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Effects of microfertilizer application methods on potato productivity and nutritional quality in the Gegharkunik Region

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ABSTRACT

Background: Optimizing mineral nutrition, particularly micronutrients, is essential for sustainable potato production and improving tuber nutritional quality. Micronutrients support key physiological processes, enhance stress resistance, and contribute to the accumulation of bioactive compounds. Identifying effective application methods alongside organic fertilization is critical for increasing yield, ensuring food safety, and promoting environmental sustainability—especially in ecologically sensitive regions like Armenia's Lake Sevan Basin.

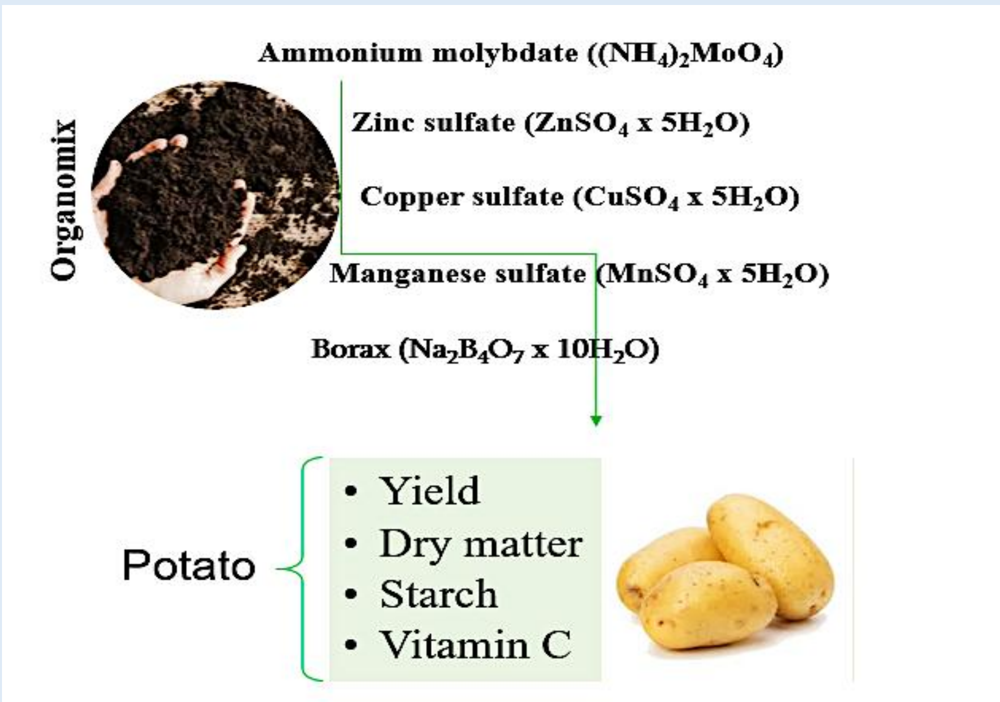
Objective: This study aimed to improve potato yield and nutritional quality through the integrated application of Organomix organic fertilizer and targeted micronutrient supplementation. The research aligns with Armenia's national strategies and global initiatives to promote sustainable, climate-resilient agriculture and improved public health.

Materials and Methods: Field trials (2022–2024) were conducted in Vardenik, Gegharkunik region, using the Marfona potato variety. Five micronutrients—borax, copper sulfate, zinc sulfate, manganese sulfate, and ammonium molybdate—were applied in combination with Organomix (8 t/ha) using two methods: pre-sowing tuber soaking and foliar spraying at flowering. Soil and tuber parameters such as dry matter, vitamin C, and nitrate content were measured. Data were analyzed using one-way ANOVA and Least Significant Difference (LSD) test ($p \le 0.05$).

Results: Micronutrient treatments significantly improved tuber yield and overall quality compared to Organomix alone, with ammonium molybdate, zinc sulfate, and copper sulfate showing the most notable effects. Increases in key nutritional parameters were positively correlated with yield gains. Although nitrate levels rose slightly, they remained within safe and acceptable limits.

Conclusion: Supplementing Organomix with targeted micronutrients—especially through pre-sowing tuber soaking—effectively enhances potato yield and nutritional quality in the Lake Sevan Basin. This integrated fertilization strategy supports sustainable soil management, reduces dependency on synthetic fertilizers, and advances environmentally responsible agriculture. By improving the nutritional profile of potatoes, it also contributes to consumer health, food security, and regional economic sustainability.

Keywords: Organomix, potatoes, microfertilizers, yield quantity, nutritional value, bioactive compounds, sustainable agriculture



INTRODUCTION

A scientifically grounded approach to crop mineral nutrition is fundamental not only for sustainable agricultural productivity but also for enhancing the functional food value of crops. With growing global demand for health-promoting foods, interest in biofortification and micronutrient-enriched cultivation strategies has intensified, as these methods improve both yield and nutritional quality. In this context, micronutrients—often referred to as bioactive elements—play a central role.

Alongside essential macronutrients such as nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), and magnesium (Mg), micronutrients like boron (B), manganese (Mn), copper (Cu), zinc (Zn), molybdenum (Mo), and cobalt (Co) are indispensable. These elements participate in photosynthesis, enzyme activation, hormone regulation, and antioxidant biosynthesis, thereby enhancing plant resilience and promoting the accumulation of health-relevant compounds in edible tissues [1–3].

Some microelements, notably B, Zn, and Co, have been shown to influence protein synthesis, antioxidant enzyme activity, and amino acid metabolism. Moreover, in ecologically sensitive regions such as those near mining or industrial sites, micronutrient imbalances in soils can affect both crop productivity and quality. Recent ecological assessments in the Armenian Highlands and the technogenic zones of the Caucasus have highlighted such imbalances, reinforcing the need for targeted micronutrient management [4–5].

Micronutrients serve a dual purpose: they are essential for physiological development and enhance the nutritional profile of crops. For instance, Zn boosts antioxidant activity and stimulates vitamin C synthesis; B contributes to amino acid transport and secondary metabolite production; Co supports nitrogen fixation and protein synthesis in legumes [6–9]. Furthermore, supplementation with micronutrients improves plant defense against abiotic stress. Zn and B have been shown to increase the activities of antioxidant enzymes such as superoxide dismutase (SOD) and catalase (CAT), reduce oxidative stress under drought and heat, and improve membrane stability under cold conditions [10–15]. The growing recognition of the connection between plant nutrition and human health has redefined agriculture's role in the development of functional foods—crops that not only provide nutrition but also reduce the risk of disease. Several studies emphasize shifting agricultural goals to include improvements in the functional properties of plant-based foods [16–18]. This approach supports the integration of agronomic biofortification as a strategy to enhance antioxidant capacity, vitamin and mineral levels, and overall crop healthfulness [15].

Potato (Solanum tuberosum L.) is globally important not only for its caloric contribution but also for its content of bioactive compounds such as vitamin C, phenolics, and resistant starch—nutrients vital to human health. Increasingly recognized as a functional food, the nutritional quality of potato tubers is closely tied to appropriate mineral nutrition, particularly during the tuber initiation and bulking phases. Balanced fertilization—whether mineral, organic, or integrated—is critical to ensuring adequate micronutrient availability [19]. In Armenia, integrated fertilization practices have shown promise. For example, in the Lori region, Martirosyan et al. [20] demonstrated that combining ammonium nitrate with biohumus or Organomix (an organic fertilizer) increased yield and reduced residual nitrogen. Between 2020 and 2022, similar results were observed in brown soils, where mineral fertilizers supplemented with biohumus enhanced tuber quality [21]. Aleksanyan et al. [22] also reported improved economic outcomes from organo-mineral fertilization in foothill regions. Globally, combining NPK with farmyard manure or vermicompost has been shown to improve tuber nutritional content while reducing nitrate accumulation [23–25].

Despite these advances, the Lake Sevan Basin—a key highland potato-growing region in Armenia—has seen limited research on fertilization strategies that simultaneously enhance yield, improve nutritional value, and support environmental sustainability. To the best of our knowledge, no previous research has examined the combined use of Organomix and micronutrients (Mo, Zn, Cu) applied through both tuber soaking and foliar spraying in potato cultivation under the agroecological conditions of the Lake Sevan Basin. Existing studies in the region have focused primarily on heavy metal accumulation in aquatic ecosystems or microfertilizer effects on cereal crops, leaving a gap in integrated fertilization strategies for potatoes.

Given the strategic and nutritional significance of potato production in this region, the present study aims to enhance tuber yield and quality, with a focus on increasing dry matter, starch, and vitamin C content as key bioactive indicators. At the same time, it seeks to minimize nitrate accumulation and promote sustainable soil management through the combined use of Organomix and micronutrient supplementation. This research aligns with Armenia's 2020–2030 Agricultural Strategy, which emphasizes sustainable intensification, and contributes to the FAO-led RECSOIL (Recarbonization of Global Soils) initiative launched in 2024 to support soil health, nutrient use efficiency, and climate-smart agriculture [26, 27].

By evaluating the synergistic effects of organic and micronutrient fertilization, this study contributes to the development of functional food crops, the enhancement of bioactive compound profiles, and the advancement of sustainable agroecological practices in Armenia's potato sector.

This study aims to evaluate the effectiveness of micronutrient application methods in combination with the organic fertilizer Organomix, with the goals of enhancing potato yield, improving tuber nutritional value, and reducing nitrate accumulation under Lake Sevan Basin conditions.

METHODS

Experimental Design and Fertilizer Application: Field experiments were conducted from 2022 to 2024 in the Vardenik administrative area of the Martuni community, located in the Gegharkunik region under the agroecological conditions of the Lake Sevan Basin. The objective was to assess the impact of various micronutrient treatments combined with the organic fertilizer Organomix, applied at a rate of 8 t/ha during planting. The following micronutrient fertilizers were used:

- Borax ($Na_2B_4O_7·10H_2O$), containing 11% B
- Copper sulfate ($CuSO_4·5H_2O$), 26.4% Cu
- Zinc sulfate ($ZnSO_4·5H_2O$), 22.7% Zn
- Manganese sulfate ($MnSO_4·5H_2O$), 22.8% Mn
- Ammonium molybdate ($(NH_4)_2MoO_4$), 50.0% Mo

Two application methods were evaluated:

- Pre-sowing soaking – potato tubers were soaked in aqueous micronutrient solutions two days prior to planting.
- Foliar spraying – plants were sprayed with the same solutions at the flowering stage.

The experiment followed a randomized complete block design with three replicates per treatment. Each plot measured 50 m². The Dutch cultivar Marfona was selected for its high yield potential, light yellow flesh, moderate resistance to common scab and late blight, and sensitivity to potato virus Y (PVY). This early to mid-early variety typically contains 18–20% dry matter and is suitable for boiling and baking.

Planting density was maintained at 36 centners per hectare (c/ha), and standard cultivation practices recommended for the region were followed.

Soil Sampling and Analysis: Composite soil samples were collected from surface and subsoil layers of each plot prior to planting. The following parameters were analyzed:

- Soil pH – measured potentiometrically [28]
- Organic carbon – determined by the Walkley–Black wet oxidation method [29]
- Total nitrogen – assessed by dry combustion using a CN analyzer (Vario Macro Cube) according to AOAC Official Method 990.03 [30]

- Total phosphorus and exchangeable potassium – determined by colorimetry and flame photometry, respectively [31]
- Easily hydrolyzable nitrogen and mobile phosphorus – analyzed using the Tyurin–Kononova and Arienus methods [31].

Determination of Soil Micronutrients: Both total and mobile forms of micronutrients were assessed using standardized procedures:

- Total Zn, Cu, B, Mo, and Mn – determined by spectrographic analysis [32]
- Mobile forms:
  - B – extracted with water and measured by the carmine color reaction [33]
  - Cu – extracted with 0.1 N HNO_3 and analyzed by the Scharrer and Schaumleffel method [34]
  - Zn and Mo – extracted with 1.0 N HNO_3 following the Rinkis protocol [35]
  - Mn – extracted using 1.0 M ammonium acetate with 0.4% sodium sulfate, according to the Peiwei method [36]

Tuber Quality Assessment: Tuber quality was evaluated based on key nutritional and technological indicators, including dry matter, starch, and vitamin C (ascorbic acid) content.

- Dry matter content – determined by the thermogravimetric method, drying samples at 105 °C to constant weight in accordance with ISO 1026:1982 [37]
- Vitamin C content – quantified by UV spectrophotometry using ascorbic acid titration with a dye, as described by Negi (2022) [38]
- Starch content – measured by an enzymatic colorimetric method based on hydrolysis to glucose, followed by quantification (AOAC Official Method 996.11) [39]
- Nitrate content – assessed using a Soeks nitrate meter for rapid field-level determination

Statistical Analysis: Experimental data from 2022 to 2024 were analyzed using one-way analysis of variance (ANOVA) to evaluate the effects of individual micronutrient treatments within each application method—pre-sowing soaking and foliar spraying. Each treatment, including the Organomix-only baseline and the unfertilized control, was conducted in triplicate. Differences among treatment means were considered statistically significant at $p \leq 0.05$. Mean values are presented in the corresponding tables. Yield gains were calculated relative to the Organomix baseline (8 t/ha) to assess the efficacy of micronutrient supplementation, while the unfertilized control served as a reference to evaluate the absolute impact of fertilization.

RESULTS AND DISCUSSION

To address the knowledge gap in integrated micronutrient and organic fertilization for potato cultivation in the Lake Sevan Basin, we conducted a three-year (2022–2024) field trial evaluating both pre-sowing tuber soaking and foliar spraying techniques. The results demonstrate the important role of micronutrient supplementation—applied via pre-sowing soaking and foliar spraying—in enhancing potato growth, development, and yield when combined with Organomix organic fertilizer. Data represent averages from three growing seasons, each with three replicates per treatment arranged in a randomized complete block design. Statistical analysis was performed using one-way ANOVA, with differences among treatment means considered significant at $p \leq 0.05$ based on the Least Significant Difference (LSD) test ($S_x\%$ = 1.3%, $LSD_0.95$ = 3.13 c/ha).

Vegetative Growth Response: Pre-sowing micronutrient treatments did not affect tuber germination rates, which remained uniformly high across all treatments. However, post-emergence evaluations revealed pronounced differences in plant vigor and vegetative development. Biometric assessments demonstrated that treatments with Mo, Cu, Zn, and Mn significantly enhanced vegetative growth compared to the unfertilized control and Organomix-only treatment. Plants showed darker foliage, greater leaf turgor, and improved shoot architecture. Average plant height across treatments reached 38 cm, with Cu, Zn, and Mn increasing height by 2.5–3.0 cm, and Mo showing the most pronounced effect (5.1–6.4 cm increase). No significant differences in flowering time or intensity were observed.

A representative view of the field during the flowering stage is development of Marfona potato plants across treatments.

Figure 1. Field view of Solanum tuberosum L. cv. Marfona during the flowering stage under the most effective micronutrient treatment combined with Organomix (8 t/ha).

Yield Performance — Pre-Sowing Soaking: All micronutrient treatments—except B—resulted in significant yield improvements compared to Organomix alone. Table 1 summarizes average potato yields (in c/ha), yield gains, and percentage increases following pre-sowing soaking with different micronutrient solutions. Among these, Mo treatment led to the highest yield gain (44.5 c/ha; 11.93%), followed by Zn and Cu. The 11.93% yield increase under Mo treatment represents a substantial improvement in production potential under local conditions. These results highlight the agronomic advantage of early-stage nutrient delivery via tuber soaking, offering a practical recommendation for farmers aiming to maximize micronutrient uptake and yield in the region. In contrast, B application resulted in only marginal yield improvement. Tables 1 and 2 summarize the effects of pre-sowing soaking and foliar spraying, respectively, on average potato yields across the three years.

Table 1. Effect of Pre-Sowing Soaking of Tubers with Micronutrient Solutions on Potato Yield (2022–2024) (Values in c/ha)

Micronutrient Treatment	Average Yield (c/ha)	Yield Gain Compared to Organomix (c/ha)	Yield Increase (%)
Organomix (8 t/ha)	373.0	–	–
+ 0.1% Mn	378.4	5.4	1.45
+ 0.2% Cu	386.5	13.5	3.62
+ 0.3% Zn	389.5	16.5	4.42
+ 0.1% Mo	417.5	44.5	11.93
+ 0.6% B	374.4	1.4	0.38
Control (no fertilization)	195.9	–	–

Foliar application of micronutrients produced similar patterns. Across all three years, foliar treatments combined with Organomix resulted in significant yield increases over the Organomix-only treatment. The detailed results of foliar spraying treatments on yield performance across the study period are summarized in Table 2, highlighting the comparative effects of each micronutrient application. Stronger yield responses in 2024 may be attributed to favorable climatic conditions or cumulative improvements in soil micronutrient availability due to repeated supplementation.

Table 2. Effect of Foliar Spraying with Micronutrient Solutions on Potato Yield (2022–2024)

Foliar Treatment	Average Yield (c/ha)	Yield Gain Compared to Organomix (c/ha)	Yield Increase (%)
Organomix (8 t/ha)	366.5	–	–
+ 0.1% Mn	371.5	5.0	1.36
+ 0.2% Cu	377.5	11.0	3.00
+ 0.3% Zn	379.0	12.5	3.41
+ 0.1% Mo	385.5	19.0	5.19
+ 0.6% B	367.9	1.4	0.38
Control (no fertilization)	190.0	–	–

Mo application resulted in the greatest yield increase (19.0 c/ha; 5.19%), followed by Zn and Cu. The limited mobility of Mo and Zn in topsoil horizons likely contributed to the pronounced yield responses observed upon their supplementation. In contrast, B treatment led to a minimal yield response. These outcomes were statistically significant (Sx% = 0.8; $LSD_{0.95}$ = 3.0 c/ha), confirming the reliability of the treatment effects.

Year-to-Year Dynamics and Nutrient Responsiveness: The strongest yield responses were recorded in 2024, likely influenced by favorable climatic conditions or cumulative improvement in soil micronutrient availability. Although not shown here, supporting laboratory analyses indicated initial deficiencies in Mo and Zn, which corresponds with the strong plant responses observed. The roles of these micronutrients in photosynthesis, nitrogen metabolism, and enzymatic activity likely explain their agronomic effectiveness under local conditions.

Comparative Evaluation of Application Methods: Both pre-sowing soaking and foliar spraying proved effective, functioning at different physiological stages. Pre-sowing soaking ensures early nutrient availability, promoting vigorous seedling establishment and root development. In contrast, foliar applications provide targeted nutrient supplementation during critical vegetative and reproductive phases; however, their efficiency may be partially influenced by environmental factors such as volatilization or leaching. Taken together, the combined application of Organomix and micronutrients—particularly Mo, Zn, and Cu—demonstrated a synergistic effect, resulting in consistently higher yields over the three growing seasons. These results highlight the benefits of combined micronutrient and organic fertilization strategies tailored to local soil and climatic conditions.

To further assess the relative efficiency of these application methods, a comparative analysis of average potato yields under pre-sowing and foliar treatments was conducted for the 2022–2024 period (Figure 2)

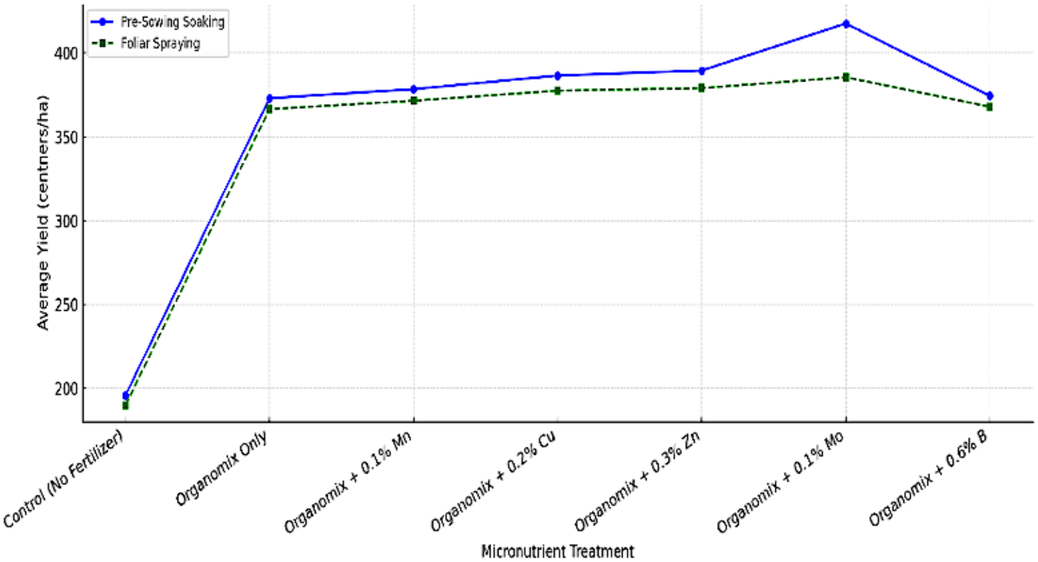


Figure 2. Average Potato Yield (2022–2024): Pre-Sowing vs. Foliar Micronutrient Applications.

Figure 2 illustrates that pre-sowing tuber soaking consistently outperformed foliar spraying across all micronutrient treatments. While both application methods produced significant yield improvements over the unfertilized control and the Organomix-only baseline, pre-sowing soaking yielded superior results for each micronutrient tested, affirming its agronomic efficacy.

Key yield comparisons (pre-sowing vs. foliar application):

- Mo: 417.5 vs. 385.5 → +32.0 c/ha
- Zn: 389.5 vs. 379.0 → +10.5 c/ha
- Cu: 386.5 vs. 377.5 → +9.0 c/ha
- Mn: 378.4 vs. 371.5 → +6.9 c/ha
- B: 374.4 vs. 367.9 → +6.5 c/ha

These consistent yield improvements suggest that pre-sowing micronutrient application enhances early physiological processes, such as root initiation, nutrient mobilization, and seedling vigor, which are critical for achieving higher productivity. In contrast, foliar spraying, though beneficial for mid-season correction and rapid nutrient uptake, may be less reliable due to potential nutrient losses from leaching, volatilization,–or limited foliar absorption under suboptimal environmental conditions. Overall, the findings confirm that pre-sowing tuber soaking is a more effective strategy for delivering essential micronutrients—Mo, Zn, Cu,- Mn, and B—under the agroecological conditions of the Lake Sevan Basin.

Tables 3 and 4 provide the chemical characteristics of the lime-free black soils in Vardenik, highlighting nutrient stratification by depth and offering guidance for site-specific nutrient management.

Table 3. Macroelements in Mountainous Lime-Free Black Soil. The A horizon (0–25 cm) exhibits the highest fertility, with substantial humus content and mobile nutrients. A marked decline in fertility is observed below 43 cm.

Layer	Depth (cm)	Humus (%)	pH	Mobile N (mg/100g)	Total P_2O_5 (%)	Mobile P_2O_5 (mg/100g)	Total K_2O (%)	Mobile K_2O (mg/100g)
A	0–25	4.9	7.1	5.2	0.41	11.4	2.4	33.4
B1	25–43	3.0	7.2	3.0	0.36	10.2	2.0	29.8
B2	43–70	1.3	7.3	trace	0.40	6.0	1.5	29.0
C	70–90	0.1	7.5	trace	0.20	3.4	0.9	27.0

Table 4. Micronutrients in Mountainous Lime-Free Black Soil.

Layer	Depth (cm)	Element	Total (mg/100g)	Mobile (mg/100g)	% Mobile
A	0–25	Mn	740	105	14.2
		Cu	16.2	4.6	28.4
		Zn	15.4	2.0	13.0
		Mo	1.1	0.2	–
		B	16.2	9.6	59.3
B1	25–43	Mn	690	78	11.3
		Cu	14.0	3.3	23.6
		Zn	12.0	1.0	8.3
		Mo	1.1	trace	–
		B	15.7	8.9	56.7
C	70–90	Mo	1.0	trace	–

Notable observations:

- Mo and Zn show low mobility, confirming field responsiveness to their supplementation.
- Cu retains moderate mobility in surface soil but becomes nearly unavailable below.
- Mn is abundant, though its mobile fraction is limited.
- B remains highly mobile at all depths, useful but prone to leaching.

These findings align with field results: yield responses were strongest for Mo and Zn, which are poorly available despite their presence in total form. Boron's high mobility enhances its availability but requires careful management to avoid leaching losses and potential toxicity. The soils in the Vardenik region require shallow cultivation and precise fertilization strategies to maintain the integrity of the nutrient-rich topsoil layer.

Based on these results, the following recommendations are proposed:

- Mo and Zn supplementation is essential due to their limited soil mobility, which can restrict plant uptake if not properly managed.
- Cu application is advisable to enhance plant resistance to pathogens, particularly Phytophthora infestans, the causal agent of late blight. Recent studies demonstrated that zinc and copper nanoparticles effectively suppress this disease in potatoes [40].
- B levels must be carefully monitored, as B is prone to leaching under these agroecological conditions, especially in light soils and high-rainfall environments.

Proper timing and method of micronutrient application—especially pre-sowing soaking of tubers—can substantially improve tuber yield, nutrient efficiency, and long-term soil fertility in mountainous ecosystems such as the Sevan Basin. The effectiveness of foliar and soil-based zinc applications was also validated in high-altitude potato production systems [41]. Key indicators of potato tuber quality include dry matter content, starch, vitamin C, and nitrate levels. During the 2022–2024 period, both pre-sowing soaking and foliar spraying with micronutrient solutions—applied on an Organomix (8 t/ha) background—led to measurable improvements in these quality parameters, in parallel with the observed yield increases (Table 5, Figure 3).

Table 5. Average effect of pre-sowing soaking and foliar spraying of micronutrient solutions on potato tuber quality (2022–2024) Values are means of three replicates; differences exceeding LSD are significant at $p \leq 0.05$

Variant	Dry Matter (%)	Starch (%)	Vitamin C (mg/100g)	Nitrate (mg/100g)
Pre-sowing soaking				
Control	16.2	12.6	9.6	82
Organomix	22.5	15.4	13.6	120
Background + Mn 0.1%	22.6	15.4	13.6	123
Background + Cu 0.2%	22.8	15.7	13.8	121
Background + Zn 0.3%	22.9	15.7	13.9	120
Background + Mo 0.1%	24.1	16.3	14.8	130
Background + B 0.6%	22.1	14.9	13.5	120
Foliar spraying				
Control	16.0	12.5	9.8	88
Organomix	20.7	13.9	11.8	132
Background + Mn 0.1%	21.1	13.5	11.8	130
Background + Cu 0.2%	21.3	13.8	11.5	139
Background + Zn 0.3%	21.4	13.7	12.1	140
Background + Mo 0.1%	22.9	14.8	14.6	150
Background + B 0.6%	21.1	13.7	13.2	100
Sx%	1.2	0.8	0.6	4.0
$LSD_{0.95}$	0.9	0.6	0.5	5.8

Mo (0.1%) produced the most significant improvements across all indicators:

- Dry matter: 24.1% (pre-sowing), 22.9% (foliar)
- Starch: 16.3% and 14.8%
- Vitamin C: 14.8 mg/100g and 14.6 mg/100g
- Nitrates: 130 and 150 mg/100g, respectively

These results confirm the essential role of Mo in improving nitrogen uptake, carbohydrate accumulation, and vitamin C content in potato tubers. Elevated nitrate levels under Mo treatment support its involvement in nitrogen metabolism through nitrate reductase activation and enhanced nitrogen use efficiency [42]. Mo also contributes to carbohydrate biosynthesis by promoting galactose and pectin accumulation [2] and supports ascorbic acid production via redox pathway regulation and aldehyde oxidase activity [43]. Zhao et al. (2025) further corroborated these findings.

Zn and Cu had positive but lesser effects on starch and vitamin C levels, while Mn showed moderate and B minimal effects, suggesting B was not a limiting factor. Overall, targeted fertilization—especially pre-sowing soaking with Mo—proved most effective for improving both yield and tuber quality.

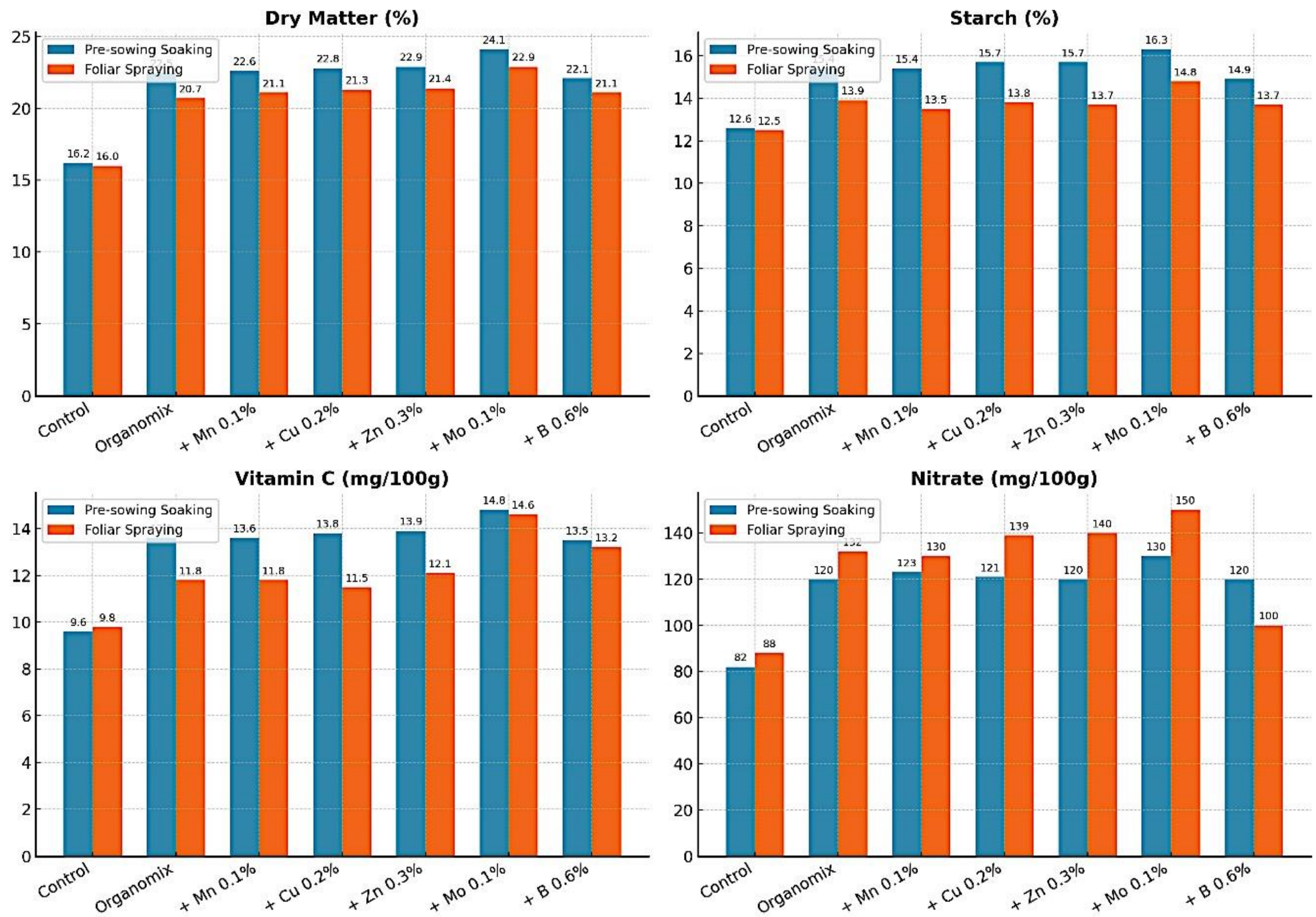


Figure 3. Effect of Pre-Sowing and Foliar Micronutrient Applications on Potato Tuber Quality Indicators (2022–2024**).** Pre-sowing soaking consistently outperformed foliar spraying across all quality parameters, particularly under Mo application.

Functional Food Implications: The observed improvements in key tuber quality indicators—namely higher dry matter, starch, and vitamin C content—underscore the potential of micronutrient-enriched fertilization to enhance both the nutritional value and functional food properties of potatoes [42, 44]. Notably, the increase in vitamin C, a vital antioxidant, elevates the health-promoting potential of the crop for consumers. Additionally, combining organic fertilizers with targeted micronutrients promotes soil health and sustainability while reducing dependence on synthetic mineral inputs, contributing to more environmentally sound production systems [43–49].

This study is the first to evaluate the combined application of Organomix with micronutrients (Mo, Zn, Cu) using both pre-sowing tuber soaking and foliar spraying methods within the specific agroecological context of the Lake Sevan Basin. This integrated fertilization strategy offers a novel approach to biofortification and yield improvement tailored to region-specific conditions, where the mobility of key micronutrients—particularly Mo and Zn—is limited. Our findings contribute new insights by demonstrating that early-stage micronutrient delivery via tuber soaking provides distinct agronomic advantages over conventional foliar application.

These results underscore the novelty of integrating tuber soaking with targeted micronutrient strategies to enhance both yield and quality, offering a scalable solution for sustainable potato cultivation in high-altitude zones.

Further Recommendations: Future research should focus on refining pre-sowing micronutrient treatments to enhance the accumulation of bioactive compounds—

particularly vitamin C—in potato tubers. Special emphasis should be placed on their role in improving functional food attributes and advancing public health. Expanding trials across genotypes and agroecological conditions would support the development of nutritionally enriched, climate-resilient potato varieties suitable for sustainable farming systems.

CONCLUSION

This study demonstrates the efficacy of integrating micronutrient supplementation with Organomix organic fertilizer in enhancing potato production in the Gegharkunik region. The local soil profile—moderately fertile with spatially variable manganese levels—significantly influenced yield outcomes and tuber nutritional composition. Supplementation with molybdenum, zinc sulfate, and copper sulfate in combination with Organomix resulted in measurable increases in yield, starch content, and vitamin C concentration, thereby enhancing the functional value of harvested potatoes. These results align with findings from Northwest China, where optimized fertilization and irrigation strategies improved tuber quality and productivity [48-49]. Other studies have also established a positive correlation between enhanced macronutrient uptake (N, P, K) and improved potato yield and quality characteristics [50-51]. Pre-sowing tuber soaking was found to be more effective than foliar application, aligning with previous reports that root-based nutrient uptake ensures greater efficiency and responsiveness in potatoes [50–53]. Although a slight increase in nitrate content was observed, all values remained within safe regulatory limits. Compared to conventional fertilization, the combined application of Organomix and key micronutrients substantially improved both tuber yield and nutritional parameters. These outcomes are validated by regional studies—for example, Martirosyan et al. reported that combining Organomix with mineral nitrogen elevated starch and dry matter content while lowering nitrate accumulation in Armenian-grown potatoes [20]. Likewise, Kurt et al. found that supplementing synthetic fertilizers with organic amendments such as vermicompost or leonardite improved potato quality in high-altitude agroecosystems [54].

This integrated fertilization approach offers a strategic model for sustainable potato production in the Sevan Basin, aligning with Armenia's national agricultural and environmental objectives. With potential yields reaching 400–420 c/ha, the model enhances both economic viability and public health outcomes while reinforcing food security across the region.

Abbreviations: ANAU – Armenian National Agrarian University; ANOVA – Analysis of Variance; B – Boron; c/ha – Centners per hectare; Cu – Copper; LSD – Least Significant Difference; mg/100 g – Milligrams per 100 grams; Mn – Manganese; Mo – Molybdenum; N – Nitrogen; P – Phosphorus; Zn – Zinc.

Competing interests: The authors declare that are no conflicts competing interests.

Authors' contributions: MG - conceptualization, methodology, validation, resources, data curation, writing-original draft preparation, writing-review and editing; AM - methodology, data curation, writing-review and editing, GM - methodology, data curation, writing-review and editing, HM - methodology, data curation, writing-review and editing, TA - methodology, data curation, resources, writing-original draft preparation, writing-review and editing; MM - resources, writing-review and editing, IH - resources, writing-review and editing; AS - resources, data curation, writing-review and editing; AV - conceptualization, methodology, validation, resources, data curation, writing-original draft preparation, writing-review and editing. All authors read and approved the final version of the manuscript.

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