Increasing the production of environmentally friendly high-quality vegetable products

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Abstract. For the first time in the zone of chestnut soils, complex scientific studies of resource-saving methods for increasing the productivity of vegetable crops in an acutely arid climate by regulating physiological and biological processes during drip irrigation were conducted and a system for applying these methods was developed. Research in the experiment was carried out according to generally accepted methods. As research has shown, irrigation and the use of mineral fertilizers and a growth regulator to a certain extent affected the content of dry matter, vitamin C and raw fiber in the fruits of sweet pepper and other indicators. The maximum amount of dry matter was observed on the variant N₃₀₀P₁₈₀K₁₆₅ + Rastvorin + Energy-M on the Pompeo F₁ hybrid – 7.98 and 8.06%, respectively, according to irrigation modes. Indicators such as vitamin C, fiber and sugar content in fruits increased with the improvement of the nutritional and water regimes of sweet pepper growth. As the result of the variety study of vegetable crops of domestic and foreign selection, the best was the Pompeo F₁ sweet pepper hybrid, which surpasses the standard variety of the Podarok of Moldova by 30.10 t/ha, on average for irrigation modes.

1. Introduction

The high quality of the products obtained is an indispensable condition for the cultivation of any vegetable crop. The influence of the irrigation regime and the use of fertilizers on the quality of the crop can be assessed from two points of view. On the one hand, it is possible to keep in mind the commercial qualities of the crop, and on the other-the content of various biologically valuable substances in the resulting crop.

The quality indicators of vegetables depend on the biological characteristics of the crop, variety, degree of maturity, soil and climatic conditions and many other related factors [1, 2, 3, 4, 5].

Pepper is one of the most valuable vegetable crops. Its fruits are rich in biologically active substances, have high taste qualities, have medicinal and curative properties [6, 7, 8, 9]. Pepper fruits contain at least 6% of dry substances. They are mainly represented by carbohydrates: sugars - 28.0...52.7%, starch - 1.78...9.34%, crude fiber - 9.68...24.00%, hemicellulose - 0.85...3.14%, pectin substances - 4.0...13.0%. The share of nitrogenous substances (mainly protein) accounts for 11.2...35.7%. Ash is 1.03...11.82% of dry substances and more than 50% consists of potassium salts. In addition to the latter, there are salts of sodium, calcium, magnesium, iron, aluminum, as well as compounds containing phosphorus, sulfur, chlorine, silicon and other elements. The sugars in pepper...
fruits consist mainly of glucose and fructose. In addition, pepper fruits are rich in antioxidants. It was found that the antioxidant activity of sweet pepper juice is 2.0...2.5 times higher than that of tomato juice. This means that eating it reduces premature aging of the body, the risk of cardiovascular and oncological diseases, etc. [10, 11, 12].

The fruits of sweet pepper are used both in technical and biological ripeness. They are used in fresh, salted, pickled, baked types, in certain doses they are included in various types of canned food in order to enrich with vitamins. In the canning industry, the fruits of technical maturity are mainly used, although they are poorer in terms of the content of dry substances, sugars and vitamin C than the fruits of biological maturity. Canned food made from sweet peppers of biological maturity contains on average from 70 to 150 mg/100 g of vitamin C. For comparison, it can be noted that zucchini caviar contains an average of 8 mg/100 g, and eggplant - 5 mg/100 g of vitamin C. The composition of canned pepper contains a significant amount of nitrogenous substances, carbohydrates in an easily digestible form, mineral salts, some proteins, etc. [13, 14, 15, 16].

When cells are saturated with water, physiological and biochemical processes occur normally in plant tissues and food elements and water are used more efficiently from the soil. Consequently, irrigation also affects the quality of products.

The content of dry matter and vitamin C in fruits decreases in watering plants compared to the fruits of non-watering plants of sweet pepper, and the content of raw fiber, on the contrary, increases. This slight change does not negatively affect the total yield of dry matter and vitamin C from a hectare of irrigated area, but, on the contrary, due to an increase in the yield of pepper fruits from irrigated areas, their gross yield is significantly ahead of plants from a non-irrigated area [17, 18, 19].

The purpose of the research is to substantiate the feasibility and efficiency of the production of environmentally high-quality vegetable products on the example of sweet pepper in the conditions of the Lower Volga region when obtaining a yield of 90 or more tons per hectare of high-quality products.

2. Materials and methods
The experimental work was carried out in 2011...2016. Pilot production site (Gorodishchensky district, Volgograd region) it was located on a typical subtype of light chestnut soils on the right bank of the Volga River, within the border of the Kalachevsky and Dubovsky districts. When setting up field experiments, the degree of favorability of specific weather conditions in the years of research was taken into account, which developed differently, which allowed for a more complete agrobiological assessment of varieties and hybrids of vegetable crops and the studied agricultural techniques. More fully characterizes the conditions of humidification, taking into account the ratio between the resources of heat and moisture of the summer period – the Selyaninov hydrothermal coefficient (HTC). Thus, 2011 was characterized as very arid, 2012 - dry, 2013 - arid, 2014 - dry, 2015 - very arid, 2016 - slightly arid.

The granulometric composition of the studied soils in 80% of the territory was heavy loamy and was characterized by a low (2.31%) humus content in the arable horizon, and at a depth of 0.400-1.000 m its amount decreased from 1.05 to 0.32%. The poverty of this soil with humus is explained by the fact that the processes of transformation of organic substances in the zone of chestnut soils have a specific zonal character. The water-physical properties of soils are directly dependent on the granulometric composition. The density of addition varied along the horizons – the lowest was noted in the layer of 0-0.100 m - 1.24 t/m³. With further deepening, this indicator increased to 1.35 in the studied soil layer of 0-0.600 m - 1.35 t/m³, in the layer of 0-1.000 m - up to 1.45 t/m³. The highest density of addition was noted at the depth of 1 m and was 1.62 t/m³. An increase in this indicator to 1.59...1.62 t/m³ significantly reduced the water permeability of the soil due to the higher salinity of these horizons. The total porosity of the arable soil layer varied from 50.4 to 47.5%, down the profile it decreased to 44.2%. The lowest moisture capacity depends on the granulometric and chemical composition, the content of organic matter, porosity and composition of the absorbed bases and ranged from 25.60% in a layer of 0.0...0.1 m to 22.82% in a layer of 0-0.600 m. On average, for a layer of 0 -1.000 m, the lowest moisture capacity was 20.4%, the wilting humidity was 8.49%. The most absolute idea of the effectiveness of soil fertility
helps to form an agrochemical characteristic that takes into account the mobile forms of nutrients that have a great impact on the development and growth of plants and contribute to an increase in yield. The studied soil had a soil solution reaction close to neutral or slightly alkaline (pH 6.8...8.0). The availability of the soil of the experimental site with hydrolyzable nitrogen (according to Cornfield) is low (less than 100 mg/kg of soil), mobile phosphorus (according to Machigin) is from low to medium (16...30 mg/kg of soil), exchange potassium (according to Machigin) is increased and high (300...500 mg/kg).

The experience was laid by the method of split plots. The arrangement of plots by varieties and hybrids is systematic, according to nutritional regimes – randomized. The registered area of plots of the first order was 295 m² (according to the water regime), plots of the second order (according to varieties and hybrids) – 100 m², plots of the third order (according to nutritional regimes) - 7.5 m². The repetition of the experience is threefold. Scheme of growing seeds of sweet pepper 0.50 + 0.90 m with the installation of humidifiers in the center of the tape along rows equidistant from each other at a distance of 0.50 m.

Factor A - agroecological assessment of varieties and hybrids of domestic and foreign breeding. In field experiments to study the productivity of sweet pepper, the following varieties and hybrids were studied: Podarok of Moldova (as a standard), Pafos F1, Pompeo F1.

Factor B - scientific justification of productivity management of the planned yield levels of sweet pepper: 50, 70, 90 t/ha. Variants of experiments: variant 1 – control; variant 2 – treatment with the growth regulator Energy-M; variant 3 – application of mineral fertilizers for a yield of 50 t/ha: N – 165 kg of active ingredient/ha, P2O5 – 100 kg of active ingredient/ha, K2O – 90 kg of active ingredient/ha; variant 4 – application of mineral fertilizers for a yield of 70 t/ha: N – 235 kg of active ingredient/ha, P2O5 – 140 kg of active ingredient/ha, K2O – 130 kg of active ingredient/ha; variant 5 – application of mineral fertilizers for a yield of 90 t/ha: N – 300 kg of active ingredient/ha; P2O5 – 180 kg of active ingredient/ha, K2O – 165 kg of active ingredient/ha; variant 6 – introduction of water-soluble fertilizer Rastvorin; variant 7 - complex treatment with water-soluble fertilizer and growth regulator Energy-M; variant 8 - complex treatment with mineral, water-soluble fertilizers and growth regulator Energy-M for a yield of 50 t/ha; variant 9 - complex treatment with mineral, water-soluble fertilizers and growth regulator Energy-M for a yield of 90 t/ha.

Factor C - the influence of irrigation regimes on the productivity of sweet pepper: 1 - maintaining the pre-irrigation humidity threshold at 75...75...75% of minimum water capacity (constant irrigation regime); 2 - maintaining the pre-irrigation humidity threshold at 70...80...75% of minimum water capacity (differentiated irrigation regime): sowing-flowering – 70% of minimum water capacity; flowering-fruit formation - 80% of minimum water capacity; fruit formation-technical ripeness – 75% of minimum water capacity.

To assess the quality of the fruits, the content was determined: dry matter - by drying; the sum of sugars – by the cyanide method according to Bertrand; vitamin C - according to Murri; the content of nitrates - by the ionometric method.

Crop accounting was carried out by the method of continuous weighing. Studies on the justification of the irrigation regimes of sweet pepper were carried out by using generally accepted methods.

3. Results and discussion

Under the influence of irrigation water, qualitative changes occurred in the sweet pepper plants. These changes were influenced, in turn, by different doses of fertilizers, depending on the degree of moisture availability.

As our research has shown, irrigation and the use of mineral fertilizers and a growth regulator to a certain extent affected the content of dry matter, vitamin C and raw fiber in the fruits of sweet pepper, and other indicators.

When watering 75...75...75% of minimum water capacity and 70...80...75% of minimum water capacity with the increase in the dose of mineral nutrition, the content of dry substances on the studied
standard variety and promising hybrids increased. The maximum amount of this indicator was observed on the variant $N_{300}P_{180}K_{165}$ + Rastvorin + Energy-M on the Pompeo F$_1$ hybrid – 7.98 and 8.06%, respectively, according to irrigation modes (Figure 1).

Improvement of soil nutrition conditions in pepper crops from $N_{165}P_{100}K_{90}$ to $N_{300}P_{180}K_{165}$ kg active ingredient/ha contributed to the increase in the values of dry matter in fruits on the standard variety Podarok of Moldova from 4.35 and 4.46 to 4.88 and 4.95%, on promising hybrids Pafos F$_1$ from 5.14 and 5.22 to 5.67 and 5.74% and Pompeo F$_1$ from 6.94 and 7.54 to 7.05 and 7.71%, respectively, according to moisture regimes.

The tendency to increase the indicators of dry matter in fruits with complex application of fertilizers (mineral and water-soluble) and a growth regulator was observed by us on constant and differentiated irrigation regimes. Thus, the promising hybrids studied by us were more responsive to the recommended energy-saving elements of the technology in combination with an improvement in the nutrient regime of the soil of the experimental irrigated area.

Indicators such as vitamin C, fiber and sugar content in fruits increased with the improvement of the nutritional and water regimes of sweet pepper growth. The highest figures of these quality characteristics were recorded on the Pompeo F$_1$ hybrid. Thus, the fiber content ranged from 0.98% (control variant) to 1.06...1.10% (variants-treatment with the growth regulator Energy-M and the use of Rastvorin), 1.25% ($N_{165}P_{180}K_{165}$ + Rastvorin + Energy-M), respectively, according to the constant humidification mode (Figure 2). Differentiation of the irrigation regime allowed to increase these values by 0.07%, 0.06...0.04%, 0.02 %, respectively, according to the variants of the experiment.

The increase in the content of vitamin C and sugar also increased from the control variant to the complete application of mineral and water-soluble fertilizers + growth regulator, from a constant irrigation regime to a differentiated one (Figure 3, 4).

![Figure 1](image-url). Dry matter content in sweet pepper fruits, % (average for 2011...2016).
Figure 2. Fiber content in sweet pepper fruits, % (average for 2011...2016).

Figure 3. Vitamin C content in sweet pepper fruits, mg% (average for 2011...2016).
No excess of nitrates in pepper fruits was recorded in any variant of the experiment. The nitrate content in all variants of the experiment was much lower than the maximum permissible concentration (200 mg/kg). The studied irrigation regimes and conditions of mineral nutrition had a direct impact on the nitrate content in the fruits of sweet pepper. Only in the variants with a differentiated water load, the amount of nitrates in the fruits was slightly lower than under a constant moisture condition (Figure 5).

The level of nitrate content in pepper fruits under constant irrigation increased from 83.3 mg/kg (control variant) to 148.8 mg/kg (variant – N300P180K165 + Rastvorin + Energy-M) on the variety-standard Podarok of Moldova; from 55.2 mg/kg (control variant) to 120.8 mg/kg (variant – N300P180K165 + Rastvorin + Energy-M) on the Pathos F1 hybrid; from 73.3 mg/kg (control variant) to 128.5 mg/kg (variant – N300P180K165 + Rastvorin + Energy-M) on the Pompeo F1 hybrid. When differentiating irrigation water by the growth phases of the sweet pepper plant, the following indicators were recorded: on the standard variety Podarok of Moldova - from 80.3 to 146.9 mg/kg, which is lower than the values of this indicator under the irrigation regime of 75...75...75% of minimum water capacity by 3.0...1.9 mg/kg, respectively, according to the experimental variants; on the hybrid Pafo F1 – from 53.4 to 116.6 mg/kg (lower by 1.8...4.2 mg/kg); on the hybrid Pompeo F1 – from 70.2 to 126.3 mg/kg (lower by 3.1...2.2 mg/kg). It should be noted that the hybrids were less susceptible to the accumulation of nitrates in the fruits, especially the promising Pafo F1 hybrid.

In general, for each irrigation regime, the minimum yield was obtained on the control variant, and the maximum - with the complex application of mineral fertilizers, water-soluble fertilizer Rastvorin and treatment with the growth regulator Energy-M (Table 1).
Figure 5. Nitrate content in sweet pepper fruits, mg/kg (average for 2011...2016).

Table 1. Productivity of sweet pepper, average for 2011...2016.

| Experience option | Podarok of Moldova | Pafos F₁ | Pompeo F₁ |
|-------------------|--------------------|---------|-----------|
|                   | 75-75-75% of min.  | 70-80-75% | 75-75-75% | 70-80-75% | 75-75-75% | 70-80-75% |
| water capacity    | water capacity     | water capacity | water capacity | water capacity | water capacity | water capacity |
| Control           | 34.8               | 38.2     | 45.8       | 49.2       | 51.0       | 54.2       |
| Energy-M          | 41.9               | 45.3     | 55.3       | 58.6       | 60.1       | 63.1       |
| N₁₆₅P₁₀₀K₉₀      | 52.1               | 57.2     | 66.7       | 69.3       | 71.6       | 75.5       |
| N₂₃₅P₁₄₀K₁₃₀     | 59.5               | 66.9     | 74.9       | 79.8       | 79.9       | 86.1       |
| N₃₈₀P₁₈₀K₁₆₅     | 66.1               | 72.3     | 82.0       | 87.9       | 87.3       | 93.4       |
| Rastvorin         | 46.7               | 51.6     | 61.3       | 66.3       | 66.5       | 71.1       |
| N₁₆₅P₁₀₀K₉₀ + Rastvorin | 55.8          | 61.0     | 71.9       | 76.4       | 76.7       | 80.7       |
| N₂₃₅P₁₄₀K₁₃₀ + Rastvorin | 65.9          | 72.7     | 82.9       | 89.3       | 88.1       | 93.1       |
| N₃₈₀P₁₈₀K₁₆₅ + Rastvorin | 72.3          | 79.0     | 90.3       | 96.8       | 95.4       | 100.9      |
| Rastvorin + Energy-M | 55.6          | 60.1     | 72.0       | 76.1       | 76.9       | 80.6       |
| N₁₆₅P₁₀₀K₉₀ + Rastvorin + Energy-M | 59.5      | 65.5     | 77.5       | 82.8       | 82.5       | 87.7       |
| N₂₃₅P₁₄₀K₁₃₀+ Rastvorin + Energy-M | 70.3          | 78.0     | 91.6       | 98.8       | 97.0       | 103.5      |
| N₃₈₀P₁₈₀K₁₆₅ + Rastvorin + Energy-M | 75.6            | 81.4     | 99.8       | 105.9      | 105.8      | 111.4      |
Treatment of crops by the growth regulator Energy-M allowed to increase the yield of sweet pepper by 7.1 and 7.1 t/ha (Podarok of Moldova), 9.5 and 9.4 t/ha (Pafos F₁) and 9.1 and 8.9 t/ha (Pompeo F₁) relative to the control variant under the irrigation regime of 75...75...75% of minimum water capacity and 70...80...75% of minimum water capacity, respectively.

The use of water-soluble fertilizer Rastvorin in sweet pepper crops contributed to an increase in yield by 11.9 t/ha (Podarok of Moldova), 34.0 t/ha (Pafos F₁) and 15.5 t/ha (Pompeo F₁) relative to the control variant under the irrigation regime of 75...75...75% of minimum water capacity. When the irrigation mode is 70...80...75% of minimum water capacity increase was at the level of 13.4 t/ha (Podarok of Moldova), 35.0 t/ha (Pafos F₁) and 17.1 t/ha (Pompeo F₁) relative to the control variant.

In the variant of joint use of Rastvorin and Energy-M, hybrids were more responsive relative to the standard variety by 16.4 and 16.0 t/ha (Pafos F₁) and 21.3 and 20.5 t/ha (Pompeo F₁), respectively, according to irrigation regimes.

The Pompeo F₁ hybrid was noted as the most sensitive in this soil-climatic zone to the studied water and nutrient regimes. On all variants, the maximum yield was recorded on this hybrid.

For the manufacturer, the most economically justified is the cultivation of sweet pepper: the best option is the background N₃₀₀P₁₈₀K₁₆₅ + Rastvorin + Energy-M. In addition, it was the Pompeo F₁ hybrid that was characterized by the highest profitability for all the variants of experience in the context of production factors. Again, the differentiated irrigation regime of the crop was optimal. In general, the experiment achieved the goal of identifying the most profitable option for agricultural producers for cultivating one of the main vegetable crops in the region. It was the background for the maximum planned yield in combination with the processing of Rastvorin + Energy-M with a differentiated 70...80...75% of minimum water capacity irrigation mode.

4. Conclusion
Evaluating the quality of the fruits of the studied varietals, it should be noted that the growth regulator Energy-M in combination with mineral fertilizers and water-soluble fertilizer Rastvorin changed the chemical composition of the fruits of the studied crops and improved their taste and marketability. As our research has shown, irrigation and the use of mineral fertilizers and a growth regulator to a certain extent affected the content of dry matter, vitamin C and raw fiber in the fruits of sweet pepper, and other indicators. The maximum amount of dry matter was observed on the variant N₃₀₀P₁₈₀K₁₆₅ + Rastvorin + Energy-M on the Pompeo F₁ hybrid – 7.98 and 8.06%, respectively, according to the irrigation modes. Indicators such as vitamin C, fiber and sugar content in fruits increased with the improvement of the nutritional and water regimes of sweet pepper growth. As a result of the variety study of vegetable crops of domestic and foreign selection, the best was the Pompeo F₁ sweet pepper hybrid, which surpasses the standard variety of Podarok of Moldova by 30.10 t/ha (N₃₀₀P₁₈₀K₁₆₅ + Rastvorin + Energy-M), on average for the irrigation modes. The highest figures of these quality characteristics were recorded on the Pompeo F₁ hybrid. Summarizing the research results, we come to the conclusion: the elements of technology for obtaining the level of the planned yield of the studied vegetable are closely related to the qualitative composition of pepper fruits.

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