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RESEARCH ARTICLE

The Balance of the Nutritional Medium Agrochemical Composition as a Factor of Productivity and Content of Sugars in Tomatoes when using Low-Volume Hydroponics

SVETLANA ANATOLIEVNA BERSENEVA[1]*

YELENA NIKOLAEVNA DEMIDENKO[1]

NATALIA VLADIMIROVNA RUDAKOVA[1]

ALEXANDER NIKITOVICH BELOV[2]

GALINA ANATOLIEVNA BELOVA[1]

[1]*Primorye State Academy of Agriculture, Ussuriisk, Russia;*

[2]*Far Eastern Federal University, Vladivostok, Russia*

*Corresponding Author: Berseneva Svetlana Anatolievna, Federal State Budget Educational Institution of Higher Education "Maritime State Agricultural Academy" Institute of Land Administration and Agricultural Technologies, Department of Agricultural Technologies, *Russia*.
E-mail: svshatal@mail.ru

ABSTRACT

The use of low-volume hydroponics in growing tomatoes is of the interest to the global academic community. We carried out experiments to study the cultivation of tomatoes in closed ground and without a substrate culture according to the experience of scientists from Japan, who studied the increase in sugars in tomatoes in low-volume hydroponics. The experiments were aimed at analyzing the factors influencing the production of a higher quality product with the necessary taste and resistance to various diseases, which would allow obtaining a higher yield with a convenient production method. For the experiments, several types of tomatoes were taken and also samples of culture media. The study of the balance of nutrients in a nutrient solution shows their influence on the organoleptic properties of the fruit. The experiments involved three types of nutrient media – Kao and Michayluk, Murashige and Skoog, and Japanese medium. The experiment revealed that the Japanese nutrient medium is the most optimal medium for increasing yields and improving the organoleptic qualities of fruits. This is because the medium contains only the nitrate form of nitrogen, and also because of the low amount of boron. It was found that the ammonium form of nitrogen in the generative period and the high content of boron compounds negatively affect both the taste of tomatoes and their crop yield.

KEYWORDS:
agrochemical composition; criteria of tomatoes; growing under cover; hydroponic systems; nutritional medium; sugar content of fruit

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INTRODUCTION

Tomato variety called *Lycopersicon esculentum Mill* has taken a leading position in the agriculture of most countries due to the high nutritional value of its fruits. The taste of tomatoes is mainly dependent on the proper proportion of sugars and organic acids in fruits (mostly of fructose and lemon acid). The combination of high levels of sugar and acids results in the best-tasting tomatoes. The pH of tomato cell fluid normally varies between 4.0 and 4.5. Lower pH-levels make tomatoes excessively sour or hard.[1,3]

The criteria of evaluating the taste of tomatoes depend both on national peculiarities and

changeable consumer preferences. For example, the French prefer sweet tomatoes of medium texture; the Japanese grow tomatoes with higher sugar content and reduced solidity. Historically, Russians preferred the fruits of hard texture with high content of sugars; those tomatoes were added to salads or even eaten with honey. After Perestroika and construction of supermarkets when tomatoes became available all year round, the exterior became more relevant. However, with time and under the influence of the older generation, Russian consumers have returned to the old standards and now look for the product of high quality and taste.

Even the same varieties of tomatoes that grow in open ground acquire different taste due to different soil and climatic conditions. For example, Budenovsky tomatoes in Khabarovsk have more solid and sweeter fruits than those in Ussuriisk.

Growing tomatoes with high content of sugar under cover is more difficult than in the open ground as most meaty and sweet heirloom varieties are susceptible to fungal diseases that are particularly active in the humid and warm microclimate. In recent years, selectionists have been working on creating the best-tasting universal hybrid varieties that are resistant to diseases and pests.[5]

The problem of sugar content in tomatoes has been especially acute for global agriculturalists. Research in this area is being actively conducted in Southeast Asia including Japan. In Chiba University, Japan, researchers have bred a variety of tomatoes with 9–9.8% sugar content. In November 2017, a group of students and teachers of the Academy (Primorsky State Academy of Agriculture) undertook a study placement in the Institute of Gardening and Agriculture, Japan, within the program of international cooperation between Chiba University and Primorsky State Academy of Agriculture. The long-term inter-university joint project "Future Agriculture with Russia" has been managed and funded by the Japanese Ministry of Agriculture, Forestry, and Fisheries.

The research conducted by the University is focused on the influence of various factors (temperature, intensity of light, humidity, CO_2 concentration, etc...) on vegetation, crop yield, and quality of the product. Research in the area of greenhouse agriculture also involves studying the problem of increasing the sugar content in tomatoes and the influence of spectral structure of light on the product quality.[1,5]

MATERIALS AND METHODS

Three tomato varieties (Lycopersicon esculentum var. cerasiforme) were selected as objects for our research based on their properties: Little Red Riding Hood (Krasnaya Shapochka), Cherry Nano, and Pinocchio. Their ontogenesis, generative phase, mineral nutrition, and biochemical composition of fruits depending on the conditions of cultivation were studied. Based on the experience of Japanese colleagues in growing tomatoes with high sugar content in hydroponics, we researched the influence of agrochemical composition of nutritional media on the sugar content of tomatoes in low-volume hydroponics at the facilities of the academy. The research included three stages: selecting the tomato variety, studying the agrochemical composition of nutritional media, analysis of morpho-physiological and biometric data of tomatoes, analysis of sugar content in tomatoes grown in different agrochemical media by means of refractometer.

The analysis of literature data and materials kindly provided by the research laboratory of Chiba University (Japan) allowed making a conclusion that tomatoes have to be cultivated in the nutrient solutions that cause a positive response with the tomato plants. In our research, the following three types of nutritional solutions that contain macro- and micro-elements were used – Kao and Michayluk, Murashige and Skoog, and Japanese medium (Table 1).

All media were experimental and had not been previously used in low-volume hydroponics.

Murashige and Skoog medium was used most often: It is universal and can be used for plant cells of many types. Kao and Michayluk, and Japanese medium are widely known nowadays (they are used for cultivation of isolated protoplasts and cells) as well as other media with different combination of components and their proportion.[4]

RESULTS

The research shows that the highest values of germination capacity and germination power were registered in Pinocchio variety seeds. Therefore, this variety was selected for further research. The first cotyledons started forming 9–10 days later.

Phenological observations show that first eumorphic inflorescences appear 29–30 days after replanting into the greenhouse; the buds opened completely on the 33rd day. The tomato plants were grown to the stage of stable flowering and formation of sets in all plants. On the 57th day the tomatoes of Pinocchio variety were replanted in duplicates for each type

Table 1 Proportion of mineral components concentration in nutritional solutions under research, mg/l

	Proportion of salts in solutions by types of media, mg/l		
Salt formulas	**Murashige and Skoog (I)**	**Kao and Michayluk (II)**	**Japanese medium (III)**
KNO_3***	24	24	1
NH_4NO_3*	3	1	0
$MgSO_4*7H_2O$	1	1	2
$Ca(NO_3)_2*4H_2O$**	0	0	1
KCI	0	4	1
KH_2PO_4*	1	1	0
$NaH_2PO_4*2H_2O$**	0	0	1
H_3BO_4	3	2	1
$CoCI_2*6H_2O$*	1	1	0

Note: * – found only in I and II types; ** – found only in type III; *** – increased concentration in comparison with type III.

into three types of nutritional media with different quantitative and qualitative agrochemical values.

At the time of replanting, the tomatoes had thick stems, rich green leaves of a regular shape, and fibrous root systems. The roots grew up to 15 centimeters; they were shortened to 5 cm during replanting. The tomato plants had inflorescences and opened buds.

First sets were formed on the 64th day. The growth of tomato fruits was uneven: within 4 days after the sets were formed, the fruits reached the size of 20 mm; the further growth of fruits was less intensive (Picture 1)

The medium of Kao and Michayluk resulted in small fruits that perished before the stage of complete ripening. The medium of Murashige and Skoog produced the fruits; however, their quantity was minimal. In the Japanese medium, the crop of tomato fruits was gathered for 3 months as the duration of plant vegetation was substantially greater.

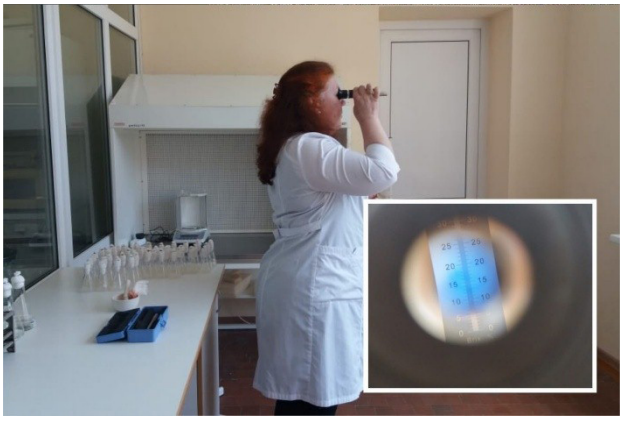
In parallel with this research, we also studied the phonological phases of Pinocchio tomatoes grown under cover (nutritional medium – soil) and analyzed their sugar content.

The sugar content was identified by means of a refractometer (Picture 2).

Two components of tomato fruits were studied in detail – the acids (apple, lemon, and glutamine) and sugars (glucose and fructose). It is their proportion that most often changes the taste.[2] The fruits of sour tomatoes contain a lot of acids and few sugars; sweet tomatoes contain a lot of sugars and little acid while tasteless tomatoes have little sugar and acid. Varieties (hybrids) with high content of both sugar and acid are considered the best and have a pleasant, rich taste. On average, the tomatoes with small-sized fruits contain more sugar than the large-fruited varieties. For example, Cherry variety contains 12% sugar. The same trend is true when pink and red tomatoes are compared: pink tomatoes have a higher concentration of sugars.

A B C

Picture 1 Results of tomato cultivation in the media under research A - Kao and Michayluk; B – Murashige and Skoog; C – Japanese medium



Picture 2 Studying the sugar content in tomatoes of Pinocchio variety.

The data obtained in the course of studying the Pinocchio tomatoes cultivated in different nutritional solutions are shown in Tables 2 and 3.

The fruits of tomatoes grown in Japanese medium have higher nutritional value, taste, and dietary properties. The calorie content of ripe tomatoes (energy value) is 19 kcal. They contain 4.5–8.1% of dry solid matter half of which is sugars, mostly glucose and fructose, and organic acids (3.5–8.5%), and fibers (0.87–1.7%).

DISCUSSION

The media of Murashige and Skoog, Kao and Michayluk contain a lot of inorganic nitrogen; in low-volume hydroponics the nutritional solution is continuously supplied in preset concentration that, in its turn, leads to continuous resupplying of nitrogen in the medium where the redundant nitrogen has a negative effect on the plant's ability to absorb other elements. In Japanese medium (type III), there is no nitrate-ammonium, potassium dihydrogen phosphate, or cobaltous chloride; the content of boron is also quite low. Being an element of mineral nutrition, boron is essential for plants during the whole period of vegetation as it is involved in transporting the carbohydrates, particularly sugars, as well as in activating the photosynthesis and other metabolic processes. However, its increased content results in the toxicosis of plants and lower crop yields.[6]

The content of nitrogen in Japanese medium is much lower due to its use only for growth of individual cells. It has no ammonium nitrogen as well. Ammonium nitrogen can be added to the medium only in the beginning of vegetation but has to be excluded from the nutritional solution from the moment of flowering and until the end of the cycle. Otherwise, the crop yield of tomatoes decreases substantially.[6]

For this reason the medium is more balanced for hydroponic systems and has a more favorable effect of the morpho-physiological development and productivity of tomatoes, according to the academic literature data.

Our research was focused on studying the balance of nutrients in nutritional solution and its influence of the organoleptic properties of the product. Our data shows that redundant nitrogen and its ammonium form during the ripening period as well as the redundancy of boron reduce the sugar content of tomato fruits.

CONCLUSION

Our data show that tomatoes cultivated in Japanese medium have higher content of sugar in comparison with the tomatoes grown in soil and in nutritional solution Murashige and Skoog. The agrochemical composition of Japanese medium is

Table 2 Results of measuring percentage of sugar content in fruits in Murashige and Skoog medium

Date of measurement	Amount of sugar in fruits (%)										Average value (%)
14.01	4.1	4.8	–	–	–	–	–	–	–	–	4.5
17.01	4.0	3.4	4.0	3.4	2.7	4.1	4.0	4.8	4.1	4.0	3.85
Total	**4.05**	**4.1**	**4.0**	**3.4**	**2.7**	**4.1**	**4.0**	**4.8**	**4.1**	**4**	**4.15**

Note: (–) – values of measurements not available

Table 3 Results of measuring percentage of sugar content in fruits in Japanese medium.

Date of measurement	Amount of sugar in fruits (%)										Average value (%)
8.02	6.0	7.1	8.0	6.9	8.1	6.2	6.0	7.2	8.1	8.0	7.2
9.02	6.0	5.0	7.2	6.0	7.8	7.1	6.2	7.9	5.2	7.7	6.6
10.02	6.0	6.2	8.1	5.9	8.2	7.1	7.2	8.1	6.1	7.1	7.0
11.02	7.8	5.0	6.1	5.8	8.0	5.0	5.8	8.7	6.1	6.4	6.5
12.02	6.2	6.2	5.6	7.0	7.2	6.2	7.0	6.0	6.0	6.6	6.4
13.02	6.2	5.6	7.4	7.2	6.8	5.2	7.4	5.6	6.4	7.0	6.5
14.02	5.0	5.8	5.8	6.0	6.0	5.6	–	–	–	–	5.7
22.02	8.0	5.2	8.2	5.6	5.0	5.0	–	–	–	–	6.2
5.03	6.2	6.0	6.0	5.0	4.4	–	–	–	–	–	5.5
9.03	7.4	7.2	7.2	7.4	9.0	9.0	10.0	–	–	–	8.2
13.03	8.2	6.0	6.0	–	–	–	–	–	–	–	6.7
23.03	9.2	–	–	–	–	–	–	–	–	–	9.2
17.04	5.0	5.0	6.0	5.0	6.0	8.2	5.6	5.6	8.0	–	6.0
Total	**6.7**	**5.9**	**6.8**	**6.2**	**7.0**	**6.46**	**6.9**	**7.0**	**6.6**	**7.1**	**6.7**

compliant with all agricultural standards of tomato cultivation in low-volume hydroponics and brings the crops with high content of sugars in fruits.

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