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Effect of Growth Factors on the Metabolism of Cucumber Crops Grown in a Greenhouse

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The article represents a three-year study of the effect of bioactive substances as part of growth promoting factors on the course of physiological processes in cucumber crops when grown under protected ground conditions (greenhouse) in the Stavropol Territory. The enhanced metabolism of the plants resulted in increase of crop yields. The studies revealed that the highest yield of cucumber exceeding the control by 14.7% was obtained at combined use of growth factors, namely Radifarm, Benefit, and Megafol.

Key words: Growth factor, respiration rate, photosynthesis rate, transpiration rate, yield, cucumber, protected ground.

Vegetables are an important component of the human nutrition. They are considered as functional food staff as they not only support the human's vital forces, but are effective therapeutic agents, recognized by both folk and standard practice medicine (Gish, & Gikalo, 2012). In terms of the climatic conditions of Russia, a priority in the fresh vegetable supply, especially during the off-season period, consists in the development of greenhouse vegetable production (Glotova, Tomilina, & Kuzmenko, 2014; Tomilina, Glotova, & Kuzmenko, 2013). Cucumber is one of the most popular vegetable worldwide. In greenhouses of Russia, cucumber is a leading crop in terms of the planting acreage and is grown as winter-spring crop (takes 70-80% of winter greenhouses), spring-summer crop (90% of spring greenhouses, cultivated after seedling), and summer-fall crop (10-15 % of the total area of greenhouses) (Akhatov, 2011).

The increase in production of greenhouse vegetables is possible first of all by increasing the areas of cultivation facilities and enhancing the efficiency of their use to provide persistently high yields of vegetable crops. Increasing the yield of vegetable crops can be achieved by optimization of all growth and development conditions (Andreev, 2002; Belogubova, Vasilev, Gil, *et al*., 2007).

The search for new efficient methods of increasing the crops yield is quite promising. One of such methods consists in the application of bioactive substances with growth promoting action. Bioactive substances fulfill trophic and ecological functions in the agrocenosis, affect the intensity of the physiological processes, keep going homeostasis in the plant, and enhance plants resistance against biotic and abiotic stresses (Voronina, 2008; Prusakova, & Chizhova, 2005). The course of physiological processes in the plant's organism is directly connected with the

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processes of growth and development of the plant's organism, and, consequently, with the final indicator, namely yield of crops (Sheudzhen, Trubilin, & Onishchenko, 2012).

Plant growth regulators (stimulators), based on bioactive substances of different nature now are widely used for all crops (including vegetables and mushrooms) both abroad and in Russia. However, the mode of growth stimulators action on plants, especially under greenhouse conditions in Russia, still remains poorly studied. In this regard, the study of the effect of bioactive substances, as part of the growth factors, such as Radifarm, Benefit, and Megafol, seems relevant.

MATERIALS AND METHODS

The study was conducted during winter-spring cycle of 2011-2013. The vegetation experiments were carried out in the winter glazed greenhouse at the greenhouse laboratory complex of the Stavropol State Agrarian University. Advanced low-volume technologies were applied for vegetable crops cultivation in high-tech greenhouse, where screening system, three-flow hot water heating, feeding of plants with carbon dioxide, climate control, additional air moistening, supplementary lighting during seedlings growing period, drip irrigation, and mineral nutrition of plants were operating in automatic mode. A mineral wool was used as a support medium for the plants cultivation. Standard culture solutions, corresponding to particular growing periods, with an appropriate balanced ratio of major and minor nutrient elements were used throughout the cucumber's growing season. These solutions served the control and the background for all experimental options.

Herman F1 cucumber (first generation hybrid) and the Radifarm, Benefit, and Megafol growth factors were subjects of the research.

Experimental design: 1 – control; 2 – Radifarm, 0.4% solution; 3 – Benefit, 0.4% solution; 4 – Megafol, 0.4% solution; 5 – Radifarm+Benefit, 0.4% solutions; 6 – Radifarm+Megafol, 0.4% solutions; 7 – Benefit+Megafol, 0.4% solutions; 8 – Radifarm+Benefit+Megafol, 0.4% solutions.

Experimental design was constructed based on the organized repetitions method with continuous placing of 3-fold replications (Dospekhov, 1985). Plots location was tier-type, number of options: randomization within repetition. Record plot area was 3.4 m^2; the plot width was 1.8 m, and the length – 3 m.

Plants treatment with the growth factors solutions at a concentration of 0.4% was carried out in accordance with the general recommendations for vegetable crops (State catalog ..., 2012). The Benefit and Megafol were used as foliar nutrition at four-time processing with an interval of 10 days: the first processing was carried out in the early fruiting phase. Radifarm was used as the root application (5 l/ha) during the phases of the first true leaf and 3-4 true leaves.

RESULTS

The respiration rate of cucumber plants

Respiration is common to all living organisms. It is an oxidative decomposition of organic substances synthesized through photosynthesis process with the consumption of oxygen and release of carbon dioxide (Asaliev, Belovolova, 2006). Oxidative transformations of respiratory substrate are important in biosynthesis process of not only proteins, fats and carbohydrates, but also regulators of metabolic processes – enzymes and coenzymes, substances of secondary origin, and hormones (Nobel, 1973; Tretyakov, *et al.*, 1998). Respiration rate of cucumber plants increased when treating them with growth stimulators. Table 1 presents analysis results along with the values of lowest average difference ($LAD_{0.05}$).

When comparing the effect of treatment by different growth factors, we noted that the best results were recorded when using the Radifarm, having in its composition vitamin complex and zinc chelate, which unlike the Megafol and Benefit, influenced the plants respiration rate. Our results confirm data from the scientific literature about the important role of zinc and vitamins in the metabolism of plants (Ageev, 1996). It is hard to overestimate the role of zinc in plant's life. Zinc is a component of many, if not all, dehydrogenases. Among this variety the activation of carbonic anhydrase, carboxypeptidase,

Table 1. The effect of growth factors on the respiration rate of cucumber plants, mg CO_2/h/100 g

Option	2011	2012	2013	Average	+/- to control
Control	1.18	1.20	1.16	1.18	-
Radifarm	1.31	1.39	1.30	1.33	0.15
Benefit	1.30	1.31	1.29	1.30	0.12
Megafol	1.28	1.35	1.27	1.30	0.12
Radifarm + Benefit	1.39	1.48	1.38	1.42	0.24
Radifarm + Megafol	1.38	1.43	1.36	1.39	0.21
Benefit + Megafol	1.35	1.42	1.33	1.37	0.19
Radifarm + Benefit + Megafol	1.43	1.55	1.41	1.46	0.28
$LAD_{0.05}$	0.08	0.12	0.09		

phosphatase, tryptophan synthetase, and catalysis of tryptophan is of particular importance. Hence, zinc is involved in protein, lipid, carbohydrate and phosphorus metabolism, as well as in the biosynthesis of vitamins, such as ascorbic acid and thiamine, and auxins - the growth-substances. Zinc's role is especially important in the plant respiration process (carbonic anhydrase).

Vitamins serve the building blocks for the formation of enzymes, which are absolutely necessary for the metabolism in the plant organism. When appearing in the plant cells, the vitamins enter into compounds with other substances and are involved in the synthesis and transformations of proteins, carbohydrates and fats (Lobanova, *et al*., 2012).

When treating plants with Radifarm, respiration rate on average over three years of experience increased by 0.15 mg CO_2/h/100 g compared to the control, and by 0.03 mg CO_2/h/100 g with regard to the treatment by the Benefit and Megafol. When combining the growth factors with each other, the best combination on average over 2011-2013 was the one consisting of Radifarm and Benefit that resulted in the highest increase of the respiration rate by 0.24 mg CO_2/h/100 g as compared with the control; joint application of Benefit and Megafol resulted in increase by 0.05 CO_2/h/100 g; while Radifarm and Megafol gave an increase by 0.03 mg CO_2/h/100 g. The combined use of Radifarm, Benefit and Megafol contributed to a significant increase in the respiration rate, which on average over three years exceeded control values by 0.28 mg CO_2/h/100 g.

Respiration rate varied by years of research: the highest rates were recorded in 2012: from 1.20 to 1.55 mg CO_2/h/100 g. In this year, the total solar radiation in winter-spring period was the lowest as compared to 2011 and 2013. The lowest respiration rates were noted in 2013: from 1.16 to 1.41 mg CO_2/h/100 g, when the photosynthetic active radiation was higher than in other study years.

The photosynthesis rate of cucumber plants

The respiration process is directly linked to the rate of photosynthesis as exactly photo-chemical reactions create the conditions for the synthesis of carbohydrates and other bioactive substances. Photosynthesis is the essential condition ("sine qua non" - in Latin) of the plants and animals life, being in fact the most large-scale synthetic process on the Earth (Boardman, 1968; Fogg, 1968; and Nobel, 1973).

The intensity of carbon dioxide assimilation during the plants vegetation can be changed by different agricultural practices. At that, fertilizers and bioactive substances may be considered the most powerful lever of photosynthesis regulation. At foliar fertilizing of plants, the intensity of carbon dioxide assimilation can rise rapidly, because mineral elements impinging on the surface of the leaves are relatively easily absorbed by photosynthetic cells (Ermakov, Arasimowich, & Yarosh, 1987).

As it follows from Table 2, the use of growth factors increased the photosynthesis rate of cucumber plants. The composition of the studied growth factors included major nutrient elements (nitrogen and potassium) and minor nutrient elements, as well as organic substances and other bio- active substances. All these components of growth factors affected the rate of photosynthesis directly or indirectly.

Table 2. The effect of growth factors on the photosynthesis rate of cucumber plants, mg CO2/m2/h

Option	2011	2012	2013	Average	+/- to control
Control	0.37	0.35	0.38	0.37	-
Radifarm	0.47	0.47	0.48	0.47	0.10
Benefit	0.44	0.42	0.45	0.44	0.07
Megafol	0.51	0.48	0.53	0.51	0.14
Radifarm + Benefit	0.52	0.51	0.54	0.52	0.15
Radifarm + Megafol	0.57	0.55	0.58	0.57	0.20
Benefit + Megafol	0.55	0.54	0.56	0.55	0.18
Radifarm + Benefit + Megafol	0.60	0.57	0.60	0.59	0.22
$LAD_{0.05}$	0.08	0.08	0.07		

The positive effect of nitrogen-containing compounds can be explained by direct and indirect action. Direct action consists in the use of nitrogen to form amino acids, i.e. the products of photosynthesis (Bocharova, Kiseleva, & Vorontsova, 2011). Indirect action can be explained by the fact that the nitrogen is required for the synthesis of green pigments, as well as proteins, which, on the one hand, are the elements of the chloroplasts structure, and on the other hand, they are the enzymes, catalyzing different photosynthesis reactions. Nitrogen absorption by roots and uptake correlate with photosynthesis. All synthetic transformations of nitrogen, both in the roots and above-ground organs, happen at use of energy and carbon chains, formed in the course of photosynthesis. Potassium effects on photosynthesis only in an indirect way by changing the structure of the photosynthetic apparatus and activating some enzymes (Yagodin, Zhukov, & Kobzarenko, 2002).

When using Benefit independently, increase in the photosynthesis rate by years of research was insignificant in relation to the control being within the same value of $LAD_{0.05}$. In other experimental options the photosynthesis rate was significantly increased compared to control.

The research conducted has shown that the most significant increase in the rate of photosynthesis of cucumber plants was observed when applying the Megafol. In a special combination with other compounds, amino acids and betaine as part of Megafol, stimulated the rate of photosynthesis and, consequently, the growth of cucumber plants, providing ready energy reserve for biological processes in stressful situations.

Combination of growth factors has shown that the best indicators were obtained applying the Radifarm and Megafol, where the photosynthesis rate on average over three years of experience was higher than the control by 0.20 mg $CO_2/m^2/h$. The combined use of the Radifarm, Benefit and Megafol contributed to a significant increase in the rate of photosynthesis on average over the entire observation period by 0.22 mg $CO_2/m^2/h$ compared with the control, and with regard to the treatment by only one of the growth stimulators the increment amounted for 0.08-0.15 mg $CO_2/m^2/h$.

The highest rates of photosynthesis for different experimental options were recorded during the period with the highest level of photosynthetic active radiation, i.e. in 2012, and increased from 0.38 in the control to 0.60 mg $CO_2/m^2/h$ when applying the combination of Radifarm, Benefit, and Megafol.

When comparing the experimental options, we can conclude that the differences between them are insignificant as they do not reach the lowest average difference (LAD), and when choosing feeding to stimulate the rate of photosynthesis we can apply any of the growth factors or their combination, as they have relatively the same effect.

The transpiration rate of cucumber plants

Cucumber is a water-loving plant, its fruits contain about 95-96% of water. Increased demand of culture to humidity and support medium is explained by weakly developed and shallow spaced roots, high transpiration coefficient and a short vegetation period, during which the plants form the harvest. Increased air humidity at optimal temperature has a particularly favorable effect on the cucumber growth. Except of the lower water flow engine (root pressure), plants have also upper engine, which is evaporation of water by leaves (Boos, 1968).

Biological significance of transpiration consists in plants thermoregulation, providing the activity of the upper terminal water flow engine to carry various substances and regulate cells saturation with water that create optimal conditions for the life processes (Tretyakov, *et al.*, 1998). The increase in temperature and decrease in relative humidity of air causes an increase in the transpiration rate and, conversely, a decrease in temperature and increase in relative air humidity reduces transpiration rate of young plants. As a consequence, in the morning the rate of transpiration is low, it increases further and reaches a maximum during the hottest hours of the day (1-2 p.m.), and in the evening decreases with decreasing temperature.

Having regard to the above, we observed the daily course of transpiration. From Table 3 it is obvious that the transpiration rate in all experimental options varied within different ranges and was high at 12 a.m., when the temperature reached its maximum.

Table 3. The effect of growth factors on the daily variations of transpiration rate of cucumber plants, g/m^2/h (on average over 2011-2013)

Option	9 a.m		12 a.m.		3 p.m.	
	average	+/- to control	average	+/- to control	average	+/- to control
Control	5.8	-	8.6	-	6.5	-
Radifarm	5.3	-0.5	7.3	-1.3	5.6	-0.9
Benefit	5.1	-0.7	6.9	-1.7	5.1	-1.4
Megafol	4.5	-1.3	6.2	-2.4	4.8	-1.7
Radifarm + Benefit	4.8	-1.0	6.6	-2.0	5.0	-1.5
Radifarm + Megafol	4.3	-1.5	5.8	-2.8	4.5	-2.0
Benefit + Megafol	4.0	-1.8	5.3	-3.3	4.2	-2.3
Radifarm + Benefit + Megafol	3.6	-2.2	5.2	-3.4	3.9	-2.6
$LAD_{0.05}$	0.3		0.3		0.3	

The highest transpiration rate was observed in control, where it fluctuated during the day within the range of 5.8-8.6 g/m^2/h. At that, along with the high values of transpiration rate in the control, more abrupt transitions of this value were recorded during the day as compared with other options. This is because the plants in the control had low water content in the leaves and high water deficit.

Treatment with growth factors reduced the transpiration rate as compared to the control. The Radifarm improved cell metabolism and contributed to the decrease in the transpiration rate with regard to the control, though affected the plants evaporation to a lesser degree than that when applying the Benefit and Megafol. When using the Radifarm, the rate of transpiration was 5.3-7.3 g/m^2/h, which was less than that for “Benefit” and “Megafol” options and amounted to 0.2-0.4 and 0.8-1.1 g/m^2/h, respectively. The lowest transpiration rates relative to the control were registered when using the Megafol and Benefit, which were applied according to the experimental design as a foliar nutrition, where nutrients enter the plant through the leaf, creating on the surface the so-called “film”. This “film” partially reduced the transpiration rate. In case of using the Benefit transpiration rate was negligibly below control by 0.7-1.7 g/m^2 per hour.

As compared to the Benefit in terms of reduction in transpiration rate, the Megafol was more active, as it contains surfactants. The Megafol, as a sticking agent, when used alone, reduced the transpiration rate as compared to the control by 1.3 g/m^2/h at 9 a.m., by 2.4 at 12 a.m., and by 1.7 at 3 p.m. In a joint application of the Benefit and Megafol the transpiration rate changed from 4.0 to 5.3 g/m^2/h.

At combined application of three growth factors, the transpiration rate was changed as follows: until 9 a.m. – 3.6 g/m^2/h, until 12 a.m. – 5.2, and until 3 p.m. – 3.9 that was less than in control by 2.2-3.4 g/m^2/h.

The yield of cucumber

In practice in the large greenhouse complexes the effect of microclimate, pathogens, agro-technical errors, lack of lighting, nutrients and water lead to the fact that actual cucumber harvest is less than the potential yield. To avoid such a reduction in yield, it is necessary to increase the metabolism processes, which are weakened due to the effect of noted negative factors. This can be achieved by enhancing metabolic processes in plants through the use of bioactive substances as part of the growth stimulators. Data from our studies confirm the possibility to increase the crops productivity by enhancing the physiological processes in plants, as shown in Table 4.

Table 4. The effect of growth factors on yield of cucumber kg^2/m^2

Option	2011	2012	2013	Average	+/- to control
Control	25.1	24.9	25.4	25.1	-
Radifarm	26.3	26.0	26.6	26.3	1.2
Benefit	26.5	26.1	26.8	26.5	1.4
Megafol	25.7	25.5	25.9	25.7	0.6
Radifarm + Benefit	27.6	27.2	28.1	27.6	2.5
Radifarm + Megafol	27.0	26.6	27.4	27.0	1.9
Benefit + Megafol	28.3	27.5	28.4	28.1	3.0
Radifarm + Benefit + Megafol	28.8	28.6	29.0	28.8	3.7
$LAD_{0.05}$	0.4	0.7	0.7		

When applying just one growth factor, the highest yields were observed while treating plants with the Benefit, where the yield of cucumber on average over the whole period of studies was significantly higher than that in the control by 1.4 kg/m^2. Benefit, consisting of nucleotides, which stimulate cell division, vitamins and amino acids (glycine, alanine, aspartic, and glutamic acids) intensified the most important metabolic reactions. The Benefit helped to increase the yield of cucumber in a natural way, without reducing taste and technological qualities of the product.

The Radifarm, containing polysaccharides, steroids, glycosides, betaine, vitamins and minor nutrient elements, contributed to the improved survival of cucumber seedlings during transplantation, stimulated the formation of well-developed root system and increased the productivity of cucumber. When using just the Radifarm the yield of cucumber was changed within the range of 26.0- 26.6 kg/m^2 that was higher than in the control by 1.1-1.2 kg/m^2.

To enhance metabolism in plants and increase the yield, we used the Megafol, which is antistress agent. The use of Megafol enhanced growth and physiological processes in the plant. When applying only Megafol the yield of cucumber was significantly higher than that for the control by 0.6 kg/m^2 (average for 2011-2013).

The yield increase when applying the double combination of growth factors was reliable not only in relation to the control, but also in relation to their independent use. The yield at combination of the Benefit and Megafol was by 0.5 kg/m^2 higher than that for the combination of the Benefit and Radifarm, and by 1.1 kg/m^2 higher than the yield at combined application of the Megafol and Radifarm.

In the experiments, the combined use of the Radifarm, Benefit and Megafol turned out to be the most productive. The yield in this case was significantly higher by 3.7 kg/m^2 over 2011-2012, and 3.6 kg/m^2 in 2013 as compared to the control. On average over three-year period the yield was significantly higher by 0.7-1.8 kg/m^2 than that for paired combinations of growth factors.

The yield of cucumber was changed by years of research. In 2013 the yield of cucumber was higher than in 2011 and in 2012. This is directly related to the solar radiation. At the greatest total solar radiation in winter-spring cycle of 2013 the yield of cucumber was varying from 25.4 to 29.0 kg/m^2 and appeared to be higher by 0.1-0.5 kg/m^2 than in 2011. In 2011 the yield of cucumber was varying within the range of 25.1-28.8 kg/m^2. The greatest number of cloudy days was in 2012, when the yield of cucumber was 24.9-28.6 kg/m^2 that is lower by 0.2-0.8 kg/m^2 as compared to 2011.

DISCUSSION

Experimental data testify that the application into a cell of cucumber plant new exogenous substances (bioactive substances as part of the Radifarm, Benefit and Megafol) causes a change in the endogenous regulatory system and the expression of genetic information, as well as raises the metabolism of plants to a higher level, especially those aspects that serve the basis for the formation of economically valuable plant organs. The impact of the biologically active substances, contained in the growth factors, on regulatory mechanisms contributes to an increase in crop yields. At that, growth factors are applied in smaller doses as compared to mineral fertilizers, whose excess in plant nutrition negatively affects the quality of the final products.

The results of research carried out to reveal the effect of bioactive substances on productivity of cucumber in greenhouses allow us to recommend the growth promoting factors for application under the protected ground conditions (greenhouses) using them additionally with the main nutrition pattern: the Radifarm – for root feeding at the phase of the 1st true leaf and 3-4 true leaves; while Benefit and Megafol – for foliar nutrition in four treatments with the interval of 10 days, carrying out the 1st treatment in the early phase of fruiting.

CONCLUSIONS

The studies showed that the use of the Radifarm, Megafol and Benefit growth factors contribute to the increase in the respiration and photosynthesis rates against slowing the transpiration process. This results in increased yield of cucumber. Under all experimental options it was significantly higher relative to the control. In addition, in the options with paired combination of growth factors the increase in yield was higher in comparison to the options in which they were used independently. The highest yield was observed at the combination of the Radifarm, Benefit and Megafol. With regard to the control the yield was significantly higher on average by 3.7 kg/m^2 over three years of research, while that compared with independent and paired application of growth factors was higher by 0.7-3.1 kg/m^2.

However, the issue concerning the effect of growth factors on the chemical composition of cucumber fruits, and in particular, on the accumulation of nitrates, still remains open. Thus, further studies on the efficiency of growth promoting factors in the greenhouse cultivation technology of tomatoes, peppers, eggplant, and green crops are quite promising.

The use of agrochemicals in agriculture must be economically and energetically feasible. Therefore there is a need to conduct later the cost-effectiveness analysis of using the Radifarm, Benefit and Megafol that would allow us not only to estimate the profit from their application, but also to identify the ways to improve individual agricultural practices associated with their use.

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