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SUNFLOWER (Helianthus annuus L.) PRODUCTIVITY UNDER THE EFFECT OF PLANT GROWTH REGULATOR IN THE CONDITIONS OF INSUFFICIENT MOISTURE

Oksana YEREMENKO[1], Svitlana KALENSKA[1], Serhii KIURCHEV[1], Anatolii RUD[2], Oleksandr CHYNCHYK[2], Oleksandr SEMENOV[2]

[1]TAVRIA STATE AGROTECHNOLOGICAL UNIVERSITY
[2] STATE AGRARIAN AND ENGINEERING UNIVERSITY IN PODILYA

*Corresponding author: e-mail: ok.eremenko@gmail.com

KEYWORDS

sunflower, productivity, plant growth regulator, hydrothermal conditions, growth and development of the plants, germination, stress resistance.

ABSTRACT

It is shown that the use of plant growth regulators of antioxidant action for presowing treatment of oilseed crops can both oppress and stimulate germination processes.

The plant growth regulator caused the activation of the growth process, which was particularly manifested through the height of plants and stem diameter. The increase in the leaf surface area of the crop by 39.3 % was defined by plant growth regulator and greatly depended on rainfall (r = 0.999) during the period of 00 65 on BBCH scale. Medium correlation (r = 0.588) was determined between rainfall in the phase of rapid growth and inflorescence diameter. Growth regulator affected the yield of sunflower significantly the share of a factor in the formation of yield was 32.7 %. The share of the impact of water deficit was 58.4 % on average over the years of research. Pollen fertility and seed emptiness of sunflower depended on relative humidity during flowering – r = 0.990 for the control plants and r = 0.973 in case of AKM application. The weight of 1000 seeds increased under PGR action by an average of 17 33 % depending on the zone of the inflorescence.

In general, hybrids and plant growth regulator as researched factors significantly affect the yield of sunflower but the proportion of influence of hybrid (factor A) (85.1 %) is significantly higher than that of the impact of PGR (factor B) (7.5 %). This should be considered when developing anti-stress techniques in technologies of sunflower cultivation in the Steppe zone of Ukraine. Correlation of high strength was found between leaf surface area and rainfall (BBCH - 00-65) for all of hybrids (r = 0.868 – 0.996). AKM showed the greatest influence on the yield of sunflower plants of Zubr and Forvard hybrids, where fluctuation was within 14.3 - 31.3 %.

1. INTRODUCTION

According to the ISTA Mielke GmbH research center in Hamburg, in recent years world consumption of oils and vegetable fats has risen by 4 % annually. the increase in oilseed crops production over the past 12 years was 3.5 million tons per year, the average consumption for the season was 123.8 million tons, and according to forecasts, by the end of the next decade, it will increase to 135 - 137 million tons per year. These figures correspond to 2.6 % - 2.8 % of annual growth. the reasons for increasing consumption are population growth, increasing living standards and productivity growth in the global agrarian sector [1].

In world production of food vegetable oils, the first place belongs to soybean oil, the second - palm, the third and fourth – to sunflower and oilseed rape oils. an important role in the total production of edible vegetable oils is given to peanut, cotton and olive oil [2].

In 2016, sown area under sunflower in the world, according to the UN Food and Agriculture Organization (FAO) and the International Sunflower Association (NAS), amounted to 25.2 million hectares (Figure 1).

Over the past 10 years, the area under sunflower has increased by 3.97 %, past 20 years - by 18.3 %, and past 30 years - by 38.9 %. an increase in sown area under sunflower indicates a high level of its economic attractiveness in leading producer countries [3].

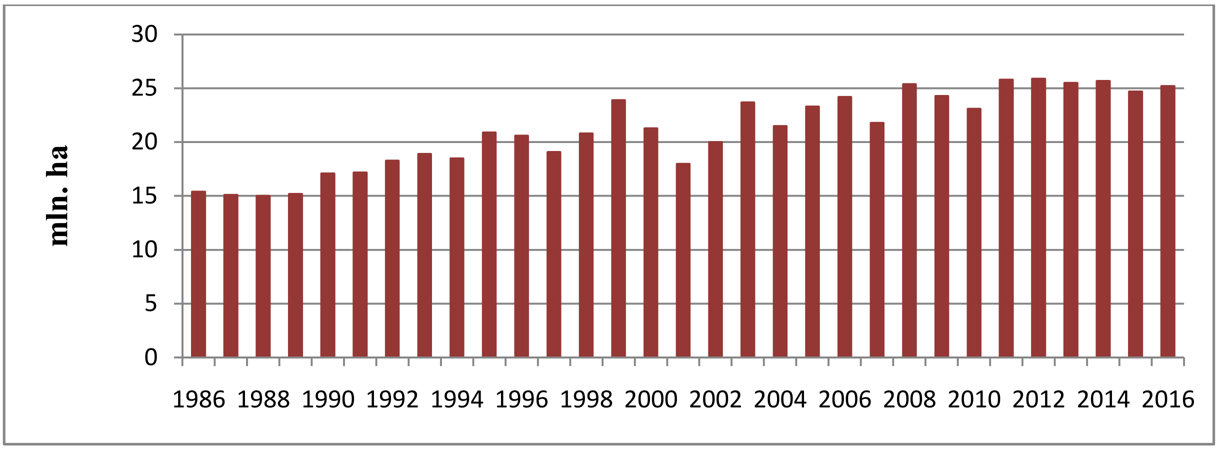

Fig. 1. Sown areas under sunflower in the world according to the NAS for the period 1986 - 2016, million hectares [4]

Over the past 10 years, the production of sunflower seeds has increased by 23.5 %, past 20 years - by 41.4 %, and past 30 years - by 2 times. Based on the results of the correlation analysis, we can conclude that the dynamics of volumes of gross production of sunflower seeds in the world are significantly affected by both changes in sown areas and yields of the studied crop. the correlation coefficient between gross production and sown area is $r = 0.891$, and between gross production and yield – 0.800. on the basis of calculated paired determination coefficients, it was established that gross production of sunflower seeds depends on 79.3% on the sown areas and 64.0% on the yield.

The average yield of this crop in the world (1986 - 2016) is 1.34 t/ha. For example, in 2008, the highest yield of sunflower was aquired in the United States – 1.60 t/ha, Argentina

-1.35 t/ha; Russia - 1.23 t/ha; France - 2.51 t/ha; Italy – 1.73 t/ha, Ukraine -1.53 t/ha, and in 2016 - in Ukraine – 2.24 t/ha; Turkey – 2.18 t/ha; Argentina – 1.84 t/ha, and Russia – 1.51 t/ha [4].

Sunflower is the leading oilseed crop in Ukraine. Due to low cost of working capital and high liquidity of the product, seed production, even on the level of yield 800 kg/ha is considered cost-effective. Its production significantly affects the economic situation in the southern region, where it holds the first place in terms of profitability. According to statistics, in many agribusinesses of southern Ukraine sunflower accounts for 55 – 75 % of the profit from the crop production [5-6].

The field of plant growing depends on the weather conditions during the entire production cycle, starting with sowing and ending with harvesting. the factor of weather risk, which significantly affects the yield of crops, is objective and one of the least predictable. by their genesis weather risks are external, not related directly to the activities of the enterprise [7]. Therefore, the production of sunflower seeds, as well as other crops in many farmsof Steppe zone of Ukraine is distinguished by a decrease in yield and its stability and increase of the cost of production.

Due to violation of the growing technologies of the studied crop, growth of aridity of the climate and stress factors that provoke the development of oxidative stress, the yield of sunflower varies (coefficient of variation of yield is 15.4 %).

There are two ways to solve the problem of finding a way to increase plant resistance to stresses: selection – breeding of resistant varieties or hybrids at the genetic level and through resistance control by technological methods. Today it is important to develop technological ways to solve this problem. the stimulation of plant growth and development, the increase of sunflower plant resistance to stress factors by differentiated use of plant growth regulators in various stages of development is an effective way to increase the yield of plants [8].

The increase of crop productivity with the use of PGR relates to the fact that they intensify the activity of plant organism cells, increase the permeability of intercellular membranes and accelerate biochemical processes in them, which leads to the optimization of processes of nutrition, respiration and photosynthesis. Thanks to these preparations, plants have higher resistance to adverse weather conditions and the damage of pests and diseases. Plant growth regulators contribute to the realization of the genetic potential of plants to a higher level [9-11].

Analysis of recent researches and publications. the efficiency of growth regulators in oilseed sunflower cultivation technologies was studied by I.I. Klimenko, Y.I. Buryak and other scientists [5,12]. in studies growth regulators with active substances of different origin and mechanisms of influence on plants are used. it was determined that in case of pre-sowing treatment of sunflower seeds with different growth regulators, field germination increases by 3 17 %, the yield of sunflower – by 0.14 0.21 t/ha, primarily by increasing the weight of 1000 seeds and number of full seeds in the inflorescence.

Hernandez claims that different plant growth regulators (N6-benzyladenine (BA), a-Naphthaleneacetic acid (NAA) and Gibberellic acid (GA3)) contribute to the increase of leaf surface area by an average of 38 % and stimulate the growth processes of sunflower plants, while causing reduction in the duration of the phases of plant growth and development [13].

According to a group of scientists: Sibgha Noreen, Muhammad Ashraf, Mumtaz Hussain and Amer Jamil [14], the use of salicylic acid as a growth regulator for sunflower cultivation reduces the negative impact of stressors by increasing the activity of antioxidant enzymes (superoxide dismutase, catalase and peroxidase). in addition, growth processes and photosynthetic activity of sunflower plants are activated.

The efficiency of growth regulators in case of sufficient moisture and abidance of the growing technology is quite high. at the same time, studies with growth regulators in low and unstable moisture conditions and high temperatures in field crop cultivation in general and large-seed sunflower varieties in particular are not sufficient, resulting to the direction of our research.

The goal of this research was to determine the influence of AKM plant growth regulator on the performance of large-seed Lakomka variety and early ripening hybrids of domestic selection: Zubr, Odes'kyi 249, Forvard, Yason [15].

2. MATERIALS AND METHODS

Iodine solution (for determining the fertility of sunflower pollen) is prepared by Gram recipe: 2 g of potassium iodide is dissolved in 5 ml of distilled water when heated. Then 1 g of metallic iodine is added into solution, which is brought to 300 ml and stored in an orange glass.

Alkalis, acids, solvents, Mohr's salt and other reagents have been purchased at "Khimlaborreaktyv" company (Kyiv, Ukraine).

Soil preparation: a soil sample, taken from the experimental plot, was air dried. Then all the roots were carefully removed, the ground was rubbed in agate mortar and sieved through a sieve with 0.25 mm holes.

The humus content in the soil was determined using I.V. Turin's method [16], which is based on the oxidation of soil organic matter by 0.4 n solution of potassium bichromate ($K_2Cr_2O_7$) till the formation of carbon dioxide. the reaction occurs by the equation:

$$3C + K_2Cr_2O_7 + H_2SO_4 = 2K_2SO_4 + 2Cr_2(SO_4)_3 + 8H_2O + 3CO_2$$

The residue of chromic mixture, not used for oxidation purposes, was titrated by Mohr's salt (double salt) of ammonium sulfate and iron oxide sulphate $[(NH_4)_2SO_4 FeSO_4]\cdot 6H_2O$. the residue of chromium compounds was determined by the number of consumed Mohr's salt, and by the difference between the original amount (idling determination result), and the remainder amount of chromium compounds, which went to the oxidation of humus.

Definition of hydrolyzed nitrogen by Cornfield [17]. the principle of the method is that soil is hydrolyzed using alkali. as a result, nitrogen of exchange ammonium, amide, aminosugars, and other compounds is released from the soil in the form of NH_3, which is caught by boric acid.

Determination of mobile forms of phosphorus and potassium in the soil using Chirikov method (DSTU 4115-2002) [18]. the method is based on "extraction" of phosphorus and potassium from the soil by 0.5 normal acetic acid at a ratio soil:solution (1:25) followed by phosphorus determination as molybdenum blue on photoelectric colorimeter, and potassium on flame photometer.

The method of comprehensive lipid extraction (Soxhlet method) is based on the highest possible lipid extraction from the analyzed material by repeated treatment with solvent until the lipid content in the material becomes insignificant. the solvent is then distilled off from the resulting extract and the residue containing lipids is dried in conditions that preclude its oxidation, and is weighed (DSTU 7577:2014) [19].

Determination of pollen fertility by iodine method [20]. it is based on the determination of starch using iodine reaction. Fertile and sterile pollen grains vary in starch content. Usually fertile pollen grains are completely filled with starch and sterile ones have none of it at all or contain only traces.

Equipment. to receive quantitative indicators during experiments on the definition of soil quality, fertility of pollen of flowers and seeds of sunflower the following equipment was used: analytical scales ANG220 (AXIS, Poland), binocular microscope THS08-04B-RC

40x-1000x (Henan, China), Multifuge centrifuge (Thermo/Heraeus, Germany), two-channel flame photometer CL22 (Russian Federation), scanning spectrophotometer UV-2800-UNICO (Russian Federation).

Soil and climatic conditions of research conduction. the study was conducted in 2011–2015 in "Agrofirma MIR" LLC of Melitopol district of Zaporizhzhya region and in the laboratory of monitoring of soil and crop products quality of the Research Institute of Agrotechnologies and Ecology of Tavria State Agrotechnological University.

Soil of the research sites is southern chernozem with average weighted humus content of 3.7 %, easily hydrolyzed nitrogen (by Cornfield) 95 mg/kg, mobile phosphorus (by Chirikov) 117 mg/kg and exchangeable potassium (by Chirikov) 145 mg/kg of the soil. the results were compared with the standards of soil fertility indexes for agricultural lands, established by DSTU (DSTU 4362:2004) [21].

Soil moisture conditions in the research years differed, both by the rainfall amount, and its uniformity (Table 1). Almost the same amount of precipitation during the growing season was observed in 2013 122 mm, while in 2011 there was twice more precipitation 249 mm. at the same time, 2013 and 2014 were distinguished by irregular rainfall, high temperatures and large soil drought during the period from germination to seed maturation. HTC indexes varied within the limits of 0.4 0.9 over the years. Hydrothermal conditions in 2011 were more optimal both by amount and uniformity of rainfall. at the same time, 2012 was characterized by the lowest humidity during flowering of sunflower (32.8 %).

Tab. 1. Hydrothermal conditions of the growing season of sunflower during research years

Indexes	2011	2012	2013	2014	2015
Rainfall during the growing season, mm	249	129	122	233	155
The sum of active (above +10 °C) temperatures, °C	2787	2889	2996	2869	2756
CHU*	3285	3334	3519	3375	3225
Hydrothermal coefficient	0.89	0.44	0.41	0.81	0.56
Minimum relative air humidity during flowering, %	49.9	32.8	61.8	36.9	45.8

Studied preparation characteristics. the study of ionol influence on the growth and development of agricultural crops was started in the 80 90’s of XX century [24]. Ionol (2,6-di-tert-butyl-4-methylphenol) has properties not only as an effective free radical and hydroperoxide inhibitor. it prevents the development of oxidative stress in the cells of plants and seeds, and controls apoptosis, cell division, differentiation of organelles and ultrastructure of plastids, thus regulating plant growth and development, increasing their adaptive capabilities, especially under adverse conditions during germination and vegetation [25-26].

Dimethylsulfoxide is an antioxidant that binds active forms of oxygen, including the most toxic OH radicals, and in concentrations of 0.1 mmol/l shows mild stimulating effect on the process of oxidative phosphorylation, increasing the energy potential of the organism [27]. Thanks to the ability of DMSO to penetrate through cell membranes without damage to the active transport of biologically active substances, its complex with ionol has a significant synergistic effect on seed germination [28-29].

The staff of the Tavria State Agrotechnological University have developed AKM growth regulator of antioxidant type, where ionol and dimethyl sulfoxide antioxidants form a composition with polyethylene glycols of different molecular weight [23,30].

Scheme of the experiment. in order to determine the effect of presowing treatment of sunflower seeds with different PGRs on germination energy and laboratory germination, we conducted a laboratory experiment using the following scheme (Table 2).

Tab. 2. Scheme of the laboratory experiment

Variant	Preparation, consumption rate, l/ton	Concentration of ai in working solution, g/l
1 (C)	Seed treater	-
2	Seed treater+Vympel, 0.26	Sodium humate, 0.78
3	Seed treater +Emistim C, 0.20	Complex of physiologically active compounds in 60% ethanol
4	Seed treater+AKM, 0.033	Ionol and dimethylsulfoxide, 0.0015
5	Seed treater+AKM, 0.330	Ionol and dimethylsulfoxide, 0.015
6	Seed treater+AKM, 3.30	Ionol and dimethylsulfoxide, 0.15

We have determined that incrustation of sunflower seeds with Vympel, Emistim C, and AKM growth regulators stimulates germination, which shows an increase in germination energy by 1.8 - 5.1 pp. relative to control (Figure 2).

The dependence of AKM effect on the concentration of active substances (ionol, dimethylsulfoxide) should be noted. at high concentrations (0.15 g/l), the effect of AKM on seed germination is unreliable. the largest effect is detected at a concentration of 0.015 g/l.

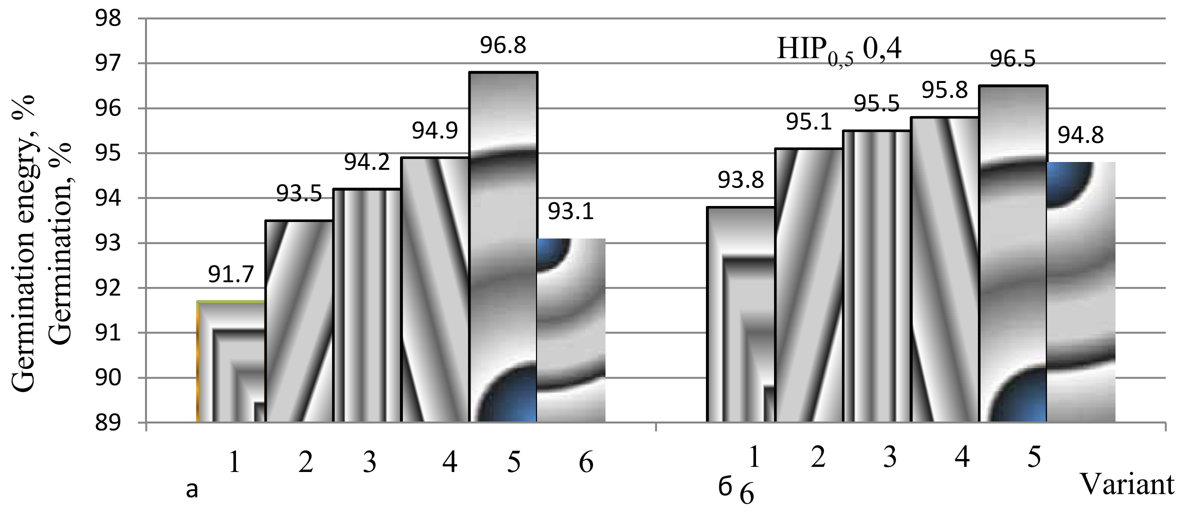

Fig. 2. Influence of plant growth regulators on germination energy (a) and laboratory germination (b) of sunflower seeds of Lakomka variety

Laboratory germination of the seeds treated with PGR increased by 1.0-2.7 pp. relative to control (Figure 2). at the same time, Vympel and Emistim C were surpassed by AKM in effect on seed germination, especially in optimal concentration (0.015 g/l). a significant advantage of AKM is also the absence of a difference between germination energy and seed germination, which in field conditions made it possible to reduce the period of seeds-shoots by 1-2 days and to obtain more even shoots. That is why seeds were treated with AKM with consumption rate of 0.33 l/ton in the field experiment.

In order to address stated objectives and goal three-factor field experiment was laid, in which factor a are different sunflower hybrids, which provided seed treatment with AKM plant growth regulator [23] – factor B and determination of the effectiveness of its action under hydrothermal conditions of the year of the research - factor C (Table 3). Seed treatment was carried out 1 2 days before sowing by incrustation method at the rate of 10 l of working solution per 1 ton of seeds.

Tab. 3. the scheme of field experiment

Variant	Preparation consumption rate, l/t	Concentration of ai in the working solution, g/l
1 (K)	Seed treater Derozal, 1.5	-
2	K + AKM, 0.330	Ionol + dimethyl sulfoxide, 0.015

The technology of sunflower cultivation in the experiment. Sunflower seeds were sown early in the third decade of April, the rate of sowing was 45,000 seeds/ha with 70 cm row spacing. the predecessor of sunflower was winter wheat. the care of crops, estimation and monitoring of growth and development of plants, yield structure formation of sunflower were carried out according to the Methods of field experience (with the fundamentals of statistical processing of study results) [31]. Pollen fertility was determined by iodine method, based on the determination of starch using iodine reaction [32]. Seeds from the inflorescence were taken after drying in the air to determine the mass of 1000 seeds [31,33].

The mathematical analysis of the results was carried out by Student's test [34-36] using licensed Agrostat computer program.

3. RESULTS AND DISCUSSION

Vegetative sunflower plant productivity depending on pre-sowing seed treatment by AKM growth regulator and hydrothermal conditions of the year. Germination of the seeds is one of the most critical stages in the life of the plant. the use of pre-sowing seed treatment activates self-regulation processes and improves germination and resistance to adverse environmental factors [37]. we have determined that the incrustation of sunflower seeds by AKM plant growth regulator stimulates germination, which is proven by increasing germination vigor by 1.8 5.1 percentage points (p. p.) relative to the control [38].

The effect of growth regulators on the germination in field conditions depends on the hydrothermal conditions of the year, especially on rainfall at the stage of seed germination. Very low rainfall in 2012 5.9 mm during seed germination (BBCH – 00 09) led to the reduction in field germination of untreated seeds by 29.6 p. p. relative to optimal moisture in 2011 (Table 4). the field germination of seeds, treated with AKM plant growth regulator during studied years, had a similar pattern to that of the control, but the difference between optimal by moisture and the most draughty years was 20 p. p. in 2011, no difference in field germination between control and experimental variants was observed.

Tab. 4. Vegetative sunflower plant productivity, depending on pre-sowing seed treatment by AKM growth regulator and hydrothermal conditions of the year

PGR (factor B)	Year (factor C)	Field germination, %	Plant height, m	Stem diameter, cm	Amount of leaves, units per plant	Leaf surface area, thousand m^2/ha
No PGR	2011	73.1	1.57	2.7	28.4	29.3
	2012	56.4	1.43	2.2	19.4	15.5
	2013	69.8	1.35	2.3	22.3	18.4
AKM	2011	73.6	1.59	2.9	29.1	33.7
	2012	61.3	1.55	2.6	20.6	23.5
	2013	72.9	1.46	2.7	24.6	22.7
LSD_{05} B		1.1	0.19	0.2	0.5	0.8
C		1.7	0.04	0.1	0.9	1.5

AKM PGR had significant effect on plant height and diameter of the stem in all studied years. For instance, in 2011, the most humidified year, plant height increased by 8 %, and stem diameter – by 15 %, which was a good measure against laying of crops.

Under AKM action the number of leaves per plant increased by 3 9 % compared to the control (Table 4). the effect of hydrothermal conditions on the effectiveness of the PGR on the performance of vegetative sunflower plant productivity was the same.

The photosynthetic activity of plants depends on leaf surface area. in our studies the leaf surface area was determined at the stage of plant development, BBCH – 61 65. the experimental variant exceeded the control by an average of 22 % for this index. Because of better moisture supply, sunflower plants in 2011 formed a larger leaf surface area than in other years studied. Attention is drawn to the fact that the difference between research variants in more stressful 2012 was maximal (34 %), proving that AKM PGR shows anti-stress properties. a correlation of high strength (r = 0.999) was found between the leaf surface area of the crop and rainfall (BBCH – 00 65) and this gives grounds to including the investigated PGR to plant growth stimulators. the share of AKM PGR impact (factor A) on the formation of the leaf surface area was 39.3 %.

The structure of sunflower yield under AKM growth regulator effect depending on hydrothermal conditions of the year. the plant density in studied years was low (Table 5). Because of unfavorable hydrothermal conditions, crop irregularity was observedin the arrangement of sunflower plants. we established a correlation (r) between the plant density and HTC (BBCH – 00 09), equal to 0.712 (control) and 0.804 (AKM).

The diameter of the inflorescence depends on the moisture supply of sunflower plants in inflorescence formation stage (BBCH – 51 53). Under PGR action the diameter of inflorescence increased, especially in the dry 2012, when this figure exceeded control by 13 %. the medium strength correlation (r = 0.588) was found between rainfall in the phase of rapid inflorescence growth and its diameter.

Tab. 5. Structure of sunflower yield under AKM growth regulator action depending on hydrothermal conditions of the year

PGR (factor B)	Year (factor C)	Plant density, thousand units/ha	Inflorescence diameter, cm	Seed weight in 1 inflorescence, g	Biological yield, t/ha	Rate of the genetic potential of the variety realization, %
No PGR	2011	32.9	21.4	79.0	2.6	74.3
	2012	25.4	18.9	55.1	1.4	40.0
	2013	31.4	23.7	86.0	2.7	77.1
AKM	2011	33.1	22.5	86.8	2.9	82.9
	2012	27.6	21.8	67.9	1.9	54.3
	2013	32.8	23.9	100.6	3.3	94.3
LSD_{05} B C		0.3 0.2	0.3 0.3	1.1 0.8	0.1 0.2	

PGR had significant influence on seed weight in the inflorescence, which increased by 9 19 % under the influence of AKM compared to control. in the dry 2012 the effect of the PGR was maximal, indicating the anti-stress effect of AKM on the formation and maturation of seeds. There was a close correlation between the mass of seeds from 1 inflorescence and rainfall (BBCH – 51 87): in the control variant, it was (r = 0.953), and in the experimental variant r = 0.864. Thus, PPP reduces negative effect of drought.

The positive impact of PGR on the formation of vegetative and generative organs of sunflower plants was reflected in such integrated index as biological productivity (Table 5), which increased by 10 26 % under the influence of AKM. the greatest influence on the sunflower yield was demonstrated by AKM in the dry 2012, when it increased by 26 % relative to the control. in general, both studied factors significantly affected the sunflower yield, but the proportion of the impact of water stress of the studied year (factor C) (58.4 %) was significantly higher than that of the impact of PGR (factor B) (32.7 %). This should be considered when developing anti-stress techniques in technologies of sunflower cultivation in the Steppe zone of Ukraine. Analyzing the impact of hydrothermal conditions of the year on the formation of biological yield of sunflower, we have established a close relationship between the relative humidity during the growing season and yield, where the correlation coefficient was 0.939 in control, and 0.990 – in the experimental variant. the correlations between biological yield and rainfall and the amount of active temperatures were weak, while with the accumulation of heat units (CHU), this relationship was average and correlation coefficient was 0.383 for the control and 0.569 for the experimental variant.

Sunflower pollen fertility of Lakomka variety under AKM growth regulator action depending on hydrothermal conditions of the year. in the Steppe zone of Ukraine during the flowering period of sunflower, the daytime temperature rises to 40 ºC, and at such temperatures pollen is drying, which in turn leads to an increase in its sterility.

it is determined that fertility and sterility of pollen cells differ by starch content [39]. Its normal content matches the final stage of sperm formation. Fertile pollen grains are completely filled with starch while sterile do not contain it at all or only have traces (Figure 3).

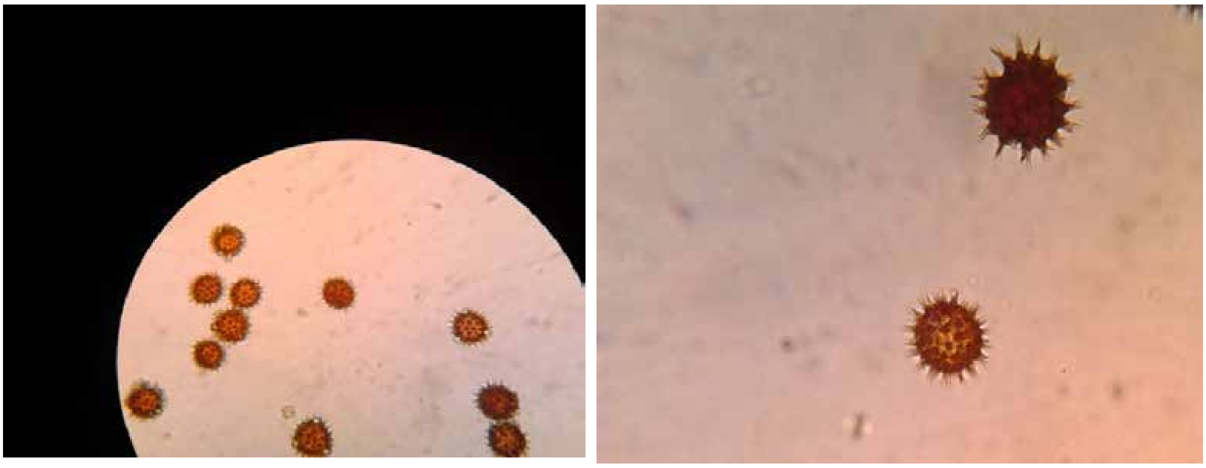

Fig. 3. Pollen grains after coloring by iodine method under a microscope (own photos)

Pre-sowing seed treatment by PGR influences the development of flower primordia considerably (Figure 4). Thus, sunflower pollen fertility in the experimental variant increased by 27 % compared to the control on average for years. Relative air humidity had the greatest influence on the fertility of sunflower pollen. Thus, the connection between research features was very high and the correlation coefficient was equal to 0.990 for control and 0.973 for AKM PGR. the sum of active temperatures during flowering (BBCH – 61 69) had significant influence on pollen fertility. in control, the variant correlation coefficient equaled 0.904, and the variant with AKM 0.684.

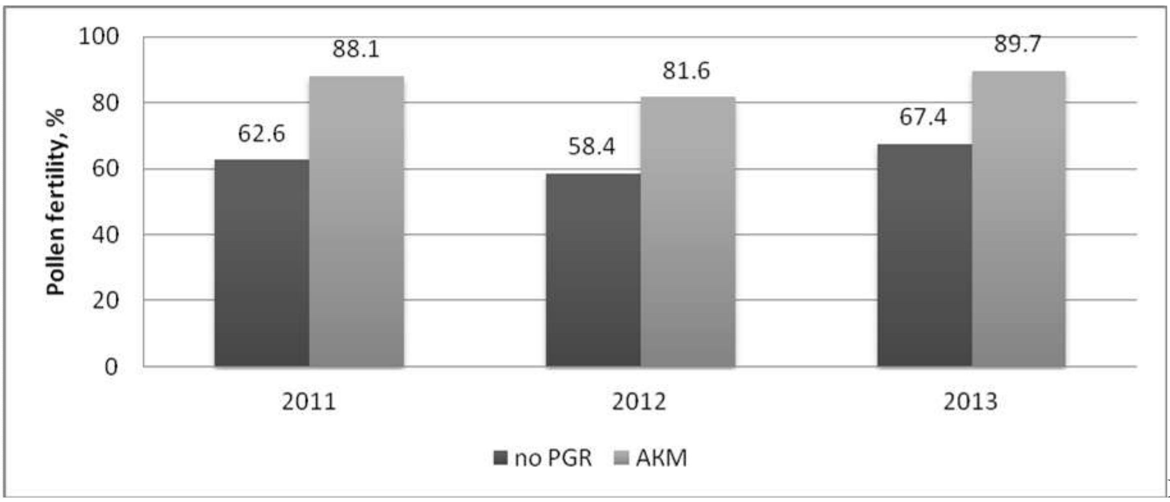

Fig. 4. Sunflower pollen fertility of Lakomka variety under AKM growth regulator action depending on hydrothermal conditions of the year

Sunflower seed quality of Lakomka variety under AKM growth regulator action depending on hydrothermal conditions of the year. Seed emptiness of sunflower seeds depends on pollen fertility. This index, similar to the mass of 1000 seeds, was determined in three different zones of the inflorescence (outside, middle, and central). the highest seed emptiness was observed in the center of the inflorescence (Table 6). in control variant, it was higher compared to the experimental variant on average by 9.3 p.p.

Relative air humidity during flowering had the greatest influence on the formation of empty sunflower seeds. the relationship between these indices was strong and inverse in all the zones of inflorescence. the highest correlation coefficient was in the central zone, amounting to r = 0.964 in control and r = 0.995 in AKM PGR variant. in the control variant, the correlation coefficient gradually decreased and in the outside zone equaled 0.761. at the same time in the PPP AKM variant it almost did not depend on the inflorescence zone. a similar dependence was observed between seed emptiness and the active temperatures, although it was weaker.

Tab. 6. Seed emptiness and weight of 1000 seeds of Lakomka sunflower variety depending on the development zone of the inflorescence

PGR (factor B)	Year (factor C)	Seed emptiness, %			Weight of 1000 seeds, g		
		Zone of the inflorescence			Zone of the inflorescence		
		Outside	Middle	Central	Outside	Middle	Central
No PGR	2011	6.5	12.5	31.1	87.2	72.8	49.1
	2012	7.3	14.7	35.7	84.3	61.5	45.3
	2013	5.2	13.4	30.2	95.3	82.1	52.3
AKM	2011	4.7	8.5	22.4	102.3	94.2	78.9
	2012	4.9	10.4	25.5	101.2	92.7	67.7
	2013	4.1	7.6	20.9	118.5	101.4	74.3
LSD_{05} B		0.2	0.1	0.3	1.3	1.6	0.9
C		0.4	0.2	0.3	0.8	0.7	1.7

The weight of 1000 seeds depends on fullness and emptiness of seeds. Maximally full seeds were formed in the outside zone of sunflower inflorescence. Under the effect of AKM plant growth regulator, the weight of 1000 seeds increased by an average of 17 33 % depending on the area of the inflorescence. the maximum deviation of the mass of 1000 seeds was characteristic to the seeds within the central zone of the inflorescence. Under optimum conditions of growth and development, large-seed Lakomka sunflower variety formed seeds with the weight of 1000 seeds – 120 130 g. in our case, the plants of control variant had almost twice lower mass of 1000 seeds. AKM PGR contributed to the formation of greater mass of 1000 seeds, but genetic potential of plants was realized only by 81 %. No significant correlation was found between 1000 seeds weight and rainfall (BBCH – 61 87). at the same time, there were considerable inverse correlations between the weight of 1000 seeds and the active temperatures (BBCH – 61 87) with the correlation coefficient of 0.999 for the control variant and from 0.608 to 0.925 for the experimental variant, depending on the zone of the inflorescence.

AKM plant growth regulator regulates not only seed emptiness and weight of 1000 seeds but also the seed size its length (Table 7). Under the application of growth regulator, the seed fraction with the length of > 7 mm in average for research years was 67.2 % and in 2011 – 86 % of the total seeds, which is 25 p. p. more compared with the control. at the same time the fractions with shorter length of seeds dominated in the control variant.

Tab. 7. Sunflower seed quality of Lakomka variety under AKM growth regulator action depending on hydrothermal conditions of the year

PGR (factor B)	Year (factor C)	Fractions of seeds by length, %			Desquamation, %	Oil content, %
		5 6 mm	6.1 7 mm	>7 mm		
No PGR	2011	10	29.0	61.0	27.5	44.7
	2012	20	52.8	27.2	29.1	43.6
	2013	22	53.4	24.6	28.6	42.5
AKM	2011	2.0	12.0	86.0	27.9	45.3
	2012	9.8	34.2	56.0	28.6	44.9
	2013	8.9	31.5	59.6	28.3	43.6
LSD_{05} B C					0.3 0.5	0.2 0.3

Only a tendency to changing seed desquamation was found during the studied years between the control and the variant using AKM PGR. in years with unfavorable hydrothermal conditions, a thicker seed shell was formed.

The highest oil content in sunflower seeds was in 2011 with favorable hydrothermal conditions. Under the application of growth regulator, there was a tendency to increasing oil content in seeds.

In further research, we were interested in considering the impact of AKM PGR on the productivity of various sunflower hybrids. Therefore, since 2013 the experiments have been carried out on Zubr, Forvard, Yason, and Odes'kyi 249 hybrids according to the scheme shown in Table 3.

Due to lack of moisture during sowing in 2013, field germination in all research variants was lower than in 2014 - 2015 (Table 8).

Tab. 8. Vegetative sunflower plant productivity, depending on pre-sowing seed treatment by AKM growth regulator and hydrothermal conditions of the year

Indices	Year (factor C)	Hybrid (factor A)								LSD05 a B C
		Zubr		Odes'kyi 249		Forvard		Yason		
		PGR (factor B)								
		no PGR	AKM	no PGR	AKM	no PGR	AKM	no PGR	AKM	
Field germination, %	2013	61.4	66.2	73.7	75.9	69.4	78.3	66.5	73.9	1.1
	2014	78.3	80.7	77.6	78.3	76.4	79.9	80.1	83.7	1.1
	2015	79.1	81.4	77.8	80.9	75.7	79.3	81.4	84.6	0.9
Plant height, m	2013	1.76	1.80	1.24	1.57	1.75	1.80	1.69	1.79	0.11
	2014	1.77	1.81	1.48	1.70	1.79	1.83	1.70	1.80	0.16
	2015	1.80	1.83	1.53	1.69	1.81	1.86	1.74	1.81	0.09
Stem diameter, cm	2013	2.6	2.8	2.2	2.4	2.5	2.9	2.7	2.8	0.1
	2014	2.7	2.9	2.2	2.5	2.7	2.9	2.8	2.8	0.1
	2015	2.8	2.9	2.4	2.5	2.7	2.9	2.8	2.9	0.2
Amount of leaves, units per plant	2013	24.2	26.7	19.6	21.1	20.4	23.3	20.9	22.1	0.6
	2014	26.8	28.2	21.4	24.4	23.9	24.2	22.1	23.4	0.5
	2015	27.3	28.5	22.7	24.9	23.6	25.0	22.7	23.1	0.7
Leaf surface area, thousand m^2/ha	2013	16.6	18.4	20.8	22.2	18.9	21.6	19.1	20.2	0.9
	2014	19.8	22.7	25.3	24.6	25.2	26.7	26.4	28.7	0.6
	2015	23.1	25.3	28.2	28.4	29.0	30.9	29.7	30.5	1.1

When applying AKM plant growth regulator for pre-sowing treatment of seeds of sunflower hybrids, field germination increased in all variants. However, in 2013 the difference between control and research variants ranged between 2.2 - 8.9 percentage points, while in 2014 - 2015 - 0.7 - 3.6 percentage points for all the studied hybrids. the increase in the difference between the sowing properties of seeds of control and research variants in a stress year (2013) shows anti-stress (antioxidant) properties of AKM growth regulator. This is confirmed by research of scientists such as purse V. Kalitka, Z. Zolotukhina, L. Pokoptseva [40-41].

AKM growth regulator had significant effect on growth of sunflower plants, particularly at the height of the stem in all investigated years. the greatest effect was observed for the plants of Odes'kyi 249 hybrid, where the fluctuation was within 9.5 - 24.0 % by year. the smallest effect (3 %) of AKM growth regulator was observed on plants of Zubr and Forvard hybrids.

The zone of southern steppe of Ukraine is characterized by frequent gusty winds. So, well-formed stem of sunflower plant is the main protector against lodging. we found that AKM PGR had significant effect on stem diameter in all years studied with an average of 6.4 %. Maximum growth regulator effect on stem diameter was observed in plants of Forvard hybrid in 2013 (13.8 %).

Under AKM effect, number of leaves per plant increased by 2 – 12 % compared to the control. Effect of hydrothermal conditions of the year on the effectiveness of the PGR on the figure was the same for all the studied hybrids.

In our studies the leaf surface area was determined at BBCH - 61-65 (flowering) stage of plant development. Research variant exceeded the control for all investigated hybrids in average by 7 % by this index. Reduction of leaf surface a trial version on 2.8 % was observed in 2014 for plants of Odes'kyi 249 hybrid, and in more stress year of 2013, research version exceeded control by 6.3 %. Between leaf surface area and rainfall (BBCH - 00-65) a correlation of high strength was found for all hybrids (r = 0.868 – 0.996), which once again confirms the hypothesis of anti-stress (antioxidant) properties of our preparation.

Plant density in researched years was low (Table 9). Due to unfavorable hydrothermal conditions irregularity was observed in the arrangement of sunflower plants in the crop. the biggest difference between the control and experimental variants in plant density was marked in arid 2013. the maximum difference was observed in the crop of Forvard sunflower hybrid and was 11.4 %. in more humid (2014 - 2015) years the difference between research and control variants was not significant.

Tab. 9. Structure of sunflower yield under AKM growth regulator action depending on hydrothermal conditions of the year

Indices	Year (factor C)	Hybrid (factor A)								LSD_{05} a B C
		Zubr		Odes'kyi 249		Forvard		Yason		
		PGR (factor B)								
		no PGR	AKM	no PGR	AKM	no PGR	AKM	no PGR	AKM	
Plant density, thousand units/ha	2013	33.8	36.4	40.5	41.7	38.2	43.1	36.6	40.6	0.4
	2014	43.1	44.4	42.7	43.1	42.0	43.9	44.1	46.0	0.2
	2015	43.5	44.8	42.8	44.5	41.6	43.6	44.8	46.5	0.2
Inflorescence diameter, cm	2013	14.34	16.17	17.03	17.46	15.42	16.07	16.45	17.37	0.3
	2014	12.09	13.31	16.12	16.61	12.23	13.62	16.42	16.83	0.2
	2015	14.89	16.05	16.63	16.69	14.61	17.39	15.37	18.32	0.2
Seed weight in 1 inflorescence , g	2013	39.60	45.31	58.55	67.11	30.18	36.25	35.08	36.71	1.0
	2014	37.43	44.79	54.81	62.13	25.36	28.81	31.75	32.08	0.7
	2015	40.80	45.94	58.47	67.37	27.24	37.19	33.96	33.67	0.8
Biological yield, t/ha	2013	1.3	1.6	2.4	2.8	1.2	1.6	1.3	1.5	0.4
	2014	1.6	2.0	2.3	2.7	1.1	1.3	1.4	1.5	0.1
	2015	1.8	2.1	2.5	3.0	1.1	1.6	1.5	1.6	0.2
Rate of the genetic potential of the variety realization, %	2013	34.2	42.1	77.4	90.3	41.4	55.2	34.2	39.5	
	2014	42.1	52.6	74.2	87.1	37.9	44.8	36.8	39.5	
	2015	47.4	55.3	80.6	96.8	37.9	55.2	39.5	42.1	

In 2014, soil and air drought in the phase of inflorescence formation (BBCH - 51-53) was observed. This had a negative impact on their formation, namely diameter. the greatest stability in performance between the control and experimental variants was shown by the plants of Odes'kyi 249 hybrid, where the fluctuation was within 0.4 - 2.9 %. Overall AKM had a positive effect on the diameter of the inflorescence and increased this figure by an average of 7.3 %.

PGR had an essential influence on seed weight in the inflorescence which under the influence of AKM increased by 11.2 - 26.8 % compared to control for Zubr, Odes'kyi 249, and Forvard hybrids. For plants of Yason hybrid this effect was unreliable. the largest mass of seeds from 1 inflorescence was formed by plants of Odes'kyi 249 hybrid in all years researched.

Positive impact of AKM PGR on the formation of vegetative and generative organs of sunflower plants was reflected in such integrated index as biological productivity (Table 8). the greatest influence of AKM on the yield of sunflower plants found for Zubr and Forvard hybrids, where fluctuation was within 14.3 - 31.3 %. Odes'kyi 249 hybrid has shown the greatest stability in yield over the years, where the difference between the control and experimental variants ranged within 14.3 - 16.7 %. Plants of this hybrid realized their genetic potential almost by 100 %.

In general, all researched factors affect the yield of sunflower (Figure 5). This should be considered when developing anti-stress techniques in technologies of growing sunflowers in the Steppe zone of Ukraine.

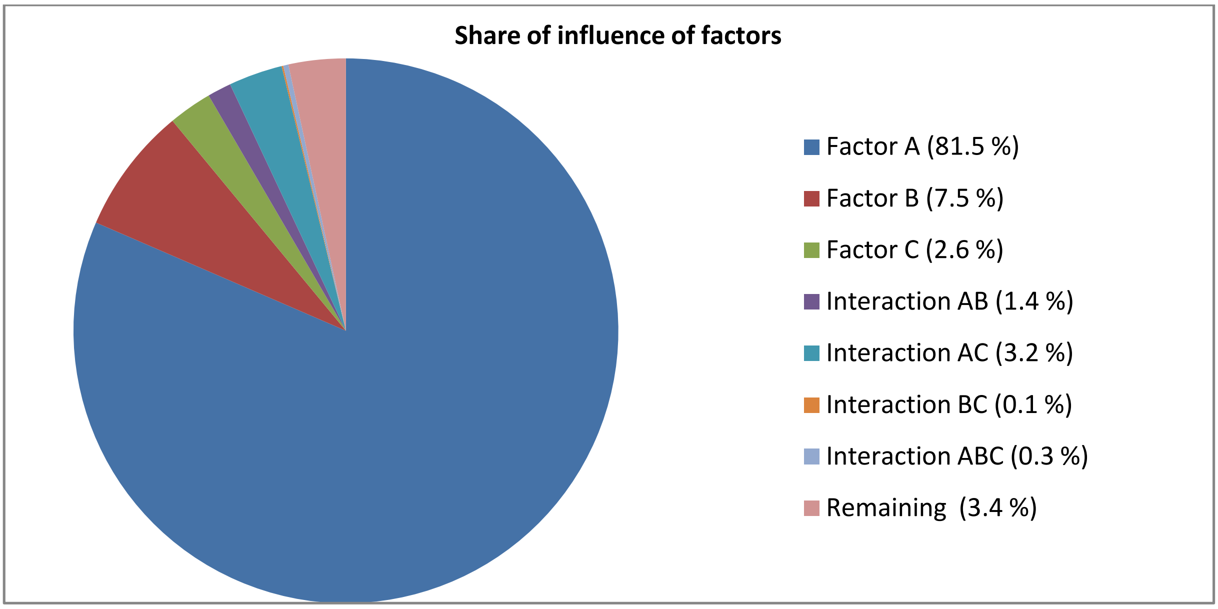

Fig. 5. the share of influence of factors on formation of sunflower yield, %

In researched years between the control and AKM application variants only a tendency to change seed desquamation was found (Table 10). in unfavorable for hydrothermal conditions years, a thicker seed shell formed.

Tab. 10. the quality of seeds of different sunflower hybrids under the effect of AKM plant growth regulator depending on hydrothermal conditions of the year

Indices	Year (factor C)	Hybrid (factor A)								LSD_{05} a B C
		Zubr		Odes'kyi 249		Forvard		Yason		
		PGR (factor B)								
		no PGR	AKM	no PGR	AKM	no PGR	AKM	no PGR	AKM	
Desquamation, %	2013	27.46	25.39	29.41	27.59	22.84	21.73	24.51	25.09	0.2
	2014	31.24	31.06	27.92	26.63	26.31	26.38	23.47	24.03	0.2
	2015	29.03	23.33	30.11	25.81	24.95	22.26	25.63	24.41	0.4
Empty-seed, %	2013	4.7	4.9	3.5	2.4	6.9	6.1	5.5	5.1	1.2
	2014	24.3	18.7	19.6	18.1	22.3	20.2	14.7	11.5	0.9
	2015	1.3	2.1	3.2	0.6	5.3	8.4	7.5	9.1	5.7
Weight of 1000 seeds, g	2013	52.39	56.18	51.66	56.32	49.27	50.04	47.31	57.74	0.7
	2014	47.52	52.74	48.41	53.74	45.39	45.72	45.14	46.08	0.8
	2015	54.18	60.89	54.98	60.57	48.85	51.17	45.72	58.41	1.3
Grain-unit, g/l	2013	269.1	283.4	343.7	362.1	333.3	349.4	340.8	335.5	8.3
	2014	260.7	271.5	327.9	345.2	327.7	330.6	332.1	321.7	7.2
	2015	276.6	308.2	370.1	383.4	332.2	351.7	324.3	332.9	7.1
Oil content, %	2013	47.5	47.9	45.3	44.9	47.7	49.1	47.6	47.8	0.3
	2014	45.3	46.2	42.4	43.4	43.4	42.7	43.4	44.1	0.2
	2015	48.2	48.4	47.1	47.6	48.2	49.8	48.5	49.3	0.7

The highest empty-seed was observed in 2014 (Table 10). AKM did not show a significant impact on this index. Empty-seed depends on the hydrothermal conditions of the year, namely the humidity during the flowering of plants. Thus the maximum difference (23 %) was found in Zubr hybrid in control variant. Correlation of high strength was established: $r = 0.786$.

Weight of 1000 seeds depends on seed fullness and empty seed (Table 10). Under the action of AKM plant growth regulator 1000 seeds weight increased by an average of 2 – 14 % depending on the hybrid. the maximum deviation of mass of 1000 seeds was characteristic for seeds of Yason hybrid. PGR AKM contributed to the formation of greater mass of 1000 seeds, but their genetic potential was realized by almost 90 % only for plants of Zubr and Yason hybrids.

Quality of seeds is determined, above all, by the genetic characteristics of the variety or hybrid. Its value is affected by a large number of factors, but dominant are climatic conditions and growing technology. the lowest grain-unit during all research years was observed in the Zubr hybrid. AKM growth regulator increased grain unit of the seeds by 1 – 10 %.

The highest oil content in sunflower seeds was observed in 2015. Under the action of growth regulator there was a tendency to increase oil content in seeds.

4. CONCLUSIONS

It was determined that the incrustation of sunflower seeds with AKM plant growth regulator stimulated seed germination, confirming the increase in field germination by 4.9 p. p. relative to control. the plant growth regulator caused the activation of the growth process, which was particularly manifested through the height of plants – which was increased by 8 %, and stem diameter – by 6.9 15 %. the increase in the leaf surface area of the crop by 39.3 % was defined by plant growth regulator and greatly depended on rainfall (r = 0.999) during the period of 00 65 on BBCH scale. the inflorescence diameter increased under PGR action, which was especially evident in the dry 2012, when this figure exceeded the control by 13 %. Medium correlation (r = 0.588) was determined between rainfall in the phase of rapid growth and inflorescence diameter. AKM action increased seed weight in the inflorescence by 9–19 % compared to control. Growth regulator affected the yield of sunflower significantly the share of a factor in the formation of yield was 32.7 %. the share of the impact of water deficit was 58.4 % on average over the years of research. Due to the use of PGR, the fertility of sunflower pollen increased by 27 % compared to control, and seed emptiness was reduced by 9.3 p. p. in different zones of the inflorescence. Pollen fertility and seed emptiness of sunflower depended on relative humidity during flowering – r = 0.990 for the control plants and r = 0.973 in case of AKM application. the weight of 1000 seeds increased under PGR action by an average of 17 33 % depending on the zone of the inflorescence. an inverse correlation was found between 1000 seeds weight and the amount of active temperatures (BBCH – 61 87): r =   0.999 for control variant and r =   (0.608–0.925) for PGR treatment depending on the zone of the inflorescence.

The maximum increase in the height of the stem (9.5 - 24.0 %) was observed in plants of Odes'kyi 249 hybrid while stem diameter increased on average by 6.4% in all investigated hybrids. in general, both hybrids and plant growth regulator as researched factors significantly affect the yield of sunflower but the proportion of influence of hybrid (factor A) (85.1 %) is significantly higher than that of the impact of PGR (factor B) (7.5 %). This should be considered when developing anti-stress techniques in technologies of sunflower cultivation in the Steppe zone of Ukraine. Correlation of high strength was found between leaf surface area and rainfall (BBCH - 00-65) for all of hybrids (r = 0.868 – 0.996). PGR had essential influence on seed weight in the inflorescence which under the influence of AKM increased by 11.2 - 26.8 % compared to control for Zubr, Odes'kyi 249 and Forvard hybrids. AKM showed the greatest influence on the yield of sunflower plants of Zubr and Forvard hybrids, where fluctuation was within 14.3 - 31.3 %. Under the action plant growth regulator AKM 1000 seeds weight increased by an average of 2 – 14 % depending on the hybrid.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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