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ORIGINAL RESEARCH PAPER

THE EFFECT OF AMBER ACID ON THE PRODUCTIVITY AND CHEMICAL COMPOSITION OF TOMATOES GROWN IN A CLIMATIC CHAMBER

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Abstract: The research was carried out in 2019 - 2020 in the department of closed artificial agroecosystems for plant growing in the Federal State Budgetary Scientific Institution "Federal Scientific Agroengineering Center VIM", Moscow. The study focused on the seeds of tomatoes (*Solanum lycopersicum* L.) variety "Lyana". Amber acid was used as a biostimulating factor at the stage of pre-sowing seed treatment (factor A) and with constant drip irrigation of plants (factor B) throughout the entire growing season – 145 days. The use of amber acid can increase the crop yield from 2.34 to 3.84 kg/bush when growing tomatoes under controlled conditions in a climatic chamber. Inoculation of seeds with a biostimulant substance promoted an increase in the content of vitamins C (23.23 mg/100 g) and B_1 (0.041 mg/100 g) and dry matter (5.06 %) compared to the control. As a result of determining the content of nitrates, it was revealed that the maximum permissible concentration in all samples did not exceed the permissible norm. Thus, the use of amber acid is very promising for growing Lyana tomato plants in artificial agroecosystems.

Keywords: *amber acid, biostimulant, climatic chamber, functional nutrition, Solanum lycopersicum* L.

INTRODUCTION

Recently, more and more attention has been paid to ensuring that food products satisfy not only the body's need for nutrients and energy, but also for certain functionalities. This is due to the fact that “functional food plays an important role in human well-being, the preservation of human health and the reduction of the risk of diseases” [1, 2]. Fresh, natural foods can act as functional ones in our body. The tomato (*Solanum lycopersicum* L.) is one of the most important and widespread vegetable in the world, it ranks second place after potato in terms of production and it ranks first place in profitability. Tomato fruits are distinguished by high nutritional, taste and dietary qualities [3]. The technology of growing tomatoes in modern vegetable growing, includes various production systems - from field plantations to industrial greenhouse complexes, climatic chambers, “city farms” and “grow boxes” with a completely closed and artificially controlled environment, aimed at the safe and constant production of high-quality and potential functional foods [4 – 6].

The production of functional food products makes it possible to maximize the use of the unique chemical composition of plants by optimizing the growing conditions and mineral nutrition [7, 8]. Hydroponic nutrient management promotes the production of low-calorie vegetables as well as low-nitrate vegetables [9]. The addition of plant growth biostimulants (gibberellic acid) to the mineral base of the hydroponic nutrient liquid facilitated more efficient use of water and nitrogen in *Lactuca sativa* L. and *Eruca sativa* L. plants, grown in a floating system [10].

The aim of the research was to assess the effect of a biostimulant (amber acid) on the productivity and physicochemical composition of *Solanum lycopersicum* L. grown in the hydroponics of the climatic chamber.

MATERIALS AND METHODS

The study was carried out in 2019 - 2020 in the department of closed artificial agroecosystems for plant growing in the Federal State Budgetary Scientific Institution “Federal Scientific Agroengineering Center VIM”, Moscow. The vegetal product analyzed was the seed of *Solanum lycopersicum* L., “Lyana” variety (tomato) included in the State Register of Breeding Achievements [11], approved for use on the territory of the Russian Federation.

Amber acid was used as a biostimulating factor at the stage of pre-sowing seed treatment (factor A) and with constant drip irrigation of plants (factor B) throughout the entire growing season - 145 days.

Tomato seeds were treated (soaked) with an aqueous liquid of amber acid for 3 hours, and the studied biostimulator was added to the nutrient solution of hydroponics. The plants were fed independently through two channels from two containers with a volume of 100 liters by means of a drip irrigation system. Seeds soaked in water with the same exposure and without adding succinic acid to the nutrient solution served as control. The experiment included 4 determinations, each determination including 12 plants (Table 1).

Table 1. *Experiment scheme*

Experiment variant No.	Characteristics of the experiment		Consumption rate of amber acid, [%]	
	soaking seeds	watering plants	soaking seeds	watering plants
1	in water	without adding amber acid to the liquid nutrient (control)	0	0
2		with the addition of amber acid to the liquid nutrient	0	0.003
3	in amber acid liquid	without adding amber acid to the liquid nutrient (control)	0.003	0
4		with the addition of amber acid to the liquid nutrient	0.003	0.003

Depending on the variant of the experiment, the seeds were sown in a substrate soaked in a nutrient solution. Mineral wool mats of the SPELAND VEGA brand (Russia) with a horizontal fiber structure were used as a substrate.
Tomato plants were grown using a low-volume technology in a climatic chamber produced by VIM (Russia) (Figure 1).

Figure 1. *Vegetation climate chamber*

During the experiment, the following conditions were maintained in the chamber: the temperature mode was maintained within the range of 24 - 26 °C during the day and at night within 14 - 16 °C with 14 hour daylight hours and a relative humidity of 60 - 65 %. The watering cycle increased as the plants grew from 3 times a day (the phase of seed germination before the formation of fruits) to 5 times a day (the stage of pouring the fruits to full ripeness) for 60 seconds. Two sodium tubular lamps (DNAT-600, yellow color) and one metal halide lamp (DRI-600/4K, white color) were used as a light source. Illumination was 13/900 lux, photosynthetic active radiation - 165 mmol·m^{-2}·sec^{-1}, radiation density - 36/500 mW·m^{-2}.
Plant nutrition was carried out according to the phases of development with mineral fertilizers. During the growing and flowering phase, the Flora Series fertilizers from General Hydroponics Europe were applied in accordance with the regulations for growing tomato plants, in hydroponic systems from William Texier. In the phase of

budding and fruiting, a nutrient liquid was used according to the developed recipe from water-soluble mineral fertilizers with the addition of microelements in a chelated form. The electrical conductivity (EC) of the liquid was maintained in the range of 2.2 - 2.5 $mS{\cdot}cm^{-1}$, *p*H was 5.8 - 6.0.

Analysis methods

Determination of the mass fraction of vitamins C in fruits

The mass fraction of the content of vitamins C in tomato fruits was determined using a fluid analyzer "FLYUORAT-02-5M" (Russia) by the fluorimetric method [12]. A weighed portion of the product was placed in a porcelain beaker with 25 cm^3 of extraction liquid and homogenized. The producing homogenate, including the pulp, was transferred into a volumetric flask with a capacity of 50 cm^3. The contents of the flask were brought to the mark with the extraction solution, filtered through a folded filter. The extract was treated with purified activated carbon with the simultaneous oxidation of ascorbic acid (AA) to dehydroascorbic acid (DAA) and then a condensation reaction with *o*-phenylenediamine in an acidic medium with the formation of a fluorescent compound and the quantitative determination of the total content of AA and DAA was conducted.

Determination of the mass fraction of vitamins B_1 and B_2 in fruits

The method for measuring the mass fraction of vitamins B1 and B2 is based on acidic and enzymatic hydrolysis of the sample, which results in the release of bound forms of vitamins [13]. The content of vitamins B_1 and B_2 was determined using a FLUORAT-02-5M analyzer (Russia).

A weighed sample was placed in a conical flask with a capacity of 100 cm^3, 70 cm^3 of a solution of hydrochloric acid with a molar concentration of 0.1 $mol{\cdot}dm^{-3}$ was added. The hydrolysis was carried out for 40 minutes in a water bath. After adjusting the *p*H, 0.10 g of a dephosphorylating enzyme was added and kept in a thermostat at 37 °C for 12 - 16 hours. The resulting hydrolysate was purified with an extractant. The bottom aqueous layer was used for analysis.

Determination of the mass fraction of nitrates

The potentiometric method is based on the extraction of nitrates from the sample with an extraction liquid of potassium alum, followed by measuring the concentration of nitrate ions in the resulting solution using ion-selective electrode. Ionometer "Itan" (Russia) was used for the analysis. A sample of the product weighing (10.00 ± 0.01) g is weighed in a beaker with a capacity of 100 cm^3, poured in a measuring cylinder of 50 cm^3 of the extraction solution and homogenized for 1 - 2 minutes. The resulting suspension is used for measurements [14].

Determination of dietary fiber

The method is based on enzymatic hydrolysis of starch and non-starch compounds. Dietary fibers were precipitated with ethyl alcohol, dried, and determined by the gravimetric method [15].

For this study, analytical scales OHAUS Explorer EX124AD, pH-meter desktop laboratory OHAUS Starter ST2100-E, UF plus drying cabinet, Memmert (Germany), a SNOL-6/10 muffle furnace (Russia) were used.

Determination of minerals in vegetable products

The method is based on the calcination of a sample in a SNOL-6/10 muffle furnace (Russia) at a temperature of 525 °C and separating mineral substances from the ash that are insoluble in hydrochloric acid. A weighed portion of a sample weighing from 4 to 25 g was placed in a crucible. After that, the sample was burned, then completely calcinated in a muffle furnace at a temperature of 525 °C. After cooling and weighing, 10 to 25 cm^3 of hydrochloric acid solution were added [16].

Determination of the mass fraction of dry matter

The method based on drying a loosened or distributed product sample at an elevated temperature in a UF plus drying cabinet, Memmert (Germany). The sample weight should be about 5.0000 g [17].

Determination of titratable acidity

The total acidity in tomato fruits was determined according to Russian standard GOST ISO 750-2013 [18]. 5 mL of the sample was diluted with purified water and titrated using a burette (Russia) 0.1 N NaOH solution in the presence of phenolphthalein as an indicator. The results were expressed as a percentage of the total acidity in terms of malic acid.

Statistical analysis

The experimental data were mathematically processed by the methods of analysis of variance using the STADIA 8.0 program. The least significant difference (LDS) was used to test the significance of the data obtained at a probability level of $p < 0.05$.

RESULTS AND DISCUSSION

The researchers showed that the use of the biostimulator succinic acid at the stage of seed pretreatment (variant 3) allowed to obtain the maximum productivity of tomato - 3.84 kg/bush, which is 64.1 % higher than that of the control sample (Figure 2).

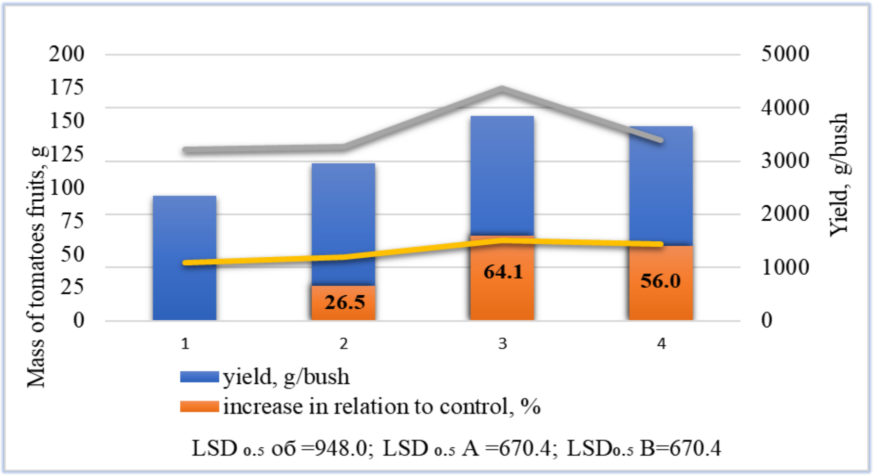

Figure 2. *The productivity of tomato plants of the variety "Lyana"*

The use of amber acid makes it possible to form an early harvest of tomatoes fruits with a total productivity of 3.65 kg/bush and an increase of 56.0 % to the control during seed inoculation and with drip irrigation (variant 4). The largest mass of tomato fruits - from 135.7 (variant 4) to 174.7 g (variant 3) - was observed in plants whose seeds were treated with an aqueous liquid of amber acid. The addition of a biostimulant to the nutrient liquid of hydroponics (variant 2) promoted the formation of plants with the lowest fruit weight 47.8 g.
The content of individual vitamins in the analyzed tomato samples is presented in Table 2. In tomato fruits, the content of vitamin C in experimental samples varied within 19.98 - 23.23 mg/100 g, which exceeds the control by 1.61 - 4.86 mg/100 g. The maximum amount of vitamin C was obtained in fruits when seeds were soaked with amber acid (variant 3).

Table 2. *The content of vitamins in the tomato fruits of the variety "Lyana"*

Experiment variant No.	Vitamins, [mg/100 g]		
	C	B_1	B_2
1	18.37±0.3	0.034±0.003	0.022±0.003
2	19.98±0.4	0.033±0.003	0.020±0.003
3	23.23±0.5	0.041±0.001	0.024±0.001
4	22.16±0.7	0.040±0.001	0.027±0.001

The content of B vitamins in tomato fruits depended more on seed inoculation than on the addition of amber acid to the nutrient liquid of hydroponics. The highest content of vitamin B_1 was determined in variant 3 and it was 0.041 mg/100 g, and for vitamin B_2 was 0.027 mg/100 g in variant 4. In other variants of the experiment, the research parameters were at the control level.
Analysis of the data obtained allows us to conclude that the use of amber acid as a biostimulant has a positive effect on the productivity and vitamin content in tomato fruits.
Table 3 shows the results obtained for individual physicochemical indicators of tomato samples.

Table 3. *Physico-chemical indicators of the studied samples*

Experiment variant No.	Content, [%]			Total acidity (in terms of malic acid), [%]
	dry matter	dietary fiber	ash matter	
1	4.17	11.78	15.04	0.54
2	4.53	8.63	14.98	0.63
3	5.06	12.10	13.38	0.71
4	4.99	10.44	13.94	0.68

As a result of the analyzes, it was found that the highest dry matter content (5.06 %) was noted in the tomato fruits collected from the plants in which the seeds were treated with an aqueous liquid of amber acid before sowing. Thus, the increase in dry matter according to the variants of the experiment ranged from 8.6 % to 21.3 % in relation to the control.

When analyzing the content of dietary fiber in tomato fruits, the effect of seed inoculation (factor A) leads to their accumulation by an average of 10.4 % in relation to the control. In the group of variants with the introduction of amber acid into the nutrient solution (factor B), a decrease in the mass fraction of dietary fiber was observed on average to 25.2 % compared to the standard nutrient solution of hydroponics. The average data on the indicator of the content of ash substances in the tomatoes of the prototypes was 14.1 %, which indicates a slight decrease in this indicator in relation to the control. The total acidity index for the variants of the experience of using succinic acid exceeded the control by 0.9 - 1.3 units, which is confirmed by the increased content of vitamin C in these samples.

Thus, the results obtained indicate that succinic acid has a multifaceted effect on the physicochemical parameters of plants. It is worth noting the increased dry matter content, as well as the total acidity due to the content of vitamin C in the fruits of the tomato plants of the prototypes. Taking into account the fact that plants serve as sources of not only useful substances but can also include substances that pose a danger to the human body, the nitrate content was determined (Table 4) for compliance with the requirements of TR CU 021/2011 “On food safety” [19].

Table 4. *The content of nitrates in the tomato fruits of “Lyana”*

Experiment variant No.	Nitrate content, [$mg \cdot kg^{-1}$]	
	the requirements of TR CU 021/2011 [19]	test samples
1	300	289.5
2		271.6
3		283.3
4		285.8

As a result of determining the content of nitrates, it was revealed that the maximum permissible concentration in all samples did not exceed the permissible norm. The average nitrate level for the variants was 280.2 $mg \cdot kg^{-1}$.

CONCLUSION

This study assesses the effect of amber acid on the productivity and qualitative composition of the tomato fruits of the variety "Lyana", grown by low-volume technology in a climatic chamber on hydroponics. Thus, it was possible to determine the most effective way to use the biostimulator: at the stage of pre-sowing seed treatment (variant 3).

The use of amber acid when growing tomatoes under controlled conditions of a climatic chamber makes it possible to increase the crop yield from 2.34 (control) to 3.84 kg/bush (variant 3). In this variant, there was an increase in the content of vitamins C (23.23 mg/100 g), B_1 (0.041 mg/100 g) and dry matter (5.06 %) compared to the control.

Thus, the use of amber acid is very promising for growing "Lyana" tomato plants in artificial agroecosystems, because it allows not only to increase the yield, but also to increase the content of certain functional ingredients, in particular, vitamins C and B_1.

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