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## Effectiveness of Different Groups of Preparations for Pre-Sowing Treatment of Winter Wheat Seeds

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**Abstract.** The first stage of modernizing cultivation of the main grain crops lies in the exogenous use of natural growth regulators and nanofertilisers for pre-sowing seed treatment. Special attention is paid to the quality of winter wheat seed material, given the high probability of seed germination in stressful climatic conditions and the need to form winter-hardy crops. Therewith, this study is relevant because modern requirements for agronomic biofortification of plant products make provision for the introduction of environmentally safe, effective, and cost-effective measures in the cultivation of agricultural crops. The use of preparations based on fulvic acids and growth regulators is an effective way to regulate the morphogenesis and productivity of winter wheat. The purpose of this paper was to investigate the effect of pre-sowing treatment of winter wheat seeds with such preparations as Fulvohumin (chelated fertiliser), 1-naphthyl-acetic acid (auxin) and succinic acid (biogenic growth stimulator, adaptogen) on germination and biometric parameters of seedlings. The study involved the use of laboratory and statistical methods. It was found that pre-sowing soaking in 1% Fulvohumin solution increased the energy of seed germination, seedlings contained a large proportion of dry matter, compared to seed treatment with 0.025% succinic acid solution or 1-naphthyl-acetic acid. In terms of germination energy and raw root mass of 7-day shoots, a combination of Fulvohumin and 1-naphthyl-acetic acid was effective. The largest total length and crude weight of 7-day seedlings were after joint seed treatment with Fulvohumin and succinic acid. According to the totality of seedling formation data, complex pre-sowing treatment of winter wheat seeds with Fulvohumin is recommended together with succinic acid and 1-naphthyl-acetic acid. Treatment exclusively with 1-naphthyl-acetic acid was ineffective. These studies are promising for programming field seed germination and mathematical modelling of winter crop growth at the initial stages of ontogenesis in the field

**Keywords:** Fulvohumin, succinic acid, 1-naphthyl-acetic acid, seed germination, wheat seedlings



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## INTRODUCTION

The productivity of field crops, including winter wheat, is dictated by a complex of agrobiological conditions, namely the optimal state of crops. A prerequisite for the formation of high-quality seedlings is the high biological value of seeds, their rapid and uniform germination. The sowing qualities of seeds determine the resistance of seedlings to adverse factors, the intensity of plant development and crop formation. Therefore, pre-sowing laboratory testing of seed material is an essential concept of agricultural technologies for strategically important agricultural crops. Only certified seed material is used for the cultivation of wheat. Batches of this material are diagnosed for germination energy, laboratory germination, purity, and sowing suitability. Industrial processing to produce high-quality commercial seeds involves the removal of chemical germination inhibitors, which is necessary to increase germination, obtain uniform seedlings, and achieve a prominent yield potential. Seeds of the main agricultural crops undergo several stages of pre-sowing treatment (Ignatz *et al.*, 2019). Conventional methods of increasing the germination rate of wheat seeds mainly involve chemical treatment, which can be environmentally dangerous. Therefore, new methods of physical influence on seed germination are being investigated. For instance, the study (Wang *et al.*, 2022) notes that water activated by plasma in experiments with wheat improved germination.

Presently, the most common means of modifying pre-sowing seed treatment are growth stimulators with microfertilisers. Their segment is becoming increasingly important in the ecological context of less use of pesticides and aggressive agrochemicals in agriculture. Modern aspects of implementing phytostimulants are focused on achieving commercial product quality standards and improving plant viability. Their practical significance lies in the formation of sustainable agricultural systems that are resistant to biotic and abiotic stresses, especially in the context of climate change (Kisvarga *et al.*, 2022).

It is important to replenish the content of nutrients to support the stability of the grain crop, and therefore fulvic acids and microfertilisers include technologies for their cultivation (Pashchak *et al.*, 2021). Fulvic acids are essential for converting mineral compounds into organic ones that will be absorbed by plants (Kumar & Alope, 2020). Kumar *et al.* (2020) found that the content of available nitrogen, potassium, and phosphorus increases after the application of fulvic fertilisers. Fulvic acids reduce the pesticide load and are effective when growing in contaminated industrial areas (Braziene *et al.*, 2021; Ali *et al.*, 2018). These acids also reduce plant uptake of toxic chlorine and cadmium compounds (Yildirim *et al.*, 2021).

To date, the problem of resistance of seeds at the germination stage to pesticide stress has been understudied (Kalytka *et al.*, 2016). For ecological management of agriculture, the advantages of using phytohormones to

intensify plant growth are determined. The role of auxins in inducing root system cell division has been established. Treatment of wheat seeds with indole-3-acetic acid stimulated the growth of the flag leaf, namely its dry weight and area (Aldesuquy, 2011). But a high dose of indolyl-3-acetic acid (50 mg/kg) weakened plant growth. Patented mixtures for pre-sowing seed treatment traditionally include auxins, namely 1-Naphthaleneacetic acid (NAA).

In the state of physiological maturity, seeds are described by low metabolic activity, so to fulfil the productivity potential, it is recommended to treat the seed material with anti-stress growth regulators. In this aspect, succinic acid is considered as an environmentally safe growth regulator. According to Kots *et al.* (2012), in the initial stages of development, seedlings from seeds treated with succinic acid have increased resistance to osmotic shock, high temperature, and pathogens (Kots *et al.*, 2012). In general, the stimulating effect of succinic acid on the intensity of respiration of germinating seeds is noted, as well as the mobilization of organic substances and an increase in winter hardiness of plants.

There is no doubt that the use of growth regulators of various mechanisms of action with trace elements for pre-sowing seed treatment is a principal factor in increasing the adaptive capabilities of plants at the initial stages of growth and the formation of their high productivity in general. Activation of growth processes and optimization of seedling nutrition is the main management strategy for efficient cultivation of agricultural crops in various soil and climatic conditions. *The purpose of this study* was to select effective combinations of preparations for pre-sowing treatment of winter wheat seeds and significantly increase the intensity of seedling formation.

## MATERIALS AND METHODS

The experiment used winter wheat of the Lazurna variety, seeds of the first reproduction, the originator – the Institute of Plant Physiology and Genetics of the National Academy of Sciences of Ukraine. The influence of growth regulators on seed germination energy and morpho-biometric parameters at the shoot level was investigated in the laboratory of the Department of Plant Protection and Quarantine of the Uman National University of horticulture in 2020-2021. The effectiveness of pre-sowing treatment of winter wheat seeds was evaluated after soaking in such test substances as succinic acid (0.025% solution), 1-Naphthaleneacetic acid (NAA, 25 mg/l) and Fulvohumin (1% solution) and their combinations: Fulvohumin+NAA, Fulvohumin+succinic acid; succinic acid+NAA, Fulvohumin+succinic acid+NAA at the rate of 10 litres of spray material per 1000 kg of seed material. A comparison option is pre-sowing treatment with water without preparations.

Such indicators as germination energy, total length of shoots, length of roots and aboveground seedlings, raw and dry mass of seedlings were evaluated. Germination

energy was found as a percentage of the total number of seeds taken for germination, as an average of six repetitions of each variant. Sprouted seeds include seeds that have a normally developed sprout and a primary root that is not shorter than the length of the seed. In an undergerminated seed, the root is underdeveloped, or it is not present, as well as the shoot. To find this indicator, 100 seeds were selected from the treated seed fraction and sprouted in Petri dishes between filter paper. Petri dishes were placed in thermostats, where the temperature was supported at 20°C, humidity – 90%. Seed germination was observed daily for seven days. After three days of germination, the germination energy was found, and after seven days – biometric parameters of sprouts (the length of roots, the length of the aboveground shoot, and the total length of seedlings were measured with a measuring ruler). Using OHAUS Pioneer analytical balances, 100 pieces of the seedling parts under study were weighed with an accuracy of 0.0000 g to find their raw mass. In the root and aboveground (shoots) parts of seedlings, the dry matter content was found according to the thermogravimetric method (Hrytsaenko *et al.*, 2003). The attachments of plant samples were weighed (per 100 pcs of roots or shoots) before and after drying (at 100-105°C). Percentage of dry matter content (DMC) was calculated according to Equation 1:

$$DMC(\%) = M_{raw} \times 100 / M_{dry} \quad (1)$$

where  $M$  is the sample weight, g.

The authors of this study used the State Standard of Ukraine 4138-2002 “Seeds of agricultural crops. Methods of determining quality” and the recommendations of the International Seed Testing Association (ISTA) to follow the methodology for determining the sowing qualities of winter wheat and biometric parameters of seedlings (Seeds of agricultural crops, 2003; International Seed Testing Association, 2011; Kalenska, 2011).

Statistical processing was performed according to the variance method (Ushkarenko, 2013). Correlation analysis and graphical representation of results – using Microsoft Office Excel 7.0 and Statistica 10.0 software. The results were calculated at a significance level of 0.05.

**Research objects.** Fulvohumin is a solution containing fulvic acids and their salts with trace elements. It is used for pre-sowing seed treatment, stimulating plant growth and development, correcting micronutrient

deficiencies, strengthening plant immunity and increasing yield. Content of active substances: N – 0.1-3.0%,  $P_2O_5$  – 0.1-2.5%,  $K_2O$  – 0.1-4.0%,  $C_{gen}$  – 16.0-18.0%, carbon of humic acids ( $C_{ha}$ ) – 0.1-4.0%, carbon of fulvic acids ( $C_{fa}$ ) – 12.0-15.0%, organic matter – 40.0-90.0% (List of pesticides and agrochemicals..., 2020).

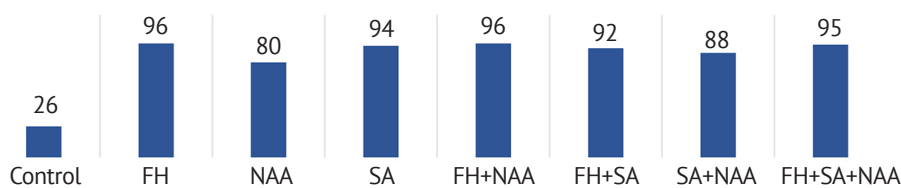
Succinic acid ( $C_4H_6O_4$ ) (SA) – (butanedioic acid, ethane-1,2-dicarboxylic acid,  $HOOCCH_2CH_2COOH$  – an organic dibasic saturated carboxylic acid. Pure acid is colourless crystals. Solid substance. Highly soluble in water and ethanol (Succinic acid, 2020).

(Alpha-) 1-Naphthaleneacetic acid (NAA) is an auxin, an odourless solid substance, white or colourless, the release form is a water-soluble concentrate. A substituted naphthalene derivative with an attached acetic acid residue, one of two possible isomers of naphthaleneacetic acid. Like many other substituted aromatic compounds of acetic acid, it has an auxin-like effect and is used in crop production as a herbicide and growth stimulator (1-Naphthaleneacetic acid, 2020).

## RESULTS AND DISCUSSION

Seeds that have a high germination energy produce friendly shoots that are more resistant to adverse conditions. Soaking wheat seeds in bioregulators activates its membrane and enzymatic activity. A close relationship was established between germination rates and wheat seed germination energy. In the experiments of Tariq *et al.* (2017), the length of the roots of seedlings from seeds treated with a 2% nutrient solution was 8-10 cm, and the length of the roots soaked only in water was 4-6 cm. Humus derivatives increased the germination energy and seed germination (Ahmed & Awad, 2020).

In this experiment, the highest germination energy of winter wheat seeds was obtained after its treatment only with Fulvohumin and in a mixture with NAA – 96% (Fig. 1). The germination energy of seeds treated with a mixture of Fulvohumin, succinic acid and NAA was 95%. Pre-sowing treatment of winter wheat seeds with 0.025% succinic acid solution turned out to be more effective against soaking in NAA. In addition, in the NAA variant of pre-sowing treatment, the germination energy was 6% lower than the control. Pre-sowing treatment of seeds with two preparations was less effective with succinic acid and NAA with a germination energy of 88%.



**Figure 1.** Germination energy of winter wheat seeds depending on pre-sowing treatment, %

**Note:** (FH – Fulvohumin, SA – succinic acid, NAA – 1-Naphthaleneacetic acid) (LSD05 – 6%, V (coefficient of variation) – 7%, experimental average – 91%)

**Source:** compiled by the authors

Furthermore, in the Fulvohumin+succinic acid variant, the seed germination energy increased by 2-4%, compared to the use of only one of these preparations. In the experiments of Karashchuk *et al.* (2020) the germination energy of winter wheat seeds treated with Quadrastim with succinic acid increased by 3-8% from the control, field germination was higher by 4-7%. For pre-sowing treatment of tomato seeds, soaking in fulvic acid with a concentration of 80 mg/l is recommended,

where germination increased by 13%, and root length – by 32% compared to the control (Zhang *et al.*, 2021).

According to the biometric parameters of wheat seedlings on the 7th day of accounting, among the variants of one-component seed treatment, the advantage of the use of Fulvohumin was noted, where the length of the roots was 6.32 cm, the total length of the seedlings was 12.02 cm, against 5.98 cm and 11.17 cm in the control, respectively (Table 1).

**Table 1.** Biometric indicators of wheat germination depending on pre-sowing treatment, cm

Variant	Root length	Length of aboveground shoots	Total length of seedlings
Control (water)	5.98	5.19	11.17
Fulvohumin	6.32	5.70	12.02
NAA	4.11	5.61	9.72
Succinic acid	5.38	4.91	10.29
Fulvohumin + NAA	4.62	4.85	9.47
Fulvohumin + succinic acid	6.12	6.25	12.37
Succinic acid + NAA	4.90	5.53	10.43
Fulvohumin + succinic acid + NAA	5.84	6.36	12.2
<i>Experimental average</i>	<i>5.41</i>	<i>5.55</i>	<i>10.96</i>
<i>LSD<sub>05</sub></i>	<i>0.27</i>	<i>0.43</i>	<i>0.61</i>
<i>V, %</i>	<i>14</i>	<i>10</i>	<i>11</i>

**Source:** compiled by the authors

The length of the roots of wheat seedlings from seeds treated with NAA was the smallest – 4.11 cm, also significantly less than the control after the joint use of NAA with Fulvohumin (by 1.36 cm) or succinic acid (by 1.08 cm).

In experiments with beans, succinic acid did not promote the growth of the root system of seedlings, the length of the main root of shoots was 5% less than the control, despite the higher seed germination (Shevchuk *et al.*, 2019). In this study by the authors, the total length of 7-day-old wheat seedlings after seed treatment with succinic acid was inferior to the control by 0.88 cm. However, the use of two-component treatment Fulvohumin + succinic acid ensured the formation of seedlings of the maximum length – 12.37 cm.

In the variant Fulvohumin + succinic acid+NAA, the seedlings had the largest length of aerial shoots – 23% more than the control, and the total length of the seedlings exceeded the control by 9%. The length of the roots after complex pre-sowing treatment with Fulvohumin+succinic acid+NAA is not significantly greater

than the control (by 0.14 cm) but exceeds other applications of NAA. Notably, after NAA treatment, the percentage of length of aboveground shoots is the highest – 58%.

The positive effect of NAA on the formation of the aboveground mass of seedlings is confirmed by the indicators of the raw mass of shoots – 4.612 g/100 pcs. (Table 2). However, the raw mass of the roots was the smallest in the experiment – 3.867 g/100 pcs. According to the indicators of raw root mass, the highest efficiency of two-component pre-sowing treatment of wheat seeds with the preparations under study was noted. Due to the pre-sowing treatment with Fulvohumin + NAA, the raw weight of the roots is 1.4-1.7 times greater, compared to the use of these preparations separately, and 48% greater than the control. The total weight of seedlings in the application of Fulvohumin + NAA was 10.910 g/100 pcs, exceeding control by 25%, and single-component processing options – by 1.2-1.3 times. In addition, when treated with Fulvohumin + NAA, the proportion of raw root mass is the highest in the experiment – 59% of the total.

**Table 2.** Raw weight of wheat seedlings, depending on pre-sowing treatment, g/100 pcs

Variant	Raw root mass	Raw mass of aboveground shoots	Total raw mass of seedlings	± to control the total raw mass
Control (water)	4.208	4.531	8.739	
Fulvohumin	4.546	4.435	8.981	0.242
NAA	3.867	4.612	8.479	-0.260
Succinic acid	4.295	3.920	8.215	-0.524

Table 2, Continued

Variant	Raw root mass	Raw mass of aboveground shoots	Total raw mass of seedlings	± to control the total raw mass
Fulvohumin + NAA	6.387	4.523	10.910	2.171
Fulvohumin + succinic acid	5.418	6.044	11.462	2.723
Succinic acid + NAA	5.479	5.178	10.657	1.918
Fulvohumin + succinic acid + NAA	4.673	4.994	9.667	0.928
Experimental average	4.859	4.780	9.639	1.028
LSD <sub>05</sub>	0.334	0.323	0.660	-
V, %	17	13	13	

Source: compiled by the authors

Despite the smallest mass of aboveground wheat shoots from seeds treated only with succinic acid – 3.920 g/100 pcs, after its combined use with Fulvohumin, the maximum value of this indicator in the experiment was noted – 6.044 g/100 pcs. Due to the combined treatment with Fulvohumin+succinic acid, the raw root mass increased by 1.210 g/100 pcs from the control, i.e., by 29%. As a result, the total raw mass of seedlings of the Fulvohumin+succinic acid variant was the maximum in the experiment – 11.462 g/100 pcs, exceeding the control by 31%.

In contrast to the elevated indicators of germination energy and seedling length, pre-sowing treatment of wheat with a mixture of Fulvohumin+NAA+succinic acid did not have a unambiguously positive effect on

the raw mass of seedlings, yielding to the options of two-component treatments. However, the total mass of seedlings substantially exceeded the control. Upon pre-sowing seed treatment with NAA or succinic acid, the total raw mass of seedlings is insignificantly lower than the control – by 0.260-0.524 g/100 pcs. On average, according to the experiment, the length and raw aboveground mass of shoots on the 7<sup>th</sup> day of accounting was 50-51% of the total, and a correlation of medium strength was established between these indicators –  $r=0.73\pm 0.01$  (Fig. 2).

Weak correlation between germination energy and total seedling length ( $r=0.36\pm 0.15$ ) and their total raw mass ( $r=0.30\pm 0.19$ ) (Figs. 3-4)

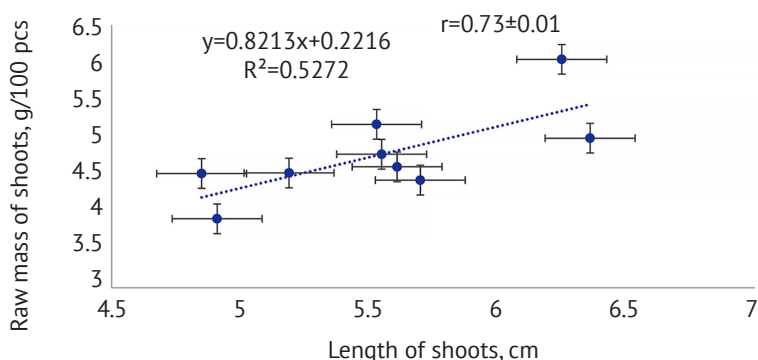


Figure 2. Correlation of indicators of length and raw mass of aboveground wheat shoots

Source: developed by the authors using Excel 2016

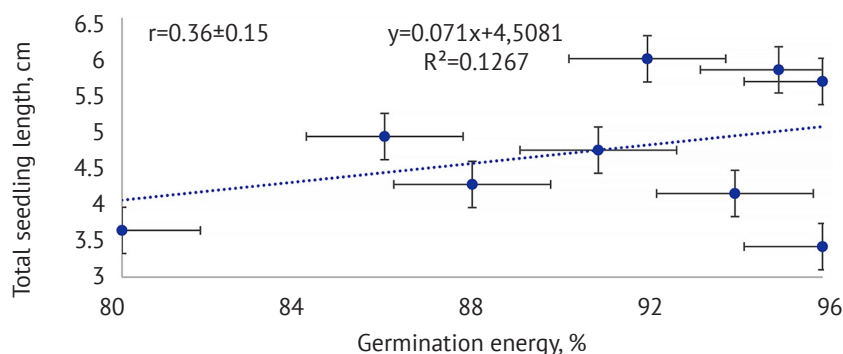
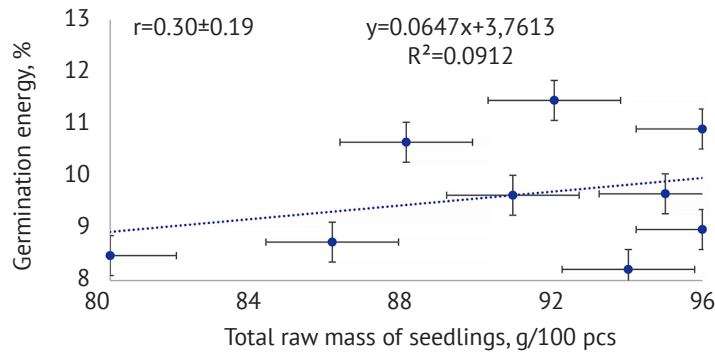


Figure 3. Correlation of seed germination energy indicators and total wheat germination length

Source: developed by the authors using Excel 2016



**Figure 4.** Correlation of indicators of the total raw mass of wheat seedlings and seed germination energy  
**Source:** developed by the authors using Excel 2016

The variation in the dry weight of wheat seedlings after single- and two-component treatments with the preparations under study was significant (Table 3).

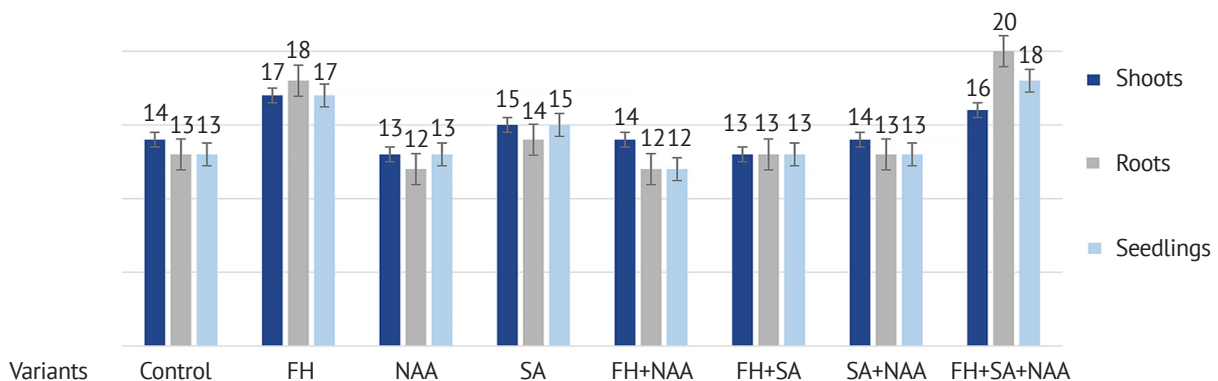
Thus, the dry mass of 7-day-old shoots of the succinic acid application options is lower than the

control – 0.5904 g/100 pcs, NAA – 0.608 and Fulvohumin + NAA – 0.6109 g/100 pcs. Fulvohumin contributed to the formation of aboveground shoots with the highest dry mass – 0.7445 g/100 pcs, which is 17% of their raw mass (Fig. 5).

**Table 3.** Dry weight of wheat seedlings, depending on pre-sowing seed treatment, g/100 pcs

Variant	Dry mass of roots	Dry mass of aboveground shoots	Total dry mass of seedlings	± to control, total dry mass
Control (water)	0.5285	0.6359	1.1644	–
Fulvohumin	0.8226	0.7445	1.5671	0.4027
NAA	0.4747	0.6080	1.0827	-0.082
Succinic acid	0.6217	0.5904	1.2121	0.0477
Fulvohumin + NAA	0.7498	0.6109	1.3607	0.1963
Fulvohumin + succinic acid	0.6896	0.7804	1.4700	0.3056
Succinic acid + NAA	0.6996	0.7290	1.4286	0.2642
Fulvohumin + succinic acid + NAA	0.9240	0.7766	1.7006	0.5362
<i>Experimental average</i>	0.6890	0.6845	1.3733	–
<i>LSD<sub>05</sub></i>	0.0550	0.0498	0.0828	
<i>V, %</i>	21	12	15	

**Source:** compiled by the authors



**Figure 5.** The share of dry mass of aerial shoots, roots, and seedlings from their raw mass, %

**Note:** (FH – Fulvohumin, SA – succinic acid, NAA – 1-Naphthaleneacetic acid)

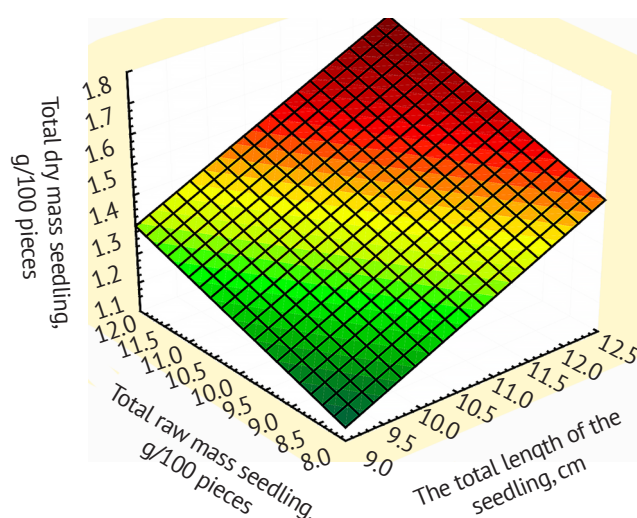
**Source:** compiled by the authors

According to this indicator, the most effective were the combinations of preparations Fulvohumin + Succinic acid – 0.7804 g/100 pcs and Fulvohumin + succinic acid + NAA – 0.7766 g/100 pcs. The share of dry mass of above-ground shoots of these variants was 13% and 16% of the raw mass, respectively. Complex pre-sowing treatment of wheat seeds with Fulvohumin+succinic acid+NAA provided the maximum dry matter content in the root part of seedlings – 0.9240 g/100 pcs, which is 20% of the raw mass and 1.8 times more than the control. The dry mass of the roots of 7-day-old seedlings after pre-sowing seed

treatment with two-component mixtures was 12-13% of the raw mass of the roots and significantly exceeded the control ( $LSD_{05} = 0.0550$  g/100 pcs).

In the control variant, the share of dry mass of aboveground shoots and roots was 13-14% of their raw mass. Dependence between the total dry weight of seedlings ( $z$ , g/100 pcs), their length ( $x$ , cm) and raw mass ( $y$ , g/100 pcs) is calculated using the following regression equation (Eq. 2, Fig. 6):

$$r=0.4899+0.115 \times x+0.0623 \times y \quad (2)$$



**Figure 6.** Data dependence diagram of total length ( $x$ ), raw ( $y$ ) and dry mass of seedlings ( $z$ )

**Source:** developed by the authors using Statistica 10.0.

There was no positive effect of NAA on the accumulation of dry matter in the root part of wheat seedlings – 0.4747 g/100 pcs, i.e., 10% below the control. The dry mass of roots in wheat seedlings from seeds treated with NAA was 12%, treated with succinic acid – 14%, while upon treatment with Fulvohumin it increased to 18%. The results of other studies show that seed induction with 1-Naphthaleneacetic acid did not contribute to substantial growth of sweet maize, Vigna, and cucumber seedlings (Somtrakoon & Kruatrachue, 2014). At a concentration of 10 mg/l, NAA showed a negative effect on the dry weight of cucumber roots.

It was found that the total dry weight of wheat seedlings strongly depends on the seed germination energy –  $r=0.69 \pm 0.06$ . The percentage content of dry matter ( $z$ , %) in wheat seedlings can be calculated based on the data of total dry mass ( $x$ , g/100 pcs) and seed germination energy ( $y$ , %) using the following regression equation (Eq. 3):

$$z=3.6525+0.020 \times x+6.3721 \times y \quad (3)$$

Thus, pre-sowing treatment of winter wheat seeds with Fulvohumin definitely contributes to the accumulation of more dry matter in the aboveground and root parts of seedlings. The total dry weight of seedlings

in the variant of pre-sowing treatment with Fulvohumin was 1.5671 g/100 pcs., which is significantly higher than the control. The indicators of the total dry mass of seedlings after treatment with two preparations are higher than the control (1.3607-1.470 g/100 pcs). As a result, wheat seedlings were formed with the highest dry mass after processing with Fulvohumin + succinic acid + NAA – 1.7006 g/100 pcs, which is 46% higher than the control. The total dry mass of seedlings from seeds treated only with Fulvohumin and in the mixture of Fulvohumin + Succinic acid + NAA was 17-18% of the total raw mass, while in the control this indicator was 13%.

Fulvic acids are organic compounds that are common in the soil, but their added application increases crop yields. Therefore, fulvic acids are part of new bio-fertilisers. The highest efficiency is observed with the complex use of edaphic preparations for seed treatment, soil and foliar fertilization (Marenych et al., 2020). It was experimentally confirmed that humic fertilisers improved root growth, contributed to the formation of high-quality seedlings, and increased the yield of field crops (Savy et al., 2020). According to the experiments of Braziene et al. (2021) pre-sowing soaking of wheat, barley, and sugar beet seeds in fulvic acid significantly

increased their germination rate. The height of wheat shoots was greater by 3%, the air-dry mass of roots – by 23%, compared to the control. As a result of the use of fulvic acid, the wheat grain yield increased by 15%. Humic substances investigated by Litvin *et al.* (2020) intensified the growth processes of wheat and simultaneously had a detoxifying effect. The germination rate of wheat seeds after processing was higher than the control by 8-11%, the total length of the roots – by 42-50%.

According to Marenych *et al.* (2019), for foliar feeding of grain crops, fractional application of the humic preparation was more effective than one-time application and gave a yield increase of 16%, compared to the control. Foliar application of fulvic acid eliminates negative conditions after biotic stress of plants. At the rate of application of fulvic acid of 6 mg/L, the highest indicators of wheat plant height (80.89 cm), weight of 1000 grains (33.60 g) and grain yield (4.16 t/ha) were obtained (Al-Haidary & Al-Zubaidy, 2020). The research of Ahmad *et al.* (2018) covered the development of an effective organo-mineral fertiliser. The soil fertiliser contained humic acid, while the leaf fertiliser included fulvic acids and gibberellic acids. Their use increased the yield of wheat.

The most active component that begins to be synthesized by plants under stressful conditions and effectively optimizes their metabolism is succinic acid (Paramo *et al.*, 2020). As an adaptogen and growth stimulator, succinic acid still has a modest sales market, but with prospects due to its biological safety. It was found that in the spring period, succinic acid intensifies the growth of the root system of winter wheat. The average root length of winter wheat plants treated with succinic acid exceeded the control by 21%, and wheat seedlings also had a 4% higher dry matter content (Pryplavko & Gaviy, 2019).

The combined use of succinic acid with microfertiliser turned out to be more effective. For instance, the seed germination of vegetable plants increased by 3%, the energy of germination increased by 10% (Kuts *et al.*, 2021). Treatment of bean seeds with vegetable aqueous solution of succinic acid increased laboratory germination by 7.7%, the number of shoots – by 5.4%, but practically did not affect the length of the hypocotyl (Shevchuk *et al.*, 2019). In experiments with asparagus seeds, succinic acid increased its germination rate by 14%. In addition, according to Shevchenko *et al.* (2021), asparagus seedlings from succinic acid-treated seeds did not substantially increase root mass, while the height of aboveground shoots was 8-14 cm higher than the control. Pre-sowing treatment of seeds with Quadrostim, which includes succinic acid, increased the germination rate of winter wheat. The length of the shoots was 3.2-3.8 cm, the weight was 6.1-6.9 g/100 pcs, while in the control it was 3.6-3.2 cm and 4.4-6.0 g/100 pcs, respectively (Karashchuk *et al.*, 2020).

Pre-sowing treatment of wheat seeds with exogenous phytohormones affects the growth and development of plants along with the differentiated dynamics

of their distribution in shoots and roots. The highest content of indolyl-3-acetic acid was noted in the roots of seedlings (Kosakivska *et al.*, 2022). From the group of auxins, 1-Naphthaleneacetic acid is actively used to enhance growth and increase the yield of grain crops (Basuchaudhuri, 2016; Alam *et al.*, 2002). According to Jahan *et al.* (2019), the use of 1-Naphthaleneacetic acid (25 mg/l) in wheat crops positively affects root growth, overall dry biomass, and yield. In the study by Hanaa & Safaa (2019), the maximum indicators of the height of wheat plants (92 cm), thousand-kernel weight (36.5 g), and grain yield (6.61 t/ha) were obtained after spraying the leaves with indolyl-3-acetic acid.

During the study of the effect of growth stimulants on the germination of *Pongamia pinnata* seeds, it was found that the greatest germination was in the seeds soaked in a solution of indole-3-butyric acid, the seedlings had a longer root length. Gibberellic acid, compared to 1-Naphthaleneacetic acid, more significantly increased the length of shoots, leaf area, and total dry mass (Venkatesh *et al.*, 2000). Treatment of maize seeds with heterocyclic compounds and auxins (indolyl-3-acetic and 1-Naphthaleneacetic acids) resulted in an intensification of seed germination and an increase in the growth parameters of maize shoots compared to untreated seeds, but 1-Naphthaleneacetic acid has a lower stimulating effect (Tsygankova *et al.*, 2016). In other experiments, foliar spraying of wheat with 1-Naphthaleneacetic acid (10 mg/l) increased the thousand-kernel weight and yield by 5.2-8.8% (Sun *et al.*, 2018). In general, pre-sowing treatment of wheat seeds should be complex, with phytohormones and nutrient compounds.

## CONCLUSIONS

The problem of reducing germination energy due to the use of chemical protectants is especially relevant in the zones of insufficient and unstable moisture, with a lack of soil moisture during the period of sowing winter cereals. Interest in nanofertilisers and bioregulators that improve the quality of crops is constantly growing, and in the future these preparations will become an essential element of the technology of growing major agricultural plants.

Treatment of winter wheat seeds with Fulvohumin or succinic acid increases the energy of its germination to 94-96%. Among the combinations of the preparations under study, the germination energy after treatment with Fulvogmin + NAA (96%) and Fulvogmin + succinic acid + NAA (95%) is significantly greater. According to statistical analysis of biometric data, only Fulvohumin contributes to a significant increase in the length of the root part of seedlings (by 0.34 cm). Pre-sowing application of Fulvohumin with succinic acid provides the formation of higher wheat shoots (12.37 cm) of a larger raw mass (11.462 g/100 pcs). The total raw mass of wheat seedlings from seeds treated with Fulvohumin exceeded the control by 3%, and the raw mass of roots – by 8%.



Pre-sowing treatment of wheat with NAA at a concentration of 0.025% did not have a significant positive effect on seed germination and seedling formation.

The biological value of plants is estimated by indicators of their dry weight. The maximum values of the dry mass of roots and seedlings in general were observed after seed treatment with Fulvohumin and in a mixture of Fulvohumin+succinic acid+NAA – 17-20%.

Total seedling dry mass is highly correlated with seed germination energy ( $r=0.69\pm 0.06$ ), while raw mass is weakly correlated ( $r=0.30\pm 0.19$ ). Evaluating the seed germination energy, the length of seedlings, their raw and dry mass, pre-sowing treatment of wheat with Fulvohumin and a combination of this preparation with succinic acid and 1-Naphthaleneacetic acid is recommended as the most effective.

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### **Ефективність різних груп препаратів для передпосівної обробки насіння пшениці озимої**

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**Анотація.** Початковим етапом модернізації вирощування основних зернових культур є екзогенне використання природних регуляторів росту та нанодобрив для передпосівної обробки насіння. Якісті посівного матеріалу пшениці озимої приділяється особлива увага, зважаючи на високу ймовірність проростання насіння у стресових кліматичних умовах та необхідність формування зимостійких посівів. Поряд з цим, сучасні вимоги до агрономічної біофортificaції рослинної продукції передбачають впровадження екологічно-безпечних, дієвих та економічно вигідних заходів під час вирощування сільськогосподарських культур, що зумовило актуальність дослідження. Застосування препаратів на основі фульвокислот та регуляторів росту – ефективний спосіб регуляції морфогенезу і продуктивності пшениці озимої. Метою досліджень було вивчення впливу передпосівної обробки насіння пшениці озимої такими препаратами, як Фульвогумін (хелатне добриво), 1-нафтил-оцтова кислота (ауксин) і бурштинова кислота (біогенний стимулятор росту, адаптоген) на проростання і біометричні параметри сходів. У процесі досліджень використовували лабораторні і статистичні методи. Встановлено, що за передпосівного намочування у 1% розчині Фульвогуміну підвищувалася енергія проростання насіння, сходи містили більшу частку сухої речовини, порівняно обробкою насіння 0,025% розчином бурштинової кислоти або 1-нафтил-оцтовою кислотою. За показниками енергії проростання і сирої маси коренів 7-денних сходів ефективною була комбінація препаратів Фульвогумін і 1-нафтил-оцтова кислота. Найбільші загальна довжина і сира маса 7-денних сходів були після сумісної обробки насіння Фульвогуміном і бурштиновою кислотою. За сукупністю даних формування сходів, рекомендується комплексна передпосівна обробка насіння пшениці озимої Фульвогуміном сумісно з бурштиновою кислотою і 1-нафтил-оцтовою кислотою. Неefективною була обробка лише 1-нафтил-оцтовою кислотою. Дані дослідження перспективні для програмування польової схожості насіння і математичного моделювання росту озимих культур на початкових фазах онтогенезу у польових умовах

**Ключові слова:** Фульвогумін, бурштинова кислота, 1-нафтил-оцтова кислота, проростання насіння, сходи пшениці