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*Plant Growing*

# Impact of Biofertilizers on the Yield and Quality of Mandarin Orange

**Zurab Mikeladze*, Nunu Kutaladze*, Sophio Papunidze*, Nino Seidishvili*, Tamar Gogolishvili*, Tsiala Bolkvadze***

* *Batumi Shota Rustaveli State University, Batumi, Georgia*

(Presented by Academy Member Vano Papunidze)

**Under the conditions of field trials and laboratory studies, we conducted experimental work on alluvial soils in a mandarin plantation, where ecologically clean biopreparations (insectofungicides) were incorporated into the agrotechnical complex alongside mineral fertilizers: Gaupsin, Bactofert, Bitoxybacillin, and Bactocid CK. The use of biopreparations followed the experimental scheme. Nitrogen, phosphorus, and potassium fertilizers were applied in the form of Russian-made NPK fertilizers, with each nutrient element comprising 15%. The studies revealed the positive effect of using biofertilizers in conjunction with mineral fertilizers. These biofertilizers contributed to an increase in yield compared to the fertilizer-free option. Among them, the use of half of the standard dose of mineral fertilizers, along with agrotechnical doses, proves to be economically beneficial, allowing for a reduction in the number of mineral fertilizers used in mandarin cultivation. This has a positive impact on yield, quality, natural storage capacity, and, most importantly, results in the production of ecologically clean products. The harvest is abundant, the fruits are of high quality and suitable for export.** *© 2025 Bull. Georg. Natl. Acad. Sci.*

biofertilizers, soil, plant, mandarin citrus

Citrus cultivation has long been and should remain a key component of subtropical agriculture in Georgia. Currently, the global production of citrus fruits exceeds 74 million tons, attracting interest from over 80 countries. These countries possess the natural and climatic conditions favorable for citrus cultivation [1,2]. It was privileged and utilized, providing economic support to the local population. However, from a scientific perspective, several issues warranted in-depth study. These included examining the impact of ecological and orthographic factors on the production and quality metrics of citrus fruits. Furthermore, there was a need to develop scientifically grounded recommendations for improving soil fertility in citrus orchards and for implementing effective strategies to control detrimental plant diseases [3,4]. The objective of our study is addressed through the development of technologies and technical means for the production, commercial, and industrial processing, storage, and sale of citrus fruits. Furthermore, this research includes the creation of scientifically substantiated proposals and recommendations that are pertinent to the current circumstances [5,6].

Preliminary large-scale studies have shown that the soil agrochemical indicators in the orchards of over 22,000 citrus farmers in Adjara are in catastrophic condition. The application of mineral fertilizers has disrupted plant nutrition, as evidenced by a significant decline in yield and quality indicators. Essentially, these findings indicate that mineral fertilisers are being applied in a non-standard manner in the region's citrus cultivation [7, 8]. The incorrect implementation or complete neglect of measures to control plant and pest diseases has reached a catastrophic point.

It is necessary to fertilize mandarin plantations with both inorganic and organic fertilizers, along with biofertilizers [9]. Recently, biofertilizers, including both organic and microbial substances, have been actively used worldwide to improve soil fertility and plant development [10]. The study contributes to reducing the consumption of inorganic fertilizers, which impacts consumer health and results in high-quality produce suitable for export.

The disruption of the previously established system of citrus fruit production, processing, and sales, along with the absence of any new, progressive systems adapted to current times and circumstances, is largely responsible for this situation. As a result, we have observed a mutually detrimental relationship between the system and the economy [11,12].

Citrus orchards (mandarin) currently span 7,725 hectares in Adjara, as reported by the Ministry of Agriculture. Of these, 5,725 hectares are classified as fully productive, though the reliability of this data may be questionable. For residents of Khelvachauri and Kobuleti municipalities, citrus cultivation continues to be a significant source of income. Citrus fruits contribute to over 27% of horticultural production and constitute 70% of the products exported outside the republic [13]. Despite existing challenges, citrus cultivation is a key component of the agricultural sector in Adjara. Its further development is recognized as a crucial strategy to boost the region's export potential and enhance the socio-economic well-being of its farmers [14].

## Experimental Part

The objective of our study was to examine the mutual effects of certain biopreparations (insecto-fungicides) and mineral fertilizers on the yield, quality, storage capacity, and pest disease resistance of mandarins and formulate relevant recommendations. Preliminary experiments commenced with mini-trials and subsequently progressed to extensive field trials within a mature mandarin orchard situated on the alluvial soils of the Kakhaberi plain (currently near the airport) within Khelvachauri Municipality, now part of Batumi. The experiments utilized the Ukrainian-made insecto-fungicide "Gaupsin," as well as several biopreparations from Spain and Russia, such as Bitoxy Bacillin, Bactocid, including the domestically produced Bactofert, and Georganica (Geohumat).

## Research Methodology

Stationary field tests and laboratory research were employed as the primary methods in this study. The field trials were conducted by the established methodology of Sh. Chanishvili (1973). The investigations took place from 2022 to 2024 within a mature 'Unshiu' mandarin orchard located on the alluvial soils of the Kakhabri plain, along the Black Sea coast of Adjara [8]. To establish the field trial, the main plot was subdivided into several smaller plots, and the experiments were conducted in six replicates. Each replicate comprised three plants, resulting in a total of 18 plants per treatment variant. Russian-manufactured NPK mineral fertilizers, containing 15% each of nitrogen, phosphorus, and potassium were applied at a rate of 160 grams per element per plant. This application provided half of the recommended agronomic dose. It was hypothesized that the remaining nutritional needs of the plants would be fulfilled by the effects of biological preparations. During the trial period, biological preparations were administered according to the following experimental scheme:

1. Bactofert: 600 g per root.
2. NPK at half dose + Geohumate: 2 packages applied per root.
3. NPK at half dose + Bitoxybacillin: Administered as a 6% solution by spraying.
4. Fertilizer free.
5. NPK at half dose + Bactofit CK: Administered as a 6% solution by spraying.
6. Geohumate: 2 packages sprayed both at the root and on the soil.
7. The experiment was conducted in three replicates.

Agrochemical analyses of soil and leaves were conducted at various stages of plant growth. The aim was to examine the variations in major nutrient levels in the soil and leaves across different treatment variants and to evaluate their effects on soil fertility, crop yield, and resistance to plant pests. Soil samples were systematically collected from around the model plants in the experimental unit, in accordance with the specified treatments, across diverse growing seasons.

Soil sampling was performed according to GOST 28168-89. The soil samples were prepared for analysis by drying, cleaning from impurities, and passing through 1- and 0.25-mm sieves, following GOST 26483-85. The hygroscopic water content was determined by the weighing and thermostatic method, conforming to GOST 28268-89. The pH of water and KCl extracts was measured potentiometrically with a pH meter, adhering to GOST 26483-85.

The total humus percentage was quantified by the Tyurin method involving titration, as per GOST 26213-91. The total nitrogen percentage was analyzed using the Kjeldahl micro chrome-titration method, following GOST 26107-84. The plant-available phosphorus (mg/100g) was estimated by the Olsen method using photometry, according to GOST 26205-91. The plant-absorbable potassium

**Table 1. Annual yield data for mandarin (2022-2024)**

| Treatments | 2022 | | 2023 | | 2024 | | Average | |
|---|---|---|---|---|---|---|---|---|
| | Per plant (kg) | t/ha | Per plant (kg) | t/ha | Per plant (kg) | t/ha | Per plant (kg) | t/ha |
| 1. Fertilizer free | 52.0 | 29.7 | 47.0 | 26.8 | 27.0 | 15.4 | 42.0 | 23.96 |
| 2. Bactofert 300 g. per root + NPK 0.5 dose | 81.5 | 46.5 | 85.2 | 48.6 | 80.0 | 45.7 | 82.23 | 46.93 |
| 3 .Bactofert 300 g. per root | 85.0 | 48.5 | 90,0 | 51.4 | 68.0 | 39.0 | 81.0 | 46.3 |
| 4. Bactofert 600 g. per root + NPK 0.5 dose | - | - | 120,0 | 68,5 | 99.0 | 56.5 | 109.5 | 62.5 |
| 5. Bactofert 600 g. per root | - | - | 105.0 | 60.0 | 100.0 | 57.1 | 102.5 | 58.55 |
| 6. NPK 0.5 dose + bitoxybacillin: administered as a 6% solution by spraying | 121.0 | 69.1 | 115,0 | 656 | 192.0 | 109.6 | 142.6 | 81.43 |
| 7. NPK 0.5 dose + bactoferit-CK: administered as a 6% solution by spraying | 99.0 | 56.5 | 59.0 | 56.5 | 176.0 | 100.5 | 111.3 | 71.16 |
| 8. Geohumate: 3 packages sprayed both at the root, on the soil and plant+ NPK 0.5 dose | 95.0 | 54.2 | 160.0 | 91.4 | 194.0 | 111.0 | 139.6 | 85.53 |
| 9. Bactoferit 300 g per root + gaupsin by spraying (mixed at a ratio of 240 mL to 12 liters of water) | 96.4 | 55.0 | 105.0 | 60.0 | 110.0 | 63.0 | 103.8 | 59.3 |

**Table 2. Results of biochemical analysis of the fruit**

| Treatments | Vitamin „C“ % | | Sugars, % | | | | | | Total sugar % | Total sugar % |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Reducing sugars | | Invert sugars | | Sucrose | | | |
| | peel | pulp | peel | pulp | peel | pulp | peel | pulp | peel | pulp |
| 1. NPK 0.5 dose + geohumate two packages, sprayed on root and plant | 87 | 27 | 6.03 | 6.74 | 2.3 | 2.1 | 3.73 | 4.4 | 6.05 | 6.50 |
| 2. NPK 0.5 dose + bitoxybacillin 6% solution with multimaster, sprayed together | 97 | 33 | 6.47 | 6.48 | 2.43 | 1.99 | 4.04 | 4.25 | 6,47 | 6,24 |
| 3. Fertilizer free | 87 | 27 | 7.05 | 6.74 | 2.43 | 2.1 | 4.3 | 4.4 | 6.81 | 6.50 |
| 4. Geohumate two packages, sprayed on root and plant | 101 | 24 | 6.89 | 6.15 | 2.25 | 1.96 | 4.4 | 3.98 | 6.65 | 5.94 |

**Table 3. Chemical composition of fruits in %**

| Teartments | Fruit | AI | B | Ba | Ca | Cr | Fe | Hg | K | Li | Mg |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. NPK 0.5 dose with Geohumate sprayed on root and plant | Peel | 0.0001 | 0.0004 | 0.0007 | 0.19 | - | 0.041 | - | 0.12 | 0.0001 | 0.0003 |
| | Plum | 0.0007 | - | - | - | - | - | 0.003 | 0.03 | 0.0005 | 0.0003 |
| 2. NPK-0.5 dose with 6% Bitoxybacillin solution sprayed | Peel | 0.003 | 0,0001 | 0.22 | - | - | 0.002 | 0.0001 | 0.17 | 0.001 | - |
| | Plum | 0.004 | - | 0.0003 | - | - | 0.004 | - | 0.08 | 0.006 | - |
| 3. NPK-0.5 dose with 6% Bactoferit-CK solution sprayed | Peel | 0.002 | 0.0003 | 0.0008 | 0.14 | 0.0001 | 0.0005 | - | 0.08 | 0.003 | - |
| | Plum | 0.001 | - | - | - | - | 0.0004 | 0.0005 | 0.03 | 0.06 | - |
| 4. Geohumate package sprayed on root and plant | Peel | 0.002 | 0.0001 | 0.001 | 0.43 | - | 0.0007 | 0.0001 | 0.04 | - | 0.009 |
| | Plum | 0.001 | - | - | - | - | 0.0003 | 0.0002 | 0.06 | 0.003 | - |

(mg/100g) was determined using the SOIL TEST-500 device method, employing photometry as specified in GOST 26209-91.

The hydrolytic nitrogen (mg/kg) was measured by the Tyurin and Kononova method, as outlined in GOST 26213-91. The total percentage of absorbed bases was quantified using the Kappen method involving titration, conforming to GOST 27821-88. The total nitrogen percentage in plants was analyzed by the Kjeldahl method, following GOST 26107-84.

The total potassium percentage in plants was determined by wet filtration, according to GOST 26570-95. The total phosphorus percentage was measured by wet filtration, adhering to GOST 26261-84 [5,6]. Additionally, an inductively coupled plasma atomic emission spectrophotometer (ICPE-9820) was employed for analysis.

As demonstrated in the Table 1, all bio-preparations tested in the experiment consistently yielded high mandarin outputs. This includes scenarios where only half of the standard agrotechnical dose of basic mineral fertilizers (NPK) was used. This finding suggests that in mandarin orchards, the application of bio-preparations can effectively reduce the need for full doses of NPK fertilizers – thus, mineral fertilizers. Additionally, the adoption of bio-preparations, which are significantly less costly than mineral fertilizers, leads to substantial cost savings while still securing a high and reliable harvest.

During the trial period, the application of Bactofert (300 g per root) combined with NPK at a 0.5

dosage was evaluated. Comprehensive studies, conducted before and after the trial, were focused on assessing yield, storage capacity, and susceptibility to pest diseases. The evaluations employed the Ukrainian-manufactured insectofungicide Gaupsin. Promising results, indicating significant improvements, were obtained from these studies.

Even in the absence of the recommended agrotechnical dosage, a fairly stable and high yield was observed, ranging from 81 to 46 tons per hectare. However, when the dosage of Bactofert was increased to 600 grams per root, yields of 109.5-62.5 tons per hectare were respectively achieved. These improvements were noted irrespective of the concurrent application of an NPK 0.5 agricultural dosage. A stable and high yield of 142.6-81.3 tons per hectare was achieved through the application of a 6% Bitoxylbacillin solution, applied periodically in conjunction with an NPK 0.5 agricultural dose. Furthermore, high yields were also obtained from periodic spraying of a 6% Bactophyte-CK solution, which, when used against the background of an NPK 0.5 agricultural dose, resulted in yields of 59 tons per hectare. Additionally, the application of three packages of Geohumate, sprayed periodically on both the soil and the plant, led to yields of 85 tons per hectare.

According to biochemical indicators (referenced in Table 2), the concentration of vitamin C is found to be twice as high in the peel as in the pulp. Among the treatments, the peel of treatment 4, as well as both the peel and pulp of treatment 2, are shown to be preferred. The content of reducing sugars is observed to be nearly identical in both the peel and pulp across all treatments. Similarly, the levels of inverted sugars maintain consistency, yet, in this instance, concentrations are notably higher in the peel than in the pulp. The total sugar content in both the peel and pulp remains virtually equivalent across the treatments. The complete chemical composition of the fruits from these selected treatments has been thoroughly analysed.

The high sensitivity of the device and the accuracy of the data allow for the acquisition of important information regarding the complete chemical composition of mandarin fruit.

## Conclusions

Based on the data collected from multi-year field and laboratory experiments conducted between 2017 and 2022, the following conclusions are drawn:

- In mature 'Unshiu' mandarin orchards situated on alluvial soil along the Black Sea coast of Adjara, it has been demonstrated that the application of basic mineral fertilizers (NPK) at a 0.5 agro dose, in conjunction with the spraying of various biological preparations (Bactofert, Gaupsin, Bitox, Bicillin, Bactofert-CK, Geohumate) on both the plants and soil, significantly enhances mandarin yields. Furthermore, these treatments have been shown to improve the natural storage capability of the fruits during normal conditions of storage and sale.
- In the absence of both mineral and biofertilizers, even over a period of two to three years, a catastrophic decrease is observed in the growth and yield of tangerine plants, which is also accompanied by a deterioration in quality indicators.
- The application of biopreparations does not significantly enhance soil fertility indicators. However, root and rootless feeding with these preparations is observed to significantly improve the nutritional regime of the plants, consequently yielding a record-high harvest.

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*მემცენარეობა*

# ბიოსასუქების გავლენა მანდარინის მოსავლიანობასა და ხარისხზე

ზ. მიქელაძე*, ნ. კუტალაძე*, ს. პაპუნიძე*, ნ. სეიდიშვილი*, თ. გოგოლიშვილი*, ც. ბოლქვაძე*

** ბათუმის შოთა რუსთაველის სახელმწიფო უნივერსიტეტი, ბათუმი, საქართველო*

(წარმოდგენილია აკადემიის წევრის ვ. პაპუნიძის მიერ)

მინდვრის ცდის და ლაბორატორიული კვლევების პირობებში ვაწარმოებდით ექსპერიმენტულ სამუშაოებს მანდარინის ბაღში, ალუვიურ ნიადაგებზე, სადაც აგროტექნიკურ ღონისძიებათა კომპლექსში მინერალურ სასუქებთან ერთად ჩართულ იქნა ეკოლოგიურად სუფთა ბიოპრეპარატები (ინოსექტოფუნგიციდები): გაუფსინი, ბაქტოფერტი, ბიტოქსიბაცილინი, ბაქტოციდი CK. ბიოპრეპარატების გამოყენება ხდებოდა ცდის სქემის მიხედვით. აზოტიანი, ფოსფორიანი, კალიუმიანი სასუქები შეგვქონდა რუსული წარმოების NPK სასუქის სახით, სადაც თითოეული საკვები ელემენტი 15%-ს შეადგენს. ჩატარებული კვლევების შედეგად, გამოვლინდა ბიოსასუქების მინერალურ სასუქებთან ერთად გამოყენების დადებითი ეფექტი. ყველა აღნიშნული ბიოსასუქი იძლევა მოსავლის მატებას უსასუქო ვარიანტთან შედარებით. მათ შორის, ძირითადი მინერალური სასუქების ნახევარი აგროტექნიკური დოზის გამოყენების ფონზე, რომელიც ეკონომიურად მომგებიანია, იძლევა საშუალებას მანდარინის აგროტექნიკაში შემცირდეს მინერალური სასუქების დოზა, რაც დადებითად მოქმედებს მანდარინის მოსავლიანობაზე, ხარისხზე, ბუნებრივ შენახვისუნარიანობასა და, რაც მთავარია, მიიღება ეკოლოგიურად სუფთა პროდუქტები. მოსავალი არის მყარი, ნაყოფი მაღალი ხარისხის და გამოსადეგი ექსპორტისთვის.

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