The vegetative grafting effect on increasing tomato fruit quality

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Abstract. In Uzbekistan, the vegetative grafting effect on the tomato fruits quality was studied. Table tomato varieties Gulkand, AVE-Maria and Marvarid (cherry tomato) were used as grafts. Each variety was grafted onto its own seedlings, as well as in combinations with four tomato accessions from the World Vegetable Center. The control was not grafted plants. The grafting of varieties depending on the rootstock helped increase the yield by 16-20% and the marketability of fruits by 97-100%. The Gulkand variety, in combination with rootstocks L03708 and CLN2071B, has its average fruit weight increased by 30-35%, AVE-Maria – by 11-18% and Marvarid – by 24-43% above the control plants. The low variability of the dry matter content (V=6.4%) and total sugar (V=9.0%), and the middle variability of the ascorbic acid content were established as well (V=12.5%). In the Gulkand and AVE-Maria varieties, the dry matter content was close to the control level, and in the Marvarid variety it has increased in combinations. Total sugar content has slightly decreased in all combinations of the Gulkand variety. The ascorbic acid has increased in all varieties in combinations. The variability of the chemical composition did not depend on the type of rootstock (Lycopersicon esculentum Mill.) or (ssp. Pimpinellifolium). The nitrate nitrogen in fruits in all varieties and combinations was 1.4–2.3 times lower than the MPC.

1. Introduction
In recent decades, the world has rapidly developed the technology of vegetable crops vegetative grafting in order to increase the yield of vegetables in greenhouses and open ground, mainly in order to combat adverse environmental factors such as drought, extreme temperatures, reduced fertility, soil salinity, as well as pests and diseases [1, 2, 3, 4].

In vegetative grafting, varieties that are resistant to adverse conditions are used as rootstocks. The rootstock through its root system supplies the graft with nutrients, and that, in turn, feeds the entire plant with organic substances produced in the leaves during photosynthesis. The rootstock and graft have a mutual influence on each other. When the rootstock affects the graft, the growth and development of the plant increases, productivity and quality increase as well, that is, the phenomenon observed is called heterosis. [5].

In various countries, fundamental and applied researches are conducted to improve productivity, knowledge of nature and physiological processes, as well as biochemical changes that occur during vegetative grafting of various vegetable crops plants [6, 7].
There is conflicting information about changes in fruit quality as a result of grafting and whether the effects of inoculation are beneficial or harmful [8].

According to recent research, most scientists conclude that grafting is a useful method for improving nutrient absorption and fruit quality, increasing yield, preventing disease, and increasing stress tolerance due to the vigorous root system of rootstocks [9, 10, 11, 12].

Research by Davis [13] has demonstrated conflicting results regarding the quality of fruits in grafted plants.

Khah [14] found that grafting did not affect changes in the concentration of soluble solids and titrated acidity, lycopene content, and pH in tomato hybrids.

The results obtained by Doltu allow us to conclude that some grafted tomatoes had a high yield and a large number of fruits, but the fruit quality did not significantly change compared to non-grafted plants [15].

Turhan found that when grafted, the content of dry matter, soluble solids, and total sugar content was lower in the fruits of grafted plants than in the fruits not grafted, but the content of titrated acid in them increased. The total sugar content was influenced by rootstocks. When grafting Yeni Talya, Swanson and Beril hybrids on the Beaufort rootstock, there was an increase in the content of total sugars in the fruit, while when grafting them on the Arnold rootstock, their content decreased. The concentration of soluble solids of the fruit of the Beril tomato hybrid grafted on the Beaufort rootstock was higher than when it was grafted on the Arnold rootstock. The highest values of titrated acidity were found in the fruits of grafted plants, while the lowest were found in non-grafted tomato plants [16].

According to Schwarz, vegetative grafting can lead to an increase in the content of titrated acids and a decrease in sugar [17].

Scientists have found an increase in the concentration of soluble solids and titrated acidity in the commercial hybrid Boludo when it is grafted on cultivated and wild (Solanum cheesmaniae) tomato [8, 15, 18, 19].

Sora and other scientists [19] conclude that grafting tomatoes on rootstock Emperador has a positive effect on improving the nutritional qualities of fruits compared to non-grafted plants, as well as plants grafted on other rootstocks (L542, L543 and L544). They specify that the fruit of the tomato variety Abellus, grafted on rootstocks L542, L543 and L544, had slightly higher dry matter content than non-grafted plants. The carbohydrate content was slightly higher in plant fruits obtained from grafted plants on all three rootstocks compared to non-grafted plants. The content of dry soluble substances was the same for grafted and non-grafted tomatoes. In the Abellus variety grafted on Dutch rootstocks, the fruit had a slightly reduced dry matter content compared to the Siriana control fruit.

Analyzing the correlation between the quality categories (top and first grade) and the content of soluble solids, a positive relationship was found between grafted and non-grafted plants on Siriana (r²= 0.4914) and Abellus (r²=0.1517) hybrids. The rootstock affected the appearance, texture, and taste of the fruit, but with minor differences, because all variants had very good indicators and an organoleptic score of 81.1 to 100 points [19].

Experiments by Gajc-Wolska and other scientists [20] demonstrated that the formation of fruit mass was influenced by the substrate. When grown on a mineral wool substrate, a higher fruit mass was observed, while plants cultivated on plates made of coconut fiber tended to form small fruits. There were no significant differences in fruit weight between grafted and non-grafted plants. The chemical composition and taste mainly depended on the date of fruit harvest and, to a lesser extent, on the substrate used and the grafted plants.

Generally, the results obtained by many scientists show the effectiveness of vegetative grafting to improve the quality of tomato fruits. These findings are important because they show that grafting is a quick and effective way to improve the quality of fruit.

In Central Asia, scientific research on vegetative tomato grafting is being conducted for the first time.
2. Methods of research
The research was carried out in 2015-2017 at Uzbek Research Institute of Vegetable, Melon Crops and Potato (Uzbekistan) in heated plastic film greenhouses in winter-spring period.

When growing tomato plants in a greenhouse in January-February, the air temperature in the daytime was +25...+ 28°C, and at night it decreased to +20...+ 23°C. In March-April, with a gradual increase in the temperature of the air outside, the temperature in the greenhouse on sunny days increased to +27...+ 32°C, and at night it was +22...+ 25°C. In January-February, the humidity in the greenhouse was 75-80%, and in the spring months it decreased to 60-65%.

Soil analysis was conducted in the greenhouse. Nitrate nitrogen was determined by the Granvald-Lage disulfur phenol method, ammonia method – with Nessler's reagent, phosphorus method – by Murphy-Riley, potassium method – by a flame photometer, bulk mass – by Ostapov, calcium and magnesium – by the Trilon method. Soil analysis showed the content of organic substances is 13.3-15.2%, water-soluble salts – 0.349–0.473%, chlorine – 0.018–0.047%, as well as water – soluble nitrogen (ammonia and nitrate) – 15.6 – 19.2 mg/100 g, phosphorus compounds – 5.0 - 6.4, potassium - 41-55, calcium - 52-64 and magnesium-42-48 mg/100 g of soil. The soil acidity (pH) was -7.6. When growing tomatoes, technological maps were used for growing seedlings and vegetable crops in protected ground structures.

In the research, three local breeding greenhouse tomato varieties zoned in Uzbekistan were used as grafts: Gulkand, AVE Maria and cherry tomato variety – Marvarid. These middle-aged varieties, belonging to the species *Lycopersicon esculentum Mill*, differed in fruit weight. The table tomato variety Gulkand usually forms fruits weighing from 150 to 250 g, the table variety AVE Maria - from 120 to 150 g, and the tomato variety Marvarid (cherry tomato) - weighing from 25 to 30 g.

4 tomato varieties introduced from the World Vegetable Center (Taiwan) were used as rootstocks. They were represented by two samples (L03708 and L06193) belonging to the currant tomato species (*Lycopersicon esculentum Mill., ssp. pimpinellifolium*), as well as two lines of CLN2071B and CLN2071D of cultivated tomato (*Lycopersicon esculentum Mill.*).

To start the experiment, in accordance with the Guidelines of the World Vegetable Center for tomato grafting [21], vegetative grafting of tomato seedlings was performed when the stem diameter reached 1.6 – 1.8 mm in the phase of 2-3 true leaves.

As a control, non-grafted plant varieties were used. A total of 15 combinations were studied when grafting seedlings of each zoned tomato variety on their own plants, as well as in four more combinations where zoned varieties served as grafts, and samples – as rootstocks.

After the growth of the stem, the grafted seedlings of all combinations of cultivars were planted in the greenhouse for a permanent place in the first decade of March. The registered area of the plot was 5 m2, 4-fold repeatability, 10 plants in each repeat, the location of the plots was randomized. During the growing season, phenological observations and accounting of tomato fruit yield were performed.

Biochemical analysis of tomato fruits was performed in the biochemistry laboratory using conventional methods [22], the dry matter content was determined by curing technique (drying in a thermostat to a constant weight at a temperature of + 75°C... + 80°C), sugar - by the cyanate method by Tilman, soluble solids - by a Refractometer, ascorbic acid - by Murri, nitrate nitrogen - by Vdovina-Medvedeva ion-selective electrodes.

Statistical processing of the obtained research results was performed according to B. A. Dospekhov [22].

3. Results and discussion
The indicators of tomato fruit quality are shape, color and taste of the fruit inherent in a particular variety, its average weight, marketability of the fruit and the content of chemical components.

In our research, we described the positive effect of vegetative grafting on improving the quality of fruits of various tomato varieties.

1. Average fruit weight
It should be noted that in tomato varieties grafted on the same variety, the average fruit weight indicators were slightly lower, in comparison with non-grafted (control) samples, as well as the variety in combinations with four rootstocks. Thus, with an average fruit weight of 179 g in the unvaccinated Gulkand (control) variety, in combinations the average fruit weight was from 231 to 241 g. The AVE-Maria control had an average fruit weight of 123 g, in combinations it ranged from 135 to 152 g. In the variety Marvarid (cherry tomato) with a fruit weight of 20 g in the control variant, in combinations it was from 26 to 30 g (table 1).

As you know, an increase in the mass and marketability of the fruit contributes to an increase in productivity. It was found that grafted on their own plants varieties do not provide an increase in fruit yield. Grafting varieties in combinations proved effective and, depending on the rootstock, contributed to an increase in yield by 16-20% and marketability of fruits from 97 to 100%. Taking into account these indicators, in comparison with the control (not grafted, taken for 100%), the gulkand variety in combinations with rootstocks L03708 and CLN2071B increased the average fruit weight by 30-35%, the AVE-Maria variety-by 11-18% and the marvarid variety – by 24-43% higher than the control. In addition to these two rootstocks, a significant increase in fruit weight alone was observed in the AVE-Maria variety in combination with L06193 by 24%, and in the Marvarid variety in combination with L06193 and CLN2071D – by 38-43%.

2. Chemical composition

The chemical composition of tomato fruits between varieties differs slightly and is a characteristic of a particular variety.

In our research, we studied the chemical composition of fruit in three varieties of tomato in comparison with grafted ones on their own plants, as well as in combinations with four rootstocks.

Indicators of the chemical composition of the fruit of three varieties of tomato grafted on chosen rootstocks differed among themselves. Regularities of components variability of of fruits chemical composition are established. Thus, the variability of the dry matter content (V=6.4%) and total sugar (V=9.0%) was low, and the ascorbic acid content (V=12.5%) was average.

Gulkand. The dry matter content of the control (non-grafted) variety self-grafted and in combinations did not differ significantly and varied from 6.1 to 6.4%. The content of total sugars was highest in the non-grafted sample and self-grafted variety – 5.0%. When grafted with L03708, the total sugar content decreased slightly to 4.7%, while in other combinations the indicators were lower (3.9-4.3%). According to the content of ascorbic acid, the lowest content was in the non-grafted variety -22.7 mg/kg. When grafting on rootstocks L03708, CLN2071B and CLN2071D its content increased from 23.6 to 23.9 mg/kg (table 1).

Thus, for the Gulkand variety in comparison with the control (if its indicators are taken as 100%), grafting on the rootstock L03708 contributed to an increase in the content of: dry matter and ascorbic acid and amounted, respectively, to 104% and 105% of the control, with a decrease in the content of total sugars (94%). When grafting on cln2071b and CLN2071D rootstocks, the content of ascorbic acid only increased and amounted to 106% of the control.

AVE-Maria. Both non-grafted and self-grafted varieties had the same dry matter content (6.2%) and total sugars (3.7%), and the ascorbic acid content was similar (19.6-20.0 mg/kg). Grafting in combinations of L03708, L06193, CLN2071B and CLN2071D gave a slight increase in the dry matter content: 6.3-6.4%, total sugars-3.8-4.0% and ascorbic acid-22.1-24.3 mg/kg. For the AVE– Maria variety, all combinations of grafting the variety on rootstocks L03708, L06193, CLN2071B and CLN2071D contributed to an increase in the dry matter content, which was 103% to control, total sugars-108% and ascorbic acid 111-121%.

Marvarid (cherry tomato). Both the non-grafted and self-grafted varieties had similar dry matter content (6.8-6.9%), total sugars (4.1%), and ascorbic acid (23.6-24.0 mg/kg), while these values were higher in combinations. The dry matter content in the combinations was from 7.1 to 7.5% and total sugars-from 4.2 to 4.5%. The highest levels of ascorbic acid were found in plant fruits in combinations with rootstocks L03708-25.1 mg/kg and CLN2071D-26.5 mg/kg, as well as high dry matter content (7.1-7.3%) and total sugars (4.4-4.5%). For the marvarid variety, the best indicators of the chemical
composition components were combined with rootstocks L03708 and CLN2071D, in which the fruit content of dry matter was 108%, total sugars – 110% and ascorbic acid - 105-110% to control.

It was found that the variability of the content of chemical composition components did not depend on the type of rootstock used - cultivated tomato (Lycopersicon esculentum Mill.) or related to the currant tomato species (Lycopersicon esculentum Mill., ssp. pimpinellifolium). When using both types of tomato, an increase in the content of individual components of the chemical composition was observed.

Nitrate nitrogen. The accumulation of nitrate nitrogen in fruits above the maximum permissible norm (MPC=150 mg/kg of raw fruit weight) is a negative factor.

In our studies, the variability of nitrate nitrogen content in fruits was average (V=12.0%). In the studied varieties and combinations, the content of nitrate nitrogen was significantly lower than the MPC and varied from 57 to 93 mg / kg. It should be noted that the slightly higher content of nitrate nitrogen compared to other varieties and combinations was in the non-grafted variety AVE-Maria (78 mg / kg), the combination of Gulkand/L06193 – 69 mg/kg and Marvarid/L06193 – 84 mg/kg, as well as Marvarid/L03708 – 93 mg/kg. It was found that the accumulation of nitrate nitrogen of the tomato varieties and combinations studied by us was 1.4-2.3 times lower than the maximum permissible norm.

Table 1. Fruit weight and chemical composition of tomato fruits when grafting in various combinations (2015–2017).

| Varieties, combinations | Average fruit weight, g | Dry matter, % | Total sugar, % | Ascorbic acid, mg/kg | Nitrate nitrogen, mg/kg |
|-------------------------|-------------------------|--------------|---------------|----------------------|------------------------|
| Gulkand – control, non-grafted | 179 | 6.1 | 5.0 | 22.7 | 60 |
| Gulkand / Gulkand | 175 | 6.1 | 5.0 | 23.0 | 57 |
| Gulkand / L03708 | 241 | 6.4 | 4.7 | 23.6 | 67 |
| Gulkand / L06193 | 231 | 6.3 | 4.3 | 23.3 | 69 |
| Gulkand / CLN2071B | 233 | 6.3 | 3.9 | 23.6 | 67 |
| Gulkand / CLN2071D | 231 | 6.3 | 4.0 | 23.9 | 68 |
| AVE-Maria – control, non-grafted | 123 | 6.2 | 3.7 | 20.0 | 78 |
| AVE-Maria / AVE-Maria | 118 | 6.2 | 3.7 | 19.6 | 75 |
| AVE-Maria / L03708 | 145 | 6.4 | 3.9 | 22.1 | 70 |
| AVE-Maria / L06193 | 152 | 6.4 | 3.8 | 23.3 | 70 |
| AVE-Maria / CLN2071B | 137 | 6.3 | 4.0 | 23.1 | 66 |
| AVE-Maria / CLN2071D | 135 | 6.4 | 3.8 | 24.3 | 68 |
| Marvarid (cherry tomato) – control, non-grafted | 21 | 6.9 | 4.1 | 24.0 | 75 |
| Marvarid / Marvarid | 20 | 6.8 | 4.1 | 23.6 | 65 |
| Marvarid (cherry tomato) / L03708 | 30 | 7.1 | 4.5 | 25.1 | 93 |
| Marvarid (cherry tomato) / L06193 | 29 | 7.3 | 4.3 | 24.6 | 84 |
| Marvarid (cherry tomato) / CLN2071B | 26 | 7.5 | 4.2 | 23.9 | 77 |
| Marvarid (cherry tomato) / CLN2071D | 30 | 7.3 | 4.4 | 26.5 | 72 |
|-------------------------------------|----|-----|-----|------|----|
| x                                   | 6.53 | 4.1 | 23.3 | 70.3 |
| LCD05                               | 0.19 | 0.17 | 1.35 | 3.90 |
| V, %                                | 6.4 | 9.0 | 12.5 | 12.0 |

4. Conclusion

Based on our research, we have established a positive effect of vegetative grafting on increasing the content of chemical components and improving the quality of fruits of various tomato varieties when grafted on various rootstocks.

Low variability of dry matter and total sugar content, and average variability of ascorbic acid content and nitrate accumulation were found.

The rootstock belonging to the type of cultivated (*Lycopersicon esculentum* Mill.) or currant (*Lycopersicon esculentum* Mill., ssp. *pimpinellifolium*) tomato did not have a special significance for increasing the chemical composition of the fruit.

When selecting rootstocks for vegetative tomato grafting, it is more important to take into account the characteristics of the rootstock itself. Rootstocks L03708 and CLN2071D had a positive effect on the improvement of most components of the chemical composition of all three studied zoned varieties, which indicates the prospect of their use for vegetative grafting.

The use of an innovative method of vegetative grafting using selected rootstocks will help to increase productivity and quality in the production of tomatoes in greenhouses.

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