to 27.10–29.40 t/ha. However, the highest yield recorded occurred in T2 (29.40 t/ha), representing an increase of 6.88 t/ha (30.55%) over the control. Comparable results were also apparent in T3, with a yield of 29.11 t/ha (+6.59 t/ha or 29.26%). The analysis of variance showed substantial ($p \leq 0.001$) differences among the treatments, confirming the reliable effect of the applied biostimulants on carrot yield. A high W value (0.99) indicates the robust consistency of the data, while a low experimental error ($m = 2.01\%$) also confirms the high accuracy of the presented results (Table 4).

Agronomic practices, including pre-sowing seed treatment, by optimizing plant nutrition and improving biometric

Table 3. Effect of hydropriming with complex preparations on biometric parameters of carrot plants (phase - technical maturity of roots).

Experimental variants	Years of study	Marketable root weight (g)		Root length (cm)		Root diameter (cm)	
		min	max	min	max	min	max
T1	2024	55.8±2.3	134.5±9.41	6.1±0.49	9.9±0.72	1.4±0.18	2.8±0.34
	2025	59.3±2.5	136.6±9.27	6.4±0.54	10.3±0.90	1.6±0.20	2.5±0.23
	Average	57.55	135.55	6.25	10.1	1.5	2.65
T2	2024	97.3±2.6	197.9 ±16.75	9.4±0.18	15.6±1.06	2.3±0.19	3.3±0.28
	2025	99.0±2.8	202.2±9.49	9.6±0.47	16.2±1.16	2.7±0.25	3.1±0.31
	Average	98.15	200.05	9.5	15.9	2.5	3.2
T3	2024	93.4±2.3	181.1±7.75	9.2±0.10	15.1±0.71	2.2±0.17	3.0±0.30
	2025	95.1±2.4	184.3±5.73	9.4±0.18	15.6±0.84	2.4±0.20	2.9±0.22
	Average	94.25	182.7	9.3	15.35	2.3	2.95
T4	2024	84.3±1.8	166.3±5.82	8.5±0.25	13.2±0.74	2.1±0.12	3.0±0.31
	2025	85.7±1.9	167.7±2.89	9.0±0.25	14.3±0.74	2.5±0.19	3.1±0.26
	Average	85.00	167.00	8.75	13.75	2.30	3.05
T5	2024	89.7±2.1	174.0 ±14.15	9.0±0.22	14.2±0.65	2.2±0.12	2.8±0.28
	2025	90.9±2.2	177.1±5.57	9.2±0.31	14.6±1.30	2.3±0.12	3.0±0.17
	Average	90.3	175.55	9.1	14.4	2.25	2.90
T6	2024	85.1±1.9	170.1±3.97	8.7±0.33	14.5±0.90	2.2±0.14	2.9±0.21
	2025	86.8±2.0	171.6±1.98	9.0±0.47	15.4±2.15	2.3±0.14	2.8±0.13
	Average	85.95	170.85	8.85	14.95	2.25	2.85
Experiment precision (m%)		2,0		23		2,6	
LSD _{0.05}		4,6		1,55		0,32	

Table 4. Effect of hydropriming with complex preparations on carrot root productivity (Average for 2024–2025).

Experimental variants	Replicates (t/ha)				Mean yield (t/ha)	Additional tuber yield	
	I	II	III	IV		t/ha	%
T1	21.6	23.3	23.5	22.0	22.52	-	-
T2	29.8	30.1	29.2	28.5	29.40	6.88	30.55
T3	28.0	29.9	27.6	30.9	29.11	6.59	29.26
T4	26.3	26.6	27.9	25.8	26.65	4.13	18.34
T5	27.5	26.9	27.2	29.3	27.72	5.20	23.09
T6	27.3	26.8	26.9	27.4	27.10	4.58	20.34
Experiment precision (m%):					2.01		
LSD _{0.05}					1.68		
ANOVA results: W:					0.99		
p-value:					< 0.001		

characteristics, have a prominent effect on the biochemical composition of carrot roots. The intensity of vegetative growth emerged as closely associated with the accumulation of biologically active compounds, such as carotenoids, ascorbic acid, and total soluble solids. The biochemical analysis showed the treatment T5 surfaced with the highest content of total soluble solids (15.96%), total sugars (13.10%), and carotene (8.84 mg/100 g). These results were consistent with the findings

of Ride *et al.* (2024), who reported that humic acids stimulate the synthesis and accumulation of sugars and dry matter. The next highest values resulted in treatment T2, which also expressed the highest carotene (8.84 mg) and sugar content (12.76%). The highest vitamin C content (8.05 mg) was evident in T3, likely due to microbial stimulants enhancing carbohydrate metabolism, which serves as a precursor for ascorbic acid synthesis.

Table 5. Effect of hydropriming with complex preparations on quality parameters of carrot roots (Average for 2024–2025).

Experimental variants	Dry matter (%)	Total sugars (%)	Vitamin C (mg %)	Carotene (mg %)	Nitrates (MPC - 400 mg/kg)
T1	14.98	7.30	6.72	6.60	104
T2	15.32	12.76	7.11	8.84	167
T3	15.70	12.05	8.05	6.60	98
T4	15.32	11.17	7.20	7.70	113
T5	15.96	13.10	7.11	8.84	151
T6	15.20	11.64	6.89	6.62	87

One should note that the low nitrate content in carrot roots, together with the increased carotene level, represents a key quality indicator of the produce, reflecting its environmental safety and high nutritional value. Overall, the obtained results confirm that pre-sowing seed treatment with biopreparations is an effective practice for improving the biological and technological value of carrot roots (Table 5).

CONCLUSIONS

Based on studies conducted in 2024–2025, these established that soaking carrot (*D. carota* L.) seeds in biological solutions (T2–T6) considerably enhanced the germination energy by 8.18%–14.24% and germination rate by 6.3%–15.14% compared with the control (T1). Microscopic analysis confirmed a reduction in the number of infected and non-viable seeds due to fungal pathogens. The proportion of healthy seeds reached 88.35%, which was 20.61% higher than the control, and the same higher values were evident in treatments T3 and T5. The most pronounced effect of seed biostimulation was distinct in the acceleration of phenological stages by 6–9 days, as well as in the enhanced development of the leaf apparatus and productive organs. The highest root yield appeared in treatments T2 (+30.55%) and T3 (+29.26%), paralleled with the improvement in biochemical composition of roots, including increased content of dry matter, total sugars, carotene, and vitamin C, while maintaining low nitrate levels.

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