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Influence of growth regulators on the increase of seed productivity of F_1 sweet pepper hybrids

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The results of research on the influence of growth regulators: gibberellic acid, succinic acid, and D-2Sl on increasing the seed productivity of sweet pepper F1 hybrids are highlighted. The research was conducted during 2018-2020 at the Institute of Vegetable and Melon NAAS, which is located in the Left Bank Forest-Steppe of Ukraine. The research material was the mother form of the sweet pepper hybrid Zlagoda F1 – L. 184/332 in the hybridization nursery. There were used drugs in plants (each in two versions of the rate of consumption): Gibberellic acid (1 mg/l; 5 mg/l), succinic acid (1 mg/l; 5 mg/l), the drug D-2Sl and 2.5 ml/l) - biologically active drug (growth regulator), a derivative of aspartic acid salt and 2-methylpyridine N-oxide, synthesized by the Institute of Bioorganic Chemistry and Petrochemistry of the National Academy of Sciences of Ukraine. Treatment with drugs was performed by double spraying in the phase of the beginning of laying the reproductive organs and in the phase of bud formation with a size of 5 mm. Control – treatment of plants with distilled water. It is established that drugs increase seed productivity by 30-50%, depending on the concentration. The highest result was found with the D-2Sl with a rate of 0.5 ml/L and gibberellic acid with a 1 mg/l compared to the control. The use of growth regulators on mother plants during hybridization has a positive effect on the formation of biometric parameters and productivity of the hybrid Zlagoda F1, which can be used as a reserve to increase seed yield and to increase seed yield improve its quality characteristics. Increasing the rate of use of growth regulators leads to a tendency to reduce the seed productivity of plants.
Keywords: seed productivity, drug treatment, sweet pepper, succinic acid, gibberellin acid.

Introduction

Most modern technologies for growing vegetable products involve synthetic and natural phytoregulators, with which you can actively influence the growth processes and the formation of plant yields (Anite, 2012). Growth regulators are used not only to increase plant productivity (which can be achieved through the use of irrigation and fertilizers) but also for friendly fruit ripening (for mechanized harvesting), early harvest, improving product quality (Sergienko et al., 2003).

Recently, a large number of substances that have a diverse focus on plants have been synthesized. For example, small doses of growth regulators lead to significant plant growth and development changes at different stages of the growing season (Bosak et al., 2018; Tarakanov & Gorcharov, 2007). In addition, growth regulators are actively used to stimulate and delay growth processes and fruit ripening and increase plant resistance to biotic and abiotic environmental factors (Vorobyova, 2017; Petrichenko, 2010; Shakirova, 2009; Shapoval et al., 2008; Kalinin, 1989).

The effectiveness of growth regulators has been proven in studies with vegetable plants of the nightshade family. Thus, in the Lower Volga region with chestnut soils, the use of foliar fertilization with complex fertilizer "Solution" and growth regulator "Energy-M" on the background of N285P115K145 fertilization provides an increase in tomato fruit yield by 10.2 t/ha (Kalmykova et al., 2019; Belyaev et al., 2019). Furthermore, according to Indonesian scientists, the drug 6-benzylaminopurine (1 mg/l) causes flowering and fruit formation of tomatoes when growing in vitro treated sprouts (Savitri et al., 2019).

Growth regulators of different nature are actively used in technological schemes of sweet pepper cultivation (Singh et al., 2012; Kannan et al., 2009; Salas et al., 2009; Sridhar et al., 2009; Sultana, 2006; Singh & Lal, 1994; Miniraj & Shanmugavelu, 1987; Yamgar & Desai, 1987). A set of growth regulators is used to improve the quality of seedlings and their engraftment, stimulate growth and development, accelerate flowering, and increase overall yield (Ivanov & Mishina, 2018; Nesterov & Solovyova, 2017). For example, the use of growth regulators paclobutrazol, Uniconizole, and mefluidide increase the tolerance of sweet peppers to low temperatures, reduced the consumption of moisture and potassium for crop formation (Kasriana et al., 2019), triple spraying of the mixture of plant parameters, and yield of sweet pepper (31.8 t/ha) (Akhter et al., 2018). In the research of Tashkent State Agrarian University, seed treatment with the growth regulator Nitrolin (0.06 g/l of water) provides an increase in seed germination energy by 15-20%, germination - by 5-10%, yield by 19.9-24.6 tons/ha (up to the level of 63.7–79.4 t/ha) (Sagdiev et al., 2019).

According to Indian scientists for the cultivation of sweet pepper is more effective foliar feeding Naphthalene acetic acid (NAA) with a concentration of 10-50 mg/l) and Tricontanol (triacontanol) with a concentration of 5-10 mg/l), which provides a yield of 55, 1–79.9 t/ha, increases plant productivity to 0.84–1.28 kg/plant (Sahu et al., 2017). Spraying with Chlormequat chloride (500–1000 mg/l) or NAA (100 mg/l) increases the yield of sweet pepper by 26–58% (Gollagi et al., 2009). Application of NAA with fertigation (0.6 ml / l) is more effective than foliar feeding of pepper plants (0.4 ml / l) (Salasa et al., 2009).

The use of the growth regulator Atonic (0.125–0.5 ml/l) increases the yield of pepper by 7.0–13.6% and increases the content of vitamin C in the fruit (186.4–188.2 mg / 100 g) (Panajotov, 1997).
Actively used in technological schemes of growing vegetable plants and natural growth regulators, such as salicylic acid, which affects photosynthesis, transpiration, absorption, and transport of ions (Jayakannan et al., 2015; Sahu, 2013; Rivas-San Vicente & Plasencia, 2011), reduces growth inhibition caused by stress (Khan, 2015), increases the yield of sweet pepper for growing in open and protected soil (Ibrahim et al., 2019; Hanieh et al., 2013; Abou El-Yazied, 2011; Elwan & El-Hamahmy, 2009). For example, four times the treatment of tomato plants with salicylic acid caused an increase in stem diameter, dry matter content, and chlorophyll, yielding marketable fruits (Yidirim & Dursun, 2009).
Intensive technologies for growing vegetable plants, especially in conditions of protected soil, involve the use of chemical plant growth regulators to control plant height (Hayashi et al., 2001). Compact plants are easier to transplant, maintain, and transport, and they are more attractive to consumers than tall, elongated plants with elongated internodes (Latimer & Scoggins, 2012). The use of growth regulators that inhibit plant growth provides higher seedling survival parameters for transplants (Chaum, 2009; Dunlap, 1991), increases resistance to abiotic stress (Duan, 2008; Al-Rumaih H. & Al-Rumaih M., 2007; Lurie, 1995), enhances flowering (Banko & Landon, 2005; Cochran & Fulcher, 2013; Keever & McGuire, 1991), and increases the yields (Wang & Gregg, 1990). In several studies, the use of Uniconazole (10 mg/l) causes a decrease in the weight of sweet pepper fruit by 30% (Villavicencio et al., 2015), seed treatment reduces the length of the hypocotyl and the height of tomato seedlings (Shin et al., 2009). Natural and synthesized growth regulators are also actively involved in the seed production of vegetable plants, which allows regulating the processes of flowering, tying, and ripening of fruits as the main components of seed productivity (Kornienko et al., 2016; Shevelukha, 1990). For example, according to Indian scientists (Kar et al., 2016), for the cultivation of sweet pepper, the use of growth regulator NAA (40 mg/l) on the background of potassium fertilizer (120 kg/ha) increases seed yield by 82%.
The positive influence of growth regulators on changes in biometric parameters of pepper plants has been confirmed (Akhter et al., 2018; Fotouo et al., 2016; Maboko & Plooy, 2015; Ozlem & Benian, 2007).
However, the issue of increasing seed productivity in the seed production of F1 hybrids of sweet pepper with the help of growth regulators has not been studied enough, which, in turn, confirms the relevance of our research.
The research aimed to establish the effectiveness of growth regulators on biometric and productive characteristics of sweet pepper plants in seed production of F_1 hybrids.

Materials and Methods

The research was conducted during 2018-2020 at the Institute of Vegetable and Melon NAAS, which is located in the Left Bank Forest-Steppe of Ukraine.
The research material was the mother form of the sweet pepper hybrid Zlagoda F1 – L. 184/332 in the hybridization nursery. Seedlings aged 60 days were planted in the second decade of May, planting scheme (70 + 40) × 40 cm. Sites of the institution were planted in the 4-fold repetition of 10 accounting plants. Agrotechnical measures included weeding, fertilizing, irrigation, pest, and disease control. There were used drugs in the plants (each in two versions of the rate of consumption): Gibberellic acid (1 mg/l; 5 mg/l), succinic acid (1 mg/l; 5 mg/l), the drug D-2Sl and 2.5 ml/l) - biologically active drug (growth regulator), a derivative of aspartic acid salt and 2-methylpyridine N-oxide, synthesized by the Institute of Bioorganic Chemistry and Petrochemistry of the National Academy of Sciences of Ukraine. Treatment with drugs was performed by double spraying in the phase of the beginning of laying the reproductive organs and in the phase of bud formation with a size of 5 mm. Control - treatment of plants with distilled water. These plants were hybridized by pollination with pollen from plants of the parent form L.183 / 331.
In the process of research, the influence of growth regulators on the biometric indicators of the maternal form - plant height, plant width, length, and width of the fruit, as well as the average weight of the seed, the number of fruits in physiological maturity of the plant, plant productivity, seed yield from one fruit and seed productivity of plants.
To identify the effect of treatment of seed plants on hybrid Zlagoda F1, following the seasons, the plants were evaluated according to the variants. Analysis of experimental data was performed using the ANOVA method. Differences between values in different variants of the experiment were determined using the Tukey test (Tukey, 1949), where the differences were considered significant at $P < 0.05$ (taking into account the Bonferroni correction (Armstrong, 2014)).

Results and Discussion

An increase in plant height, plant width, and fruit length was found (Table 1).The height of the plant has increased by 3–10 cm depending on the drugs used. The most positive effect of this indicator of the maternal form was provided by using Gibberellic acid with a lower dosage (1 mg/l) and succinic acid with a rate of 5 mg/L. Gibberellic acid with a dosage of 1 mg/l more than other drugs also increased the plant's width (57.38 cm at 48.88 cm in the control version). Succinic acid increased the width of the plant by 4–6 cm. The drug D-2Sl in both norms studied caused an increase in plant height by 7–7.25 cm, plant width – by 3.87–6.25 cm.
The most considerable length of the fruit was (7.75 cm) in the variant of treatment of plants with succinic acid at a rate of 1 mg/liter. Moreover significantly exceeded the control variant of both variants of treatment with gibberellic acid. On the other hand, an indicator such as fetal width did not respond well to treatment with drugs and did not differ significantly from the control.

The most significant average fruit weight was in the variant of treatment with gibberellic acid with a consumption rate of 1 mg/L and was 52.38 g, which is 7 g more than in the control variant (Table 2). The option with a higher concentration of Gibberellic acid did not significantly increase the average weight of the fruit. Among the options for treating plants with succinic acid, a significant increase in the average weight of the fruit was observed at higher concentrations. Variants with D-2Sl treatment showed a slight increase in the average weight of the fruit by 1.50-3.63 g

Table 1. Influence of growth regulators on biometric indicators of the maternal form L. 184/332 (average for 2018-2019).

Preparation	Consum-ption rate	Plant height, cm	Plant width, cm	Fruit length, cm	Fruit width, cm
Control	–	70,88 ± 0,21	48,88 ± 0,39	7,13 ± 0,21	4,63 ± 0,09
Gibberellic acid	1 mg/l	81,38 ± 0,73	57,38 ± 0,64	7,63 ± 0,15	4,75 ± 0,08
Gibberellic acid	5 mg/l	74,38 ± 0,85	51,38 ± 0,28	7,69 ± 0,19	4,75 ± 0,08
Succinic acid	1 mg/l	75,25 ± 0,54	55,13 ± 0,34	7,75 ± 0,14	4,75 ± 0,08
Succinic acid	5 mg/l	81,50 ± 0,44	52,88 ± 0,36	7,38 ± 0,13	4,63 ± 0,09
D-2Fig	0,5 mg/l	78,13 ± 0,41	55,13 ± 0,32	7,50 ± 0,17	4,75 ± 0,08
D-2Fig	2,5 mg/l	77,88 ± 0,50	52,75 ± 0,58	7,38 ± 0,13	4,75 ± 0,08
Numerical data in the table are presented as x ± SD (n = 10).					

Table 2. Signs of productivity of the maternal line of sweet pepper L.184 / 332 depending on growth regulators' action (average for 2018-2019).

Preparation	Consumption rate	The average weight of the fruit, g	The number of fruits on the 1st plant, pcs.	Plant productivity, g
Control	–	45,38 ± 2,36	8,38 ± 0,37	334,25 ± 12,19
Gibberellic acid	1 mg/l	52,38 ± 2,66	11,25 ± 0,46	524,75 ± 13,93
Gibberellic acid	5 mg/l	45,75 ± 2,09	9,75 ± 0,34	411,50 ± 13,75
Succinic acid	1 mg/l	47,50 ± 1,79	10,00 ± 0,32	446,75 ± 10,82
Succinic acid	5 mg/l	50,25 ± 2,21	10,38 ± 0,50	461,38 ± 12,46
D-2Fig	0,5 mg/l	49,00 ± 1,91	11,50 ± 0,25	539,75 ± 14,31
D-2Fig	2,5 mg/l	46,88 ± 1,65	10,88 ± 0,45	480,25 ± 14,30
Numerical data in the table are presented as x ± SD (n = 10).				

We found that the use of growth regulators provides a significant increase in both the numbers of fruits per plant (by 1.37–3.12 pc.) and an increase in overall plant productivity (by 77.25–205.5 g). The most significant number of fruits (on average 11.5 pcs.) and the highest productivity were found in the variant of treatment of plants with the drug D-2Sl with a rate of 0.5 ml/L. In addition, these two parameters responded positively with a lower dose (1 mg/l) of Gibberellic acid and a higher rate of use of succinic acid (5 mg/l). Increasing the rate of use of the drug D-2Sl to 2.5 ml/L has caused a negative trend in the impact on the productivity parameters of sweet pepper plants.
Treatment of plants with growth regulators leads to an increase in seed yield from one fruit, which, in turn, increases seed productivity compared to control (Table 3).

Table 3. The impact of growth regulators on the seed productivity of sweet pepper plants (average for 2018-2019).

Preparation	Consumption rate	Seed yield from the fruit, g	Seed productivity, g
Control	–	1,33 ± 0,04	10,30 ± 0,32
Gibberellic acid	1 mg/l	1,50 ± 0,05	15,61 ± 0,35
Gibberellic acid	5 mg/l	1,40 ± 0,04	13,38 ± 0,44
Succinic acid	1 mg/l	1,49 ± 0,04	14,43 ± 0,34
Succinic acid	5 mg/l	1,41 ± 0,04	13,74 ± 0,48
D-2Fig	0,5 mg/l	1,41 ± 0,04	15,61 ± 0,36
D-2Fig	2,5 mg/l	1,36 ± 0,04	14,25 ± 0,47
Numerical data in the table are presented as x ± SD (n = 10).			

A significantly positive effect on the yield of seeds from one fruit provides the use of succinic and gibberellic acid at a dosage of 1 mg/l (0.16-0.17 g more than in the control version). The use of the drug D-2Sl slightly increased the yield of seeds from one fruit compared to the control version. Seed productivity of plants in all experimental variants was significantly higher than the control variant and ranged from 13.74 g in the variant with succinic acid with a rate of 5 mg/L to 15.61 g in the variants using gibberellic acid with a rate of 1 mg/L and D-2Sl with a rate of 0.5 ml/l. Increasing the rate of consumption of all drugs has led to a decrease in seed productivity of sweet pepper plants relative to lower concentrations.
When evaluating the Zlagoda F1 hybrid plants grown from seeds obtained from different treatment options of mother plants (Table 4), an increase in plant height was found in almost all variants except the treatment variant succinic acid with a rate of 1 mg/L. Treatment of mother plants with gibberellic acid provided an increase in the height of hybrid plants by 8-9.75 cm compared to the control variant. Treatment with the drug D-2Sl gave an increase of 5.75–7.75 cm. Higher concentrations of the drugs gave an increase in the height of the hybrid plant.
The width of the hybrid plant in the variants after treatment with gibberellic acid and the drug D-2Sl was more significant than in the control variant. Treatment of parent plants with succinic acid, in contrast, reduced the plant width of the Zlagoda F1 hybrid. Higher concentrations of Gibberellic and succinic acids increased the width of the hybrid plant, while the drug D-2Sl flowed in the direction of decreasing. The length of the fruit in all variants showed an increase of 0.25-0.5 cm. The fruit width was more significant than the control variant in the variants with the treatment of mother plants with gibberellic acid at a rate of 1 mg/L, succinic acid 5 mg/l, and the drug D-2Sl in both concentrations.
In terms of productivity and its components, all experimental variants significantly exceeded the control variant. Variants showed the most significant increase in productivity with the treatment of mother plants with the drug D-2Sl, and plant productivity increased with the increasing concentration of the drug. The higher drug concentration caused an increase in the number of fruits

per plant and a decrease in the average fruit weight. The same effect was observed in the variants using gibberellic acid. On the contrary, when using succinic acid, increasing the concentration of the drug reduced plant productivity and fruit number and increased the average weight of the fruit.

Table 4. Biometric parameters and plant productivity of the Zlagoda F1 hybrid (average for 2019-2020).

Drug consumption rate	Plant height, cm	Plant width, cm	Fruit length, cm	Fruit width, cm	The average weight of the fruit, g	The number of fruits on the 1st plant, pc.	Plant productivity, g
Control	80,25 ± 0,28	55,0 ± 0,41	10,75 ± 0,08	5,0 ± 0,01	70,05 ± 0,14	9,25 ± 0,08	648,0 ± 6,13
Gibberellic acid, 1 mg/l	88,25 ± 0,69	56,25 ± 0,34	11,25 ± 0,08	5,25 ± 0,08	76,05 ± 0,59	9,50 ± 0,17	720,0 ± 7,12
Gibberellic acid, 5 mg/l	90,0 ± 0,68	59,0 ± 0,36	11,25 ± 0,08	5,0 ± 0,01	71,53 ± 1,03	11,25 ± 0,16	803,38 ± 13,83
Succinic acid, 1 mg/l	80,0 ± 0,49	53,50 ± 0,22	11,25 ± 0,08	5,0 ± 0,01	75,02 ± 0,68	10,0 ± 0,19	747,50 ± 10,20
Succinic acid, 5 mg/l	82,25 ± 0,96	54,25 ± 0,39	11,25 ± 0,08	5,25 ± 0,08	78,15 ± 1,14	9,50 ± 0,10	740,0 ± 6,08
D-2Fig, 0,5 ml/l	88,0 ± 0,36	58,0 ± 0,30	11,25 ± 0,08	5,25 ± 0,08	78,31 ± 1,15	11,25 ± 0,08	880,13 ± 12,08
D-2Fig, 2,5 ml/l	86,0 ± 0,65	57,0 ± 0,24	11,00 ± 0,01	5,25 ± 0,08	75,51 ± 0,80	12,25 ± 0,08	924,25 ± 8,98

Numerical data in the table are presented as x ± SD (n = 10).

Conclusion

Therefore, summarizing the obtained research data, it should be noted that the growth regulators gibberellin acid, succinic acid, and the drug D-2Sl contribute to the increase of biometric parameters of both the initial forms and the hybrid Zlagoda F1. The drug D-2Sl with a rate of 0.5 ml/l and gibberellic acid with a rate of 1 mg/L increases the number of fruits per plant, plant productivity, and seed productivity. Increasing the rate of use of growth regulators leads to a tendency to reduce the seed productivity of plants. The use of growth regulators on mother plants during hybridization has a positive effect on the formation of biometric parameters and productivity of the hybrid Zlagoda F_1, which can be used as a reserve to increase seed yield and to increase seed yield and improve its quality characteristics.

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