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ORIGINAL ARTICLE

The influence of biological products on the growth and development of sunflower plants (*Helianthus annuus* L.) in the northern steppe of Ukraine

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To neutralize negative factors (excessive technogenic load, deterioration of water, nutrient regime, and humus state of the soil) and improve the nutritional system of sunflower plants, it is necessary to use more widely mineral, organic, and micronutrient fertilizers, plant growth regulators. Thanks to the regulatory mechanisms of biological products, the development of the leaf surface are enhanced, the main functions are essential for the life of sunflower plants, and they are activated by: membrane processes, cell division, respiration and nutrition, the activity of enzyme systems, photosynthesis, a branched root system with enhanced absorbing capacity is created at the growth period. The main goal of this work was to study the influence of the growth of regulatory substances, different in the direction of action, on the morphogenesis, growth, and development, and productivity of sunflower plants of different ripeness groups in the conditions of the Northern Steppe of Ukraine. Moreover, the determination of the most rational stimulants of the growth of sunflower plants, which ensure the resistance of plants to diseases and adverse environmental factors, optimal growth and development of plants, and contribute to obtaining high and sustainable yields of oilseed crops. The laying and carrying out of field experiments was carried out following the generally accepted methodology of experimental work. The experimental part of the work was performed during 2018–2020 on the scientific and research field of the National Scientific and Research Center of Dnipro State Agrarian and Economic University in the stationary experiment of the Plant Science Department in five-crop rotation pure steam – winter wheat – corn – barley – sunflower to study the effectiveness of modern elements in technologies for growing cereals, legumes, and oilseeds. Scientific studies have established that the formation of the maximum leaf surface area of sunflower was observed using the growth stimulant Tseron (0.5 L/ha) to 70.9–78.1 thousand m^2/ha, or 5.5–10.2% more for control. Here, sunflower plants formed the largest diameter of the basket – 23–26 cm (11.5–30.4% more than the control), and the maximum number of seeds in 829–951 pcs. The highest weight of 1000 seeds was characteristic of the medium-early hybrid Sumico HTS – 54.0–60.0 g, and the lowest for the medium-late Subaro HTS – 51–55 g, due to the biological characteristics of the hybrids. Plant growth stimulants on sunflower contributed to an increase in crop yields 1.01–1.7 times. The most significant increase in grain for all hybrids was provided by the agent Tseron (0.5 L/ha) – 0.16–0.75 t/ha, or 8.2–43.3%. The application of restricted drugs Tseron (0.5 L/ha) and Architect (0.5 L/ha) contributed to the growth of oil content by 3–8 and 4–6 percentage points.
Keywords: sunflower; hybrids; biological products; leaf surface area; chlorophyll; yield capacity; seed quality

Introduction

Changing priorities of agricultural development in the steppe of Ukraine against the background of changing natural ecosystems (Andrusevich et al., 2018; Pokhylenko et al., 2019; Savosko et al., 2018), climate (Khromykh et al., 2018; Lykholat et al., 2019a, 2019b; Zhao et al., 2017), crop violation, due to expansion of sunflower areas in the structure of crops in some places up to 40%, and their complete neglect is accompanied by increased erosion processes, excessive artificial load, deterioration of water, nutrient regimes and humus condition of chernozem. In this regard, there is a need to eliminate negative factors and improve the nutrition of sunflower plants in the direction of broader use, except mineral and organic fertilizers, microfertilizers, plant growth regulators, taking into account soil and climatic conditions, chernozem humidity, minimizing tillage, post-harvest residues of the predecessor, phytosanitary condition of crops (Abobaker et al., 2018; Domaratskiy et al., 2018; Tsyliuryk et al., 2018; Tkalich et al., 2019; Tsyliuryk et al., 2018). Among the elements of sunflower cultivation technology, which aim to realize the genetic potential of modern hybrids, special attention should be paid to pre-sowing seed treatment: inoculation treatment, treatment with growth stimulants (Kocira et al., 2020; Polat et al., 2017).

The advantages of using agents of different origins are that the mutagenic effect of herbicides and other anthropogenic factors is significantly reduced. Due to regulatory mechanisms, the development of the leaf surface is enhanced, the main essential functions for plant life are activated: membrane processes, cell division, respiration and nutrition, enzyme systems, photosynthesis, and a branched root system with enhanced absorption. Seed treatment helps increase crop production's economic efficiency and reduce the content in the main products of nitrates, heavy metal ions.

These agents have significant antistress effects (Chena et al., 2021; Filippo et al., 2019; Kuryata et al., 2017). To biostimulate seeds and improve their quality, scientists and experts have proposed a number of tools (biological agents, physiologically active substances, and growth regulators), each of which, if being used skillfully, can become an effective element of adapted technologies for growing crops (Caruso et al., 2019; Basile et al., 2021).

It is proved that some regulators of the growth of new generation plants have good fungicidal properties, and it is advisable to make them in combination with pesticides, which significantly enhances the effect of the latter on pathogens. They can be used together to pre-sow seed treatment and spraying crops (Kozlova et al., 2020). In addition, the combination of plant growth regulators with pesticides makes it possible to reduce the dose of the latter (by 25–30%) without reducing their protective effect (Domaratskyi et al., 2020; Kalenska & Stoliarchuk, 2018; Kalenska & Taran, 2018; Kalenska et al., 2018; Szparaga et al., 2019).

Plant growth regulators are natural or synthetic organic substances that can stimulate or inhibit the growth and development of plants without leading to their death. Natural growth regulators are phytohormones, formed in small quantities and necessary for their vital functions. These include auxins, gibberellins, cytokinins, and brassinosteroids, stimulating plant growth and development (Islam et al., 2021; Basile et al., 2021). Synthetic plant growth regulators with anti-gibberellin action are widely used as retardants; they are substances that slow down plants' growth while strengthening the stems, which is especially important to prevent the lodging of cereals in wet conditions.

The most important of these are chlormequat chloride, mepiquat chloride, ethephon, which treat cereal crops (Spitzer et al., 2018; Sethy et al., 2016). In connection with the introduction into production of the latest growth regulators and biological products, as well as new high-yielding sunflower hybrids, the influence of these elements of technology on the process of leaf and root formation and crop formation (Akuaku et al., 2020; Melnyk et al., 2019; Yeremenko et al., 2017; Ryzhenko et al., 2020) insufficiently studied, which is of scientific and practical interest (Baylis & Dickst, 1983; Ernst et al., 2016; Eremenko et al., 2018).

The solution to this problem is to optimize the productivity of valuable oilseeds, the introduction of the technology of growing sunflower natural plant growth stimulants (Vimpel K-2, Treptolem, Regoplant, and Tseron), which provide: protection of sunflower seeds in case of prolonged exposure to adverse conditions; activation of root system development; increasing the activity of cellular respiration; stabilization of vital microflora of the soil; increasing the effectiveness of pesticides, and as a result of increasing the yield of oilseeds. However, data on the effectiveness of various plant growth stimulants on sunflower are currently scarce, and in addition, they are often contradictory.

The main purpose of our work is to study the influence of different growth-regulating substances on the morphogenesis in different directions of action, growth and development, and productivity of sunflower plants of different maturity groups in the Northern Steppe of Ukraine. We also identified the most rational stimulators of sunflower plant growth, which ensure the resistance of plants to diseases and adverse environmental factors, optimal plant growth and development, and contribute to high and sustainable yields of oilseeds.

Materials and Methods

The successful development of agricultural production involves the widespread introduction of the latest scientific developments, which are obtained through modern research methods. The methodological basis of our research was the principle of unity and interconnection of the object with environmental conditions. In establishing the truth in analyzing the results obtained, this approach is most consistent with the principle of knowledge of objectively existing reality.

The climate of the study area is temperate-continental, with significant fluctuations in weather conditions over the years. The average annual air temperature is 9.6 °C warm, with a deviation in some years from 8.4 °C to 10.8 °C. The average annual rainfall is 509 mm and varies from 420.7 mm to 832.7 mm. Most of them (68% of the annual amount) fall during the warm period (April–October) and are primarily spent on evaporation and runoff due to the predominance of heavy rainfall in the undulating terrain.

In recent decades, significant agrometeorological changes in the direction of global warming have taken place in the world, and in particular in Ukraine (Kalenska & Ryzhenko, 2020).

Hydrothermal conditions of 2018–2020 in experiments are characterized as unstable and complex with uneven distribution of weather elements over time. A characteristic feature of the beginning of spring in 2018 and 2019 is rather sharp fluctuations of plus (day) and minus (night) air temperatures, which restrained the soil's physical maturity. Night frosts lasted until the end of March. However, from April 1st, a rapid increase in daily averages with a surcharge to the long-term norm of 1.8–3.5 °C was recorded. The absolute temperature maximum (+30 ... +33 °C) fell on the first (2018), second, and third (2019) decades of May. In March 2020, the temperature exceeded the standard by 6.3 ° C. Instead, April was marked by cool weather, with a minus value at night recorded until the 22nd. May could be considered as moderately warm, windy. The amplitude of fluctuations in air temperature during the day in most cases was 10–15 °C, so the soil warmed up slowly, which led to delayed germination and inhibited plant development (Table 1).

Table 1. Meteorological conditions of the sunflower growing season (Dnipro city meteorological station)

Years	Months of the year					For the period
	April	May	June	July	August	
		Air temperature, °C				
2018	12.9	19.0	21.7	22.5	23.5	19.9
2019	11.2	17.9	24.0	21.5	21.2	19.2
2020	9.0	13.9	21.7	23.5	22.1	18.0
Average	11.0	16.9	22.5	22.5	22.3	19.0
Long-term norm (for the last 30 years)	9.4	16.0	19.6	21.3	20.6	17.4
		Precipitation, mm				
2018	16.4	31.7	51.9	77.9	0.0	177.9
2019	32.3	48.3	30.6	59.2	57.5	227.9
2020	11.5	78.1	48.5	30.4	12.0	180.5
Average	20.0	52.7	43.6	55.8	23.2	195.4
Long-term norm (for the last 30 years)	38	46	59	56	37	236

March 2018 had turned out to be extremely rainy. During the month, 22 days with precipitation from 0.2 to 25.3 mm were documented. Their sum was 145.1 mm with an average monthly long-term indicator of 34 mm. April and May were arid. In the period from 1.04 to 20.05 (50 days) received only 22.4 mm of atmospheric moisture (34% of normal), with the vast majority of rains were unproductive (up to 5 mm). During the decrease in relative humidity to 20–25%, a decrease in the turgor of sunflower leaves and inhibition of assimilation processes were observed. Due to the rapid dehydration of the upper (0–7 cm) layer of soil, relatively low efficiency of pre-emergence herbicides was observed.

In March 2019, there was about the norm of precipitation of varying intensity with a 0.1–12.3 mm layer. The following spring months were marked by highly uneven rainfall. For example, in the first and third decades of April received 0 and 2.7 mm, respectively, in the second decade of May – 0.4 mm. Therefore, the plants were periodically in a state of stress with corresponding consequences for their productive potential.

According to the humidity level, the spring of 2020 in the area of experiments should be considered unfavorable for sunflower. The absence of agronomically significant precipitation (more than 10 mm) lasted from 22.03 to 28.05, i.e., 66 days. In April, they dropped only 11.5 mm (30% of normal). This figure exceeded the average long-term values by 1.7 times in May, but only one rain at the end of the month (28.05–27.2 mm) was helpful for plants. In combination with the intense wind regime and significant differences in night and day temperatures, this led to a violation of the duration of certain stages of organogenesis by cultivated crops, delaying their growth or development.

The summer season was characterized by an uneven distribution of precipitation in the temporal dimension, i.e., rainless intervals alternated with showers with a layer of 20–40 mm. The total amount of atmospheric moisture received during the summer was equal in 2018 – 129.8 mm, 2019 – 147.3 mm, 2020 – 90.9 mm, 85%, 97%, and 60% of the norm, respectively. The timing of their loss, in most cases, coincided with the critical phases of water consumption of sunflower, which had a positive effect on its yield. At the same time, the temperature regime in the summer of 2018-2020 exceeded the long-term indicators by 1.7–2.1°C. Every year during the summer there were several periods of hot weather, when the air temperature reached + 35 ... + 38 °C, the soil – +55 ... + 65 °C. The driest was August 2018, June 2019, and July 2020.

In general, weather conditions during the research can be assessed as relatively favorable for sunflower cultivation, except for the summer period of 2020 when drought was observed.

The laying and carrying out of field experiments was carried out following the generally accepted methodology of experimental work (Dospekhov, 1985; Steel et al., 1997). The experimental part of the work was performed during 2018–2020 on the scientific and research field of the National Research Center of the Dnieper State Agrarian and Economic University in a stationary experiment of the Department of Crop Production of Dnipro State Agrarian and Economic University in five-field crop rotation pure steam – winter wheat – corn – barley for studying the effectiveness of modern elements of cereals, legumes, and oilseeds growing technologies. Agro-technique of sunflower cultivation is generally accepted for the Steppe zone. In general, the background tillage was carried out by double peeling of stubble with heavy disc harrows BDV-3 to a depth of 8–10 cm. The primary cultivation – is shelf-plowing (processing in October with a plow PO-3-35 to a depth of 20–22 cm).

Soil herbicide based on acetochlor 900 g/L – 2.5 L/ha was spread under pre-sowing cultivation, and mineral fertilizers at a dose of $N_{30}P_{30}K_{30}$ were added under pre-sowing cultivation. Sowing was carried out with a seeder Great Plains PD8070, with a seeding rate of 55 thousand/ha. In the experiment, zoned maize hybrids of different maturity groups were sown: SY Kupava – medium-ripe; Sumico HTS – medium early; Subaro HTS – mid-late.

On the background of the above, the hybrids laid out four options for the introduction of plant growth stimulants: Control (without the introduction of agents), Vimpel K-2 (0.7 L/ha), Architect (0.5 L/ha), Tseron (0.5 L/ha). Spraying was carried out with a small-sized rod sprayer OM-4 (width 4 m) in the phase of 6–8 pairs of sunflower leaves. The scheme of the experiment is shown in Table 2.

Table 2. The experiment schemed to study the effectiveness of plant growth stimulants in sunflower crops

Sunflower hybrids, ripeness group	Plant growth stimulants
Subaro HTS	Control (without agents' application)
(mid-late)	Vimpel K-2 (0.7 L/ha)
	Architect (0.5 L/ha L/ha)
	Tseron (0.5 L/ha)
SY Kupava	Control (without agents' application)
(medium-ripe)	Vimpel K-2 (0.7 L/ha)
	Architect (0.5 L/ha)
	Tseron (0.5 L/ha)
Sumico HTS	Control (without agents' application)
(medium early)	Vimpel K-2 (0.7 L/ha)
	Architect (0.5 L/ha)
	Tseron (0.5 L/ha)

SY Kupava sunflower hybrid – medium-ripe hybrid belongs to the linoleic type. The growing season is 106–115 days. The height of the plant is 150–170 cm. The hybrid belongs to the intensive type of adaptability. The initial stage of development has a high growth rate. SY Kupava shows high stability in drought conditions. The hybrid is unique in its protective function against diseases, i.e., tolerant to all races of broomrape (A, B, C, D, E, F, G, and more aggressive than G), sclerotinia, phomopsis. It is recommended for the cultivation of modern agro-technologies.

Sumico HTS sunflower hybrid is a medium-early linoleic-type sunflower hybrid optimized to Express herbicide application. Resistant to wolf race AE. There is a high tolerance to Phomopsis and phomosis. Intensive hybrid has an average growth rate in the early stages of development. The height of the plant is 155–170 cm, growing season, 106–115 days. It is recommended for cultivation with modern agro-technologies.

Subaro HTS sunflower hybrid is a simple medium late hybrid; the growing season is 116–120 days. When it is ripe, the plants reach 165–175 cm in height. It is optimized to Express Sun application (genetic resistance to Granstar herbicide). It has high stability and productivity with rapid initial growth. It is characterized by high resistance to common diseases: white rot, phomosis, fomopsis, powdery mildew, macrofomin, and most pests.

Plant growth stimulator Vimpel K-2 - contains a set of carboxylic acids that participate in the Krebs cycle, which is a key stage in the respiration of all cells and a source of energy for the synthesis of vital compounds such as carbohydrates and amino acids. Modified humic acids are stable in acidic and alkaline media, which gives stability to the drug in a wide pH range without reducing its activity. Foliar application of the agent helps increase the amount of chlorophyll, enhancing the development of the plant. The agent optimizes the processes of plastic and energy metabolism, making photosynthesis in plants as efficient as possible.

Plant growth stimulator, fungicide Architect – is 100 g/L (active ingredient – pyraclostrobin, 150 g/L mepiquat chloride, 25 g/L calcium prohexadione). The type of action is systemic and translaminar. It optimizes plant architectonics and transportation, nutrient, and water absorption. The broadest range of controls of significant sunflower diseases: septoria, Alternaria, rust, phomosis, fomopsis, and sclerotiniosis. It increases the drought resistance of sunflower and the transfer of high temperatures.

Plant growth stimulator Tseron 480 SL, RK is an agent for preventing the lodging of plants during ripening and growing season. The agent is developed based on phosphoric acid derivatives. Tseron stimulates the growth of the root system and inhibits stem growth. The highest effectiveness of the agent Tseron is achieved by applying in the phase of elongation of the sunflower stem (VVSN 30-33). In the case of double use, the period between treatments should be at least 14 days.

Phenological observations were carried out according to the method of state variety testing. To do this, the areas where the time of onset of a particular phenophase was marked were fixed. The phase was taken as the state when 15% of plants reached this phase and the whole phase – when 75% of plants reached it. Linear plant growth was monitored by measuring plant height in the primary phases. The length of 10 plants was measured in 5-fold reiteration (Dospekhov, 1985; Steel et al., 1997; Olas et al., 2019).

Growth dynamics were studied by growth phase; weight gain of plants is recognized by the difference between the sample's weight and previous sampling dates. We measured the plant stem height, while the number of leaves and their area is determined on 100 plants constantly allocated for this purpose, followed by the derivation of the arithmetic mean of the variant of the experiment according to research methods. The area of the leaf apparatus was determined by the contour method (fingerprint method) in the flowering phase of sunflower plants. Chlorophyll content was registered in the flowering phase on the leaves by photoelectrocolorimetry. Determination of chlorophyll content was performed in fresh material by spectrophotometric method on a spectrophotometer SF-18 (Bazaliy, 2016). We also determined the diameter of the basket, the number of seeds in the basket, the weight of 1000 seeds using conventional methods (Dospekhov, 1985; Steel et al., 1997). The sunflower harvest was recorded in sections by the method of direct threshing with the Sampo-500 combine. After determining the clogging and moisture content of the grain, the yield was counted at 100% purity and 8% moisture.

The oil content in the seeds is determined according to generally accepted existing state standards. Seed quality was assessed by oil content following the technical conditions of the standard DSTU 3768-2009. The soils of the experimental fields of the National Research Center of the Dnieper State Agrarian and Economic University are represented mainly by chernozems of ordinary low-humus medium-loamy soils. The thickness of the humus horizon is 38–43 cm. The humus content is in one layer of 0–30 cm – 3.6%, in a 20–40 cm – 3.31% layer. The absorbed bases are mainly calcium 20.4 and magnesium 7.8 mg/eq per

100 g of soil. The degree of saturation of the soil on the base is 94.18%. Due to this, the reaction of the soil solution is close to neutral (pH 6.6–6.8). The gross content of nutrients in one layer of soil is in the range: total nitrogen 0.15–0.19, phosphorus 0.11–0.14, potassium 2.0–2.4%, mobile form of phosphorus (in acetic extract according to Chirikov) 9–10, exchangeable potassium (according to Maslova) 14–15 mg per 100 g of soil.
Mathematical processing of field experiment data was performed according to Dospekhov (1985) and Steel et al. (1997).

Results and Discussion

Studies have shown that sunflower plant growth stimulants directly or indirectly affect biometrics (plant height, leaf surface area, basket diameter, number of seeds in the basket) and weight of 1000 seeds, yield, and seed quality. Thus, the height of plants varied slightly depending on the introduction of growth regulators for sunflower. Thus, the agent Tseron has the maximum effect on plant height on all sunflower hybrids, i.e., the lowest plant height was noted here – 191–205 cm because the agent inhibits the growth of stems in length and strengthens it. The worst results were provided by the agent Vimpel K-2; the height of plants here for all hybrids was 200–210 cm (Table 3).

Table 3. Influence of plant growth stimulators on the height of sunflower plants for 2018–2020

Sunflower hybrids	Plant growth stimulants	Height of sunflower plants, cm years			
		2018	2019	2020	average
Subaro HTS (medium-late)	Control (without agents' application)	198±5.5	215±6.2	210±4.8	207±4.3
	Vimpel K-2 (0.7 L/ha)	196±6.0	205±6.2	200±5.2	200±4.9
	Architect (0.5 L/ha)	197±5.7	205±5.8	198±5.5	200±5.1*
	Tseron (0.5 L/ha)	195±5.8	195±5.5	193±5.3	194±4.9
SY Kupava (medium ripe)	Control (without agents' application)	220±5.2*	235±6.5	231±5.2	228±6.2
	Vimpel K-2 (0.7 L/ha)	218±5.3	210±5.5	204±5.7	210±6.2
	Architect (0.5 L/ha)	218±5.5	205±5.2	193±4.8	205±4.9
	Tseron (0.5 L/ha)	219±5.8	195±5.1	191±.4.9	201±4.5
Sumico HTS (medium early)	Control (without agents' application)	217±6.2	225±6.0	219±5.0*	220±5.2
	Vimpel K-2 (0.7 L/ha)	216±3.9	210±6.3	206±5.1	210±4.9
	Architect (0.5 L/ha)	210±4.8	205±5.5*	200±5.2	205±.4.2
	Tseron (0.5 L/ha)	209±5.1	205±5.5	197±5.3	203±4.5

Note: * – the difference between the control and experimental variants is statistically significant for P < 0.05.

Reducing the height of sunflower plants has some advantages in the technology of its cultivation, reducing the fragility of the stem from pests and diseases, increasing the leaf surface area and basket diameter, and improving the performance of high-clearance self-propelled sprayers, and more. As for the leaf surface area determined by the contour method (fingerprint method), after the introduction of agents also had the most significant effect of the agent Tseron, the leaf area increased by 70.9–78.1 thousand m^2/ha, or 5.5–10.2% more than the control, and the most negligible impact on the leaf surface area had the agent Vimpel K-2 – 70.8–75.4 thousand m^2/ha (Fig. 1).

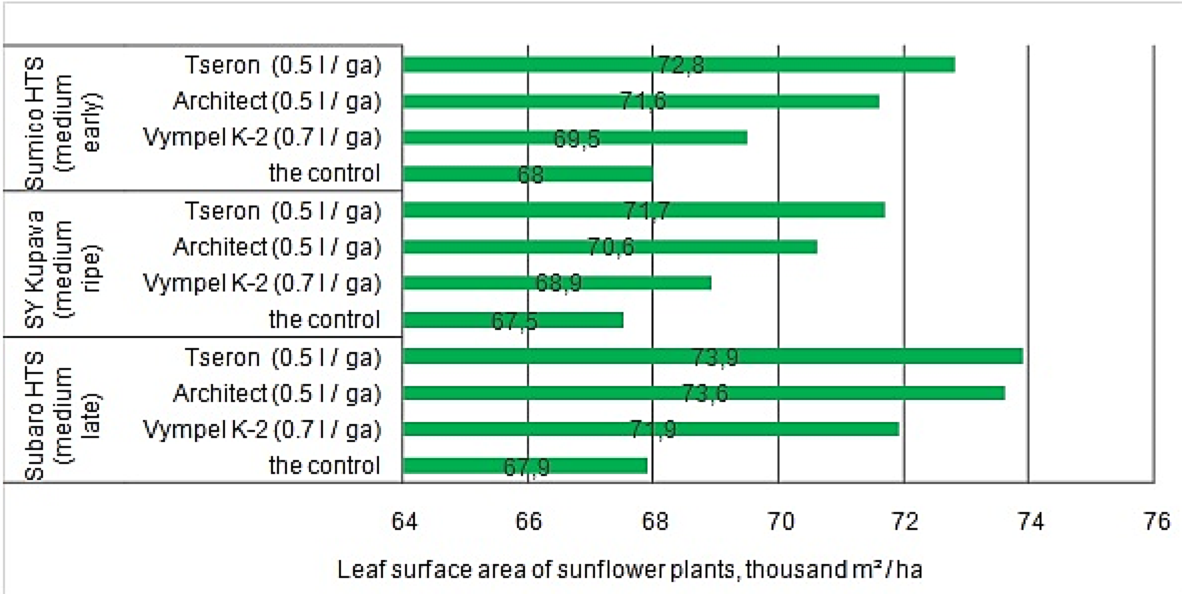

Fig. 1. The leaf area of sunflower plants depends on plant growth stimulants on average for 2018–2020

To determine chlorophyll, the leaves were selected in the flowering phase, crushed, formed an average sample for analysis, and then extracted chlorophyll with ordinary ethyl alcohol. The degree of green color of the extract determined the level of chlorophyll in the leaves. Chlorophyll fractions were determined by colorimetry at two wavelengths – 640 and 715 nm. The effect of plant growth stimulants on chlorophyll content is shown in Fig. 2.

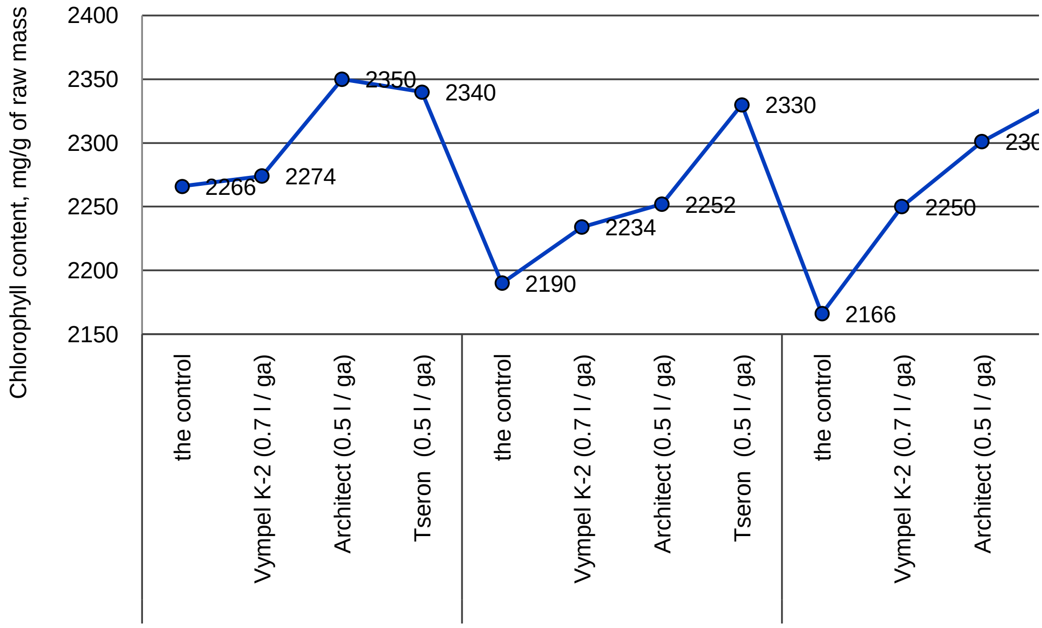

Fig. 2. The content of chlorophyll in sunflower leaves depends on plant growth stimulants (average for 2018–2020, mg/g of raw weight)

Plant growth stimulants positively affected the total chlorophyll content in sunflower leaves, so compared with the control, its content increased by 3.7–7.0%. Sunflower plants, even visually, had a darker green color compared to the control, indicating an increase in leaf chlorophyll. The chlorophyll content in the leaves of hybrid sunflower differed slightly, so the hybrid Subaro HTS (medium late) prevailed, respectively, 2266–2350 mg/g against Sumico HTS (medium early) chlorophyll content of 2166–2335 mg/g of raw weight. It should also be noted that the increase in chlorophyll content from the use of biological products was due to the fraction "a"; the ratio of fraction "a" to "b" varied in the ratio from 2.34 to 2.43:1.0.
The increase in the area of the leaf apparatus and the chlorophyll content in it had a positive effect on forming the generative organs of sunflower plants, namely, the basket. Thus, the value of the diameter of the basket was directly proportional to the leaf surface area and chlorophyll content in all studied hybrids where growth regulators were applied, and in particular increased in the variant of application of the drug Tseron – 23–26 cm (11.5–30.4% more than control) and Architect – 20–25 cm (by 8.0–20.0%) (Fig. 3). Increasing the diameter of the basket contributes to an increase in the number of seeds in the basket, and accordingly, to proper and sufficient plant nutrition to increase the yield of oilseeds. The agent provided the minimum increase in the diameter of the basket Vimpel K-2 – 20–25 cm (increase relative to the control 1.0–8.0%).

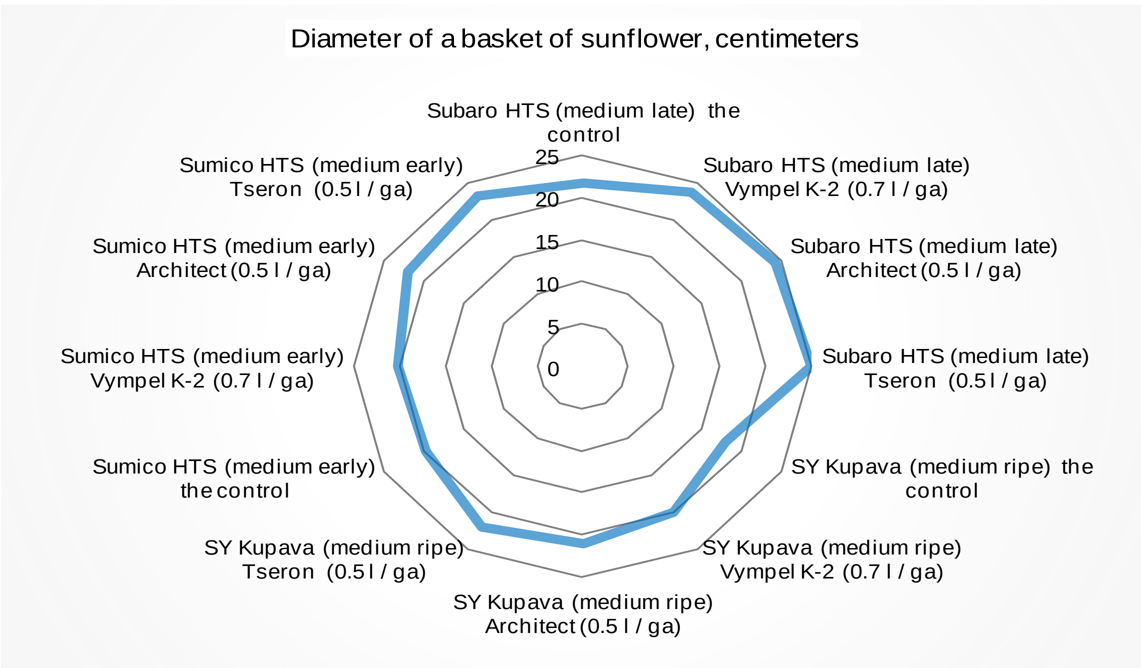

Fig. 3. Change in the diameter of the basket depending on the use of plant growth stimulants (2018–2020, cm)

All plant growth stimulants had almost no effect on the duration of the interphase vegetation periods of sunflower plants; there was only a slight tendency to reduce the vegetation period by 1–2 days using plant growth stimulants (Table 4).

Table 4. The duration of the interphase periods of vegetation of sunflower plants depends on the plant growth stimulators on average for 2018–2020

Sunflower hybrids	Plant growth stimulants	Interphase periods, days				
		Sowing-emergence of seedlings	Stairs-formation of baskets	Formation of flowering baskets	Flowering-full maturity	Duration of the growing season
Subaro HTS (medium-late)	Control (without agents' application)	12±0.7	30±1.2	22±0.7	40±1.7	104±2.5
	Vimpel K-2 (0.7 L/ha)	12±0.6	30±1.4	20±0.5	43±1.8	105±2.3
	Architect (0.5 L/ha)	12±0.7	29±1.3	21±0.6	41±1.9	103±2.2
	Tseron (0.5 L/ha)	12±0.5	30±1.7	20±0.7	41±1.7*	103±2.1
SY Kupava (medium ripe)	Control (without agents' application)	11±0.5	30±1.5	18±0.8	35±1.5	94±2.0
	Vimpel K-2 (0.7 L/ha)	11±0.6	29±1.3	18±0.6	36±1.6	94±2.1
	Architect (0.5 L/ha)	11±0.5	27±1.3*	16±0.7	37±1.7	91±1.9
	Tseron (0.5 L/ha)	11±0.5	28±1.2	17±0.8	38±1.7	94±2.2
Sumico HTS (medium early)	Control (without agents' application)	10±0.4	27±1.5	16±0.9	38±1.8	91±1.7
	Vimpel K-2 (0.7 L/ha)	10±0.5	25±1.4	18±0.8	37±1.5	90±1.8
	Architect (0.5 L/ha)	10±0.6	25±1.4	17±0.9	35±1.6*	87±1.5
	Tseron (0.5 L/ha)	10±0.4*	26±1.5	17±0.8	35±1.7	88±1.9

Note: * – the difference between the control and experimental variants is statistically significant for $P < 0.05$.

The number of seeds in the basket depended somewhat on the use of plant growth stimulants. The maximum number of seeds was definitely noted in the application of Tseron – 829–951 pieces, which exceeded the control by 3.4–5.6%. Application of Vimpel K-2 (0.7 L/ha) provided a minimum result of 827–936 pieces; the number of seeds increased by only 2.2–3.2% compared to the control (Table 5).

Table 5. The number of seeds in the basket depends on the use of plant growth stimulants (2019–2020, pcs)

Sunflower hybrids	Plant growth stimulants	The number of seeds in the basket, pcs years			
		2018	2019	2020	average
Subaro HTS (medium-late)	Control (without agents' application)	820±22.1	897±20.1	864±23.1	860±24.1
	Vimpel K-2 (0.7 L/ha)	899±20.3	936±23.8*	909±26.5	914±27.1
	Architect (0.5 L/ha)	920±25.4	951±24.5	924±26.8	931±25.6
	Tseron (0.5 L/ha)	918±20.1	951±24.2	926±26.1	931±23.3
SY Kupava (medium ripe)	Control (without agents' application)	815±20.1*	836±22.1	831±22.2	827±25.2
	Vimpel K-2 (0.7 L/ha)	850±22.5	914±25.3	893±24.1	885±22.2
	Architect (0.5 L/ha)	870±23.8	925±24.8	901±26.1	898±21.2
	Tseron (0.5 L/ha)	880±25.1	928±23.3	918±28.0	908±24.3
Sumico HTS (medium early)	Control (without agents' application)	825±24.1	808±20.1	800±19.8	811±23.3*
	Vimpel K-2 (0.7 L/ha)	830±23.2	829±23.3	827±20.2	828±22.5
	Architect (0.5 L/ha)	870±23.5	838±26.1	831±23.1	846±22.6
	Tseron (0.5 L/ha)	873±24.1	864±25.1	859±25.3	865±23.1

Note: * – the difference between the control and experimental variants is statistically significant for $P < 0.05$.

The weight of 1000 seeds was higher in the variants where the agent Architect was applied on medium-early and medium-late hybrids – 54.0–60.0 grams, the agent Tseron provided the best result on medium-late hybrids – 51.0–57.0 g. The weight of 1000 seeds depends on the hybrid fertilizer rate and practically did not depend on plant growth stimulants. Thus, the enormous mass of 1000 seeds was characteristic of the medium-early hybrid Sumico HTS – 54.0–60.0 g, and the smallest for the medium-late Subaro HTS – 51–55 g, which is explained by the biological characteristics of the hybrids (Fig. 4).

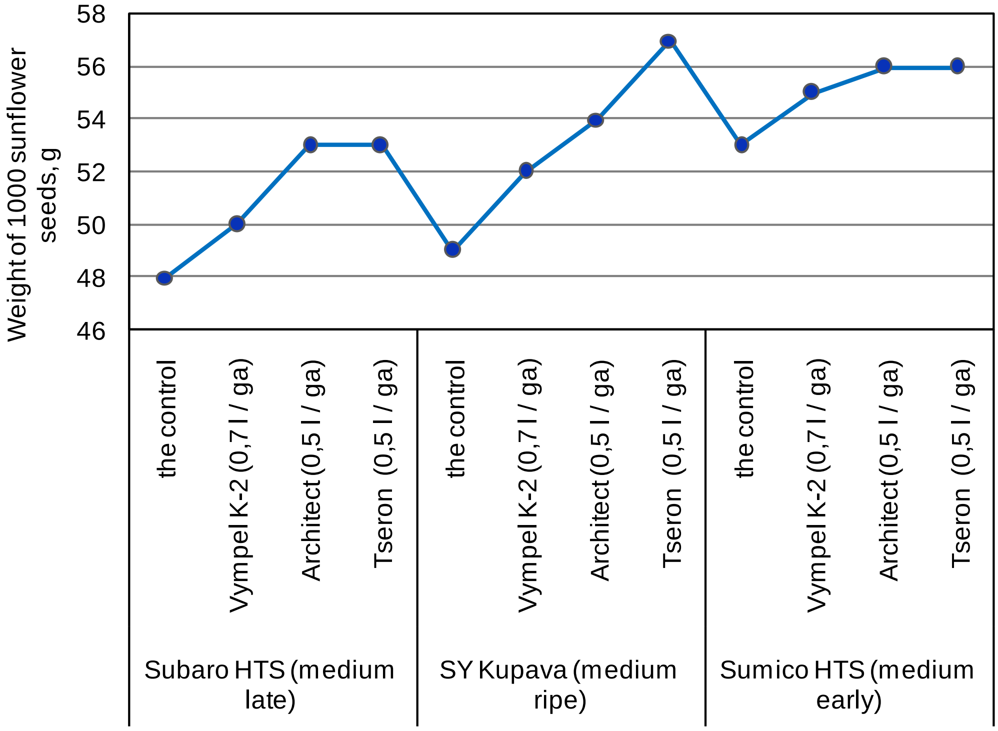

Fig. 4. Weight of 1000 sunflower seeds depending on plant growth stimulants for 2019–2020, g

The use of plant growth stimulants on sunflower contributed to an increase in crop yields of 1.01–1.7 times. Seed yields in 2020 were lower due to unfavorable, arid weather conditions of the growing season. The most significant increase in grain for all hybrids was provided by the agent Tseron (0.5 L/ha) – 0.16-0.75 t/ha, or 8.2–43.3%. The minimum increase from the use of plant growth stimulants was in the agent Vimpel K-2 (0.7 l/ha) – 0.06–0.56 t/ha, or 0.03–36.3%. The agent Architect occupied an intermediate position between agents Tseron and Vimpel K-2 (Table 6).

Table 6. Yields of sunflower hybrids of different maturity groups depending on plant growth regulators, t/ha

Sunflower hybrids	Plant growth stimulants	The yield of sunflower seeds, t/ha years			
		2018	2019	2020	середнє
Subaro HTS (medium-late)	Control (without agents' application)	1.77±0.09*	1.85±0.17	0.98±0.05*	1.50±0.07*
	Vimpel K-2 (0.7 L/ha)	1.80±0.11	1.91±0.15	1.54±0.08	1.75±0.09
	Architect (0.5 L/ha)	1.92±0.12	2.01±0.19	1.69±0.07	1.87±0.08
	Tseron (0.5 L/ha)	2.03±0.14	2.03±0.17	1.73±0.09	1.93±0.09
SY Kupava (medium ripe)	Control (without agents' application)	1.90±0.12	1.88±0.18	1.11±0.08	1.63±0.07
	Vimpel K-2 (0.7 L/ha)	1.92±0.15	1.98±0.17	1.51±0.07	1.80±0.08
	Architect (0.5 L/ha)	2.02±0.15	1.77±0.14	1.67±0.08	1.82±0.08
	Tseron (0.5 L/ha)	2.05±0.18	2.02±0.20	1.77±0.09	1.94±0.09
Sumico HTS (medium early)	Control (without agents' application)	1.82±0.19	1.79±0.18	0.99±0.06	1.53±0.05*
	Vimpel K-2 (0.7 L/ha)	1.91±0.14	1.82±0.14	1.16±0.09	1.63±0.06
	Architect (0.5 L/ha)	2.03±0.18	1.98±0.16*	1.19±0.09	1.73±0.07
	Tseron (0.5 L/ha)	2.06±0.20	1.95±0.17	1.24±0.07	1.75±0.08

Note: * – the difference between the control and experimental variants is statistically significant at $P < 0.05$.

The introduction of plant growth stimulants had some effect on the quality of sunflower seeds, namely, the oil content; there was a tendency to increase oil content compared to the control, mainly on the options where the drugs Tseron (0.5 L/ha) and Architect (0.5 L/ha), the increase in oil content here was 3–8 and 4–6 percentage points. The use of Vimpel K-2 (0.7 L/ha) contributed to the increase in oil content by only 1–3 percentage points (Fig. 5).

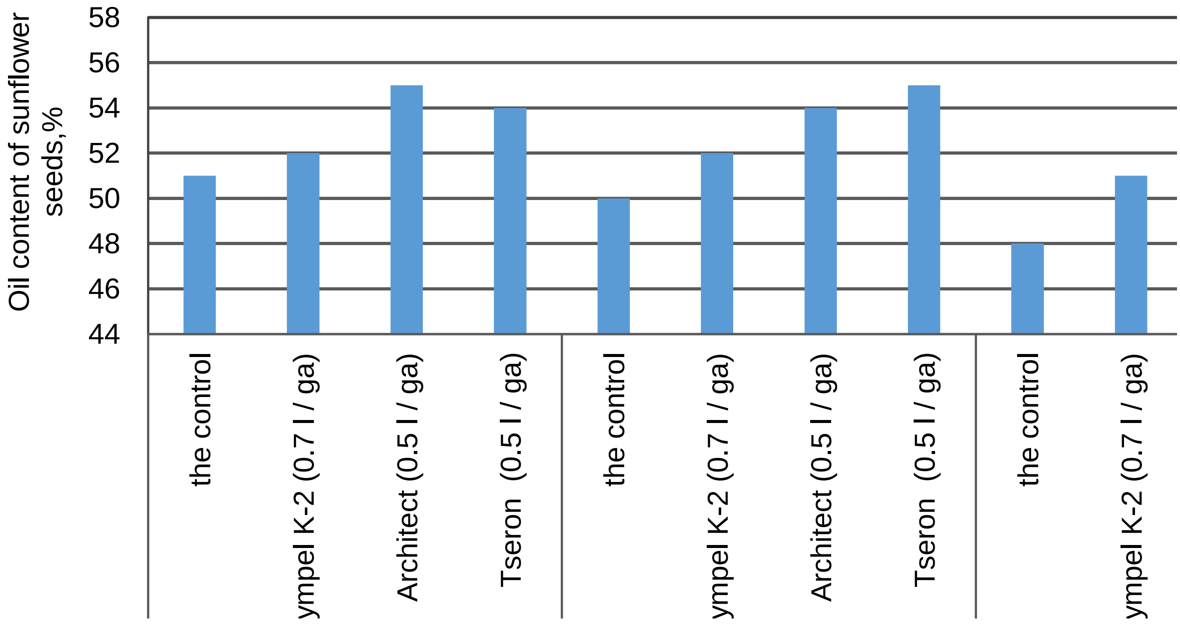

Fig. 5. The oil content of sunflower seeds of hybrids of different maturity groups depends on the use of plant growth stimulants on average for 2018–2020 %

Conclusions

The formation of the maximum leaf surface area of sunflower was observed using the growth stimulant Tseron (0.5 L/ha) on 70.9–78.1 thousand m^2/ha, or 5.5–10.2% more than the control. Here, sunflower plants formed the largest diameter of the basket – 23–26 cm (11.5–30.4% more than the control), and the maximum number of seeds in it, 829–951 pieces, exceeded the control by 3.4–5.6 %. The highest weight of 1000 seeds was characteristic of the medium-early hybrid Sumico HTS – 54.0–60.0 g, and the lowest for the medium-late Subaro HTS – 51–55 g, due to the biological characteristics of the hybrids. The use of plant growth stimulants on sunflower contributed to an increase in crop yields of 1.01–1.7 times. The most significant increase in grain for all hybrids was provided by the agent Tseron (0.5 L/ha) – 0.16–0.75 t/ha, or 8.2–43.3%. The use of regulatory agents Tseron (0.5 L/ha) and Architect (0.5 L/ha) contributes to the increase in oil content by 3–8 and 4–6 percentage points, respectively.

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