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Sustainable fertilization strategies for climate-resilient vegetable production: Optimizing yield, nutritional quality, and mitigating nitrate risks in the Lake Sevan basin

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ABSTRACT

Background: Climate change challenges vegetable production by altering yield potential and nutrient dynamics, affecting food security and functional quality. Potatoes, table beet, and white cabbage are key dietary staples rich in bioactive compounds. Therefore, developing ecologically sustainable cultivation practices is essential for public health and food safety.

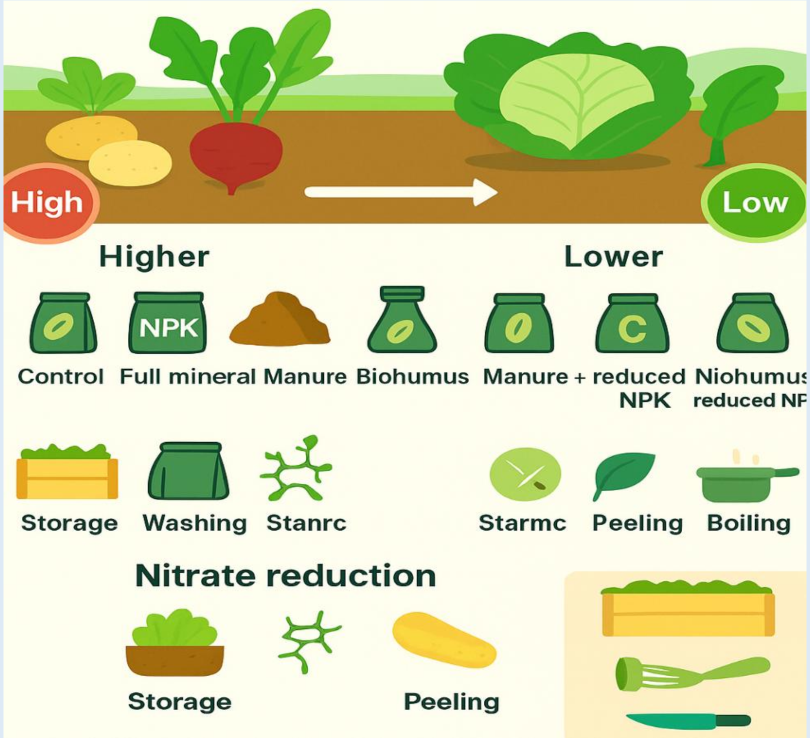
Objective: This study evaluated the effects of six fertilization systems on yield, nitrate accumulation, and post-harvest nitrate reduction in potatoes, table beet, and white cabbage cultivated in Armenia's Lake Sevan basin.

Materials and Methods: Field experiments were conducted from 2020 to 2022 in the Martuni district on floodplain soils using a randomized complete block design (n = 3). Treatments included: (1) Control (no fertilizer), (2) $N_{160}P_{160}K_{160}$, (3) Manure (35 t ha^{-1}), (4) Biohumus (8 t ha^{-1}), (5) Manure (25 t ha^{-1}) + $N_{50}P_{50}K_{50}$, and (6) Biohumus (6 t ha^{-1}) + $N_{35}P_{35}K_{40}$. Yields were expressed as centners per hectare (c ha^{-1}), and nitrate contents were compared with maximum permissible concentrations (MPC). Post-harvest treatments—including controlled storage (10 °C, 50% RH), washing, peeling, and boiling—were assessed for nitrate reduction. Statistical analyses were performed using ANOVA, and data were expressed as mean ± SD (n = 3). Significance was determined using the LSD test at $p < 0.05$.

Results: The highest yields were obtained under Biohumus (8 t ha^{-1}) and Biohumus + $N_{35}P_{35}K_{40}$**,** reaching 420–440 c ha^{-1} in potatoes, 230–240 c ha^{-1} in table beet, and 500–520 c ha^{-1} in cabbage, while nitrate levels remained within MPC limits. Excessive nitrogen from Manure (35 t ha^{-1}) or $N_{160}P_{160}K_{160}$ led to nitrate accumulation beyond safe thresholds. Controlled storage and processing reduced nitrate content by 30–60%, with the most pronounced decline observed after boiling. Biohumus-based fertilization also increased dry matter (DM), starch, Total sugar, and Vitamin C in all crops, enhancing both yield and functional quality.

Conclusion: Integrated fertilization with Biohumus—alone or with reduced mineral fertilizer—achieves high yields, safe nitrate levels, and improved nutritional quality of potatoes, table beet, and white cabbage. Combined with post-harvest treatments, this holistic approach ensures food safety, maximizes functional quality, and provides a sustainable protocol linking field practices to public health outcomes.

Keywords: integrated fertilization, biohumus, nitrate mitigation, functional quality, post-harvest reduction, food safety, potato, table beet, white cabbage



Graphical Abstract: Biohumus and reduced mineral fertilization improve yield and functional quality while lowering nitrate levels in vegetables grown in the Lake Sevan Basin.

INTRODUCTION

Climate change and shifting environmental conditions pose significant challenges to agricultural production, impacting both crop yield and food security [1]. Vegetable crops, such as potatoes, table beet, and white cabbage, are susceptible to soil fertility, nutrient management [2], and climatic variability. These factors affect not only productivity but also the accumulation of potentially harmful compounds such as nitrates, as well as beneficial bioactive and functional compounds [3].

According to Martirosyan and Ekblad [2], environmental stressors and fertilization regimes significantly influence the concentration of functional compounds in vegetables, reinforcing the need for integrated nutrient management strategies that support both yield and nutritional quality [3-4]. Therefore, optimized fertilization strategies are critical for achieving sustainable productivity while maintaining food safety.

Excessive accumulation of nitrate (NO_3^-) in vegetables is a recognized public health concern due to its potential to form carcinogenic nitroso compounds in the human body [5-6]. Field and greenhouse studies have demonstrated that organic fertilizers and bio-organic amendments can reduce nitrate accumulation compared to mineral fertilizers alone. For example, leafy vegetables cultivated with organic rather than synthetic fertilizers showed significantly lower nitrate levels and higher vitamin C content [7]. Similarly, reducing mineral nitrogen input while applying bio-organic fertilizers can enhance crop quality, nutrient use efficiency, and food safety [8].

Fertilization practices also affect broader quality traits, including DM, starch, vitamin C, and sugar content. Substituting part of the mineral fertilizer with organic amendments has been shown to improve several quality parameters while maintaining or even increasing yield in crops such as maize and soybean, suggesting similar benefits in vegetable systems [9–12]. Recent findings in Functional food science further support this, showing that fertilization regimes influence the synthesis and retention of functional compounds—such as antioxidants, flavonoids, and vitamin C—with implications for nutritional value and post-harvest stability [13].

Nevertheless, despite these insights, comprehensive field-based studies comparing mineral, organic (manure, biohumus), and combined fertilization strategies on root and leafy vegetables (potato, table beet, and cabbage) under floodplain soil conditions remain limited, particularly when considering post-harvest effects on quality and nitrate reduction [14].

Galstyan et al. [15] demonstrated that supplementing organo-mineral fertilizers with targeted micronutrients, particularly via pre-sowing tuber soaking, significantly enhanced potato yield and nutritional quality under Lake Sevan Basin conditions. Furthermore, Al-Nawaiseh and Mashal [16] reported that post-harvest treatments, such as washing, peeling, and cooking, significantly reduced nitrate levels in vegetables, highlighting their potential to improve food safety.

Therefore, the present study aimed to evaluate the effects of six fertilization systems (control, full mineral $N_{160}P_{160}K_{160}$, manure only, biohumus only, manure + reduced NPK, biohumus + reduced NPK) on yield, nitrate content, and quality parameters (DM, starch, Vitamin C, and Total sugar) of potatoes, table beet, and white cabbage grown on floodplain soils in the Martuni district of the Gegharkunik region from 2020 to 2022. Additionally, the study assessed the effectiveness of post-harvest treatments—storage, washing, peeling, and cooking—in reducing nitrate levels and improving food safety. The findings aim to inform sustainable fertilization practices that enhance both productivity and quality in vegetable production under local agroecological conditions.

MATERIALS AND METHODS

Experimental Site and Design: Field trials were conducted from 2020 to 2022 in the Martuni district of Armenia, located within the Lake Sevan basin. The experimental soil was classified as floodplain soil with moderate fertility [17].

The study followed a randomized complete block design (RCBD) with three replicates ($n = 3$) [18]. Each experimental plot measured 10 m^2, and six fertilization treatments were applied as follows:

1. Control (no fertilizer)
2. Mineral fertilizer – $N_{160}P_{160}K_{160}$ kg ha^{-1}
3. Manure – 35 t ha^{-1}
4. Biohumus – 8 t ha^{-1}
5. Manure + reduced mineral fertilizer – 25 t ha^{-1} + $N_{50}P_{50}K_{50}$ kg ha^{-1}
6. Biohumus + reduced mineral fertilizer – 6 t ha^{-1} + $N_{35}P_{35}K_{40}$ kg ha^{-1}

The tested crops included potato (*Solanum tuberosum* L.), table beet (*Beta vulgaris* L.), and white cabbage (*Brassica oleracea* var. *capitata* L.) [19].

Yield and Nitrate Analysis: Crop yield was recorded at full maturity by harvesting the entire plot, and results were expressed in centners per hectare (c ha^{-1}) [20]. Nitrate content was determined in fresh edible tissues using a spectrophotometric method based on the salicylic acid reaction, following the guidelines of the AOAC [21, 22]. Concentrations were expressed in mg kg^{-1} fresh weight. MPCs were set at 250 mg kg^{-1} for root vegetables and 400 mg kg^{-1} for cabbage [23].

To evaluate post-harvest nitrate reduction, samples were stored under controlled conditions (10 °C, 50% RH) for 2 and 5 months. After storage, all samples (potato, table beet, and cabbage) were washed and boiled, with peeling performed only for potatoes. Nitrate concentrations were then re-measured, and nitrate reduction (%) was calculated using the following formula [24]:

Nitrate reduction (%) = ((Nitrate_initial – Nitrate_after treatment) / Nitrate_initial) × 100

Quality Indicators: Edible portions of crops were analyzed for DM, starch, vitamin C, and total sugar content. Measurements were performed as follows:

DM (%) – Determined by oven-drying at 105 °C until constant weight [25]:DM (%) = (Weight of dried sample (g) ÷ Weight of fresh sample (g)) × 100

Starch (%) – Extracted and quantified using the anthrone method, with absorbance measured at 620 nm [26]. Calculations were based on a standard starch curve: Starch (%) = (Amount of starch (mg) ÷ Weight of dry sample (mg)) × 100

Vitamin C (mg 100 g^{-1} FW) – Determined using the 2,6-dichlorophenolindophenol titrimetric method [27]: Vitamin C (mg 100 g^{-1}) = (Volume of dye used (mL) × Concentration of dye (mg/mL) × 100) ÷ Weight of sample (g)

Total Sugars (%) – Measured by Fehling’s titration after extraction with 80% ethanol, following the Lane and Eynon method [28]. Results were expressed as a percentage of fresh sample weight.

Statistical Analysis: Data were subjected to one-way analysis of variance (ANOVA) to evaluate the effects of fertilization treatments. Mean comparisons were performed using the least significant difference (LSD) test at a significance level of $p < 0.05$. Standard deviations (SD) were calculated based on three replicates per treatment ($n = 3$). All statistical analyses were conducted using GraphPad Prism software (version 9).

RESULTS

Crop Yield and Fertilization Effects: Fertilization significantly influenced both yield and nitrate accumulation in potato, table beet, and white cabbage

(Table 1, Figure 1). Biohumus-based treatments—applied alone (8 t ha^{-1}) or combined with reduced mineral fertilizers (Biohumus + $N_{35}P_{35}K_{40}$ kg ha^{-1})—produced the highest yields: potatoes (420–440 c ha^{-1}), table beet (230–240 c ha^{-1}), and cabbage (500–520 c ha^{-1}). The control treatment consistently exhibited the lowest yields, highlighting the importance of nutrient supplementation for optimal productivity.

Excessive mineral fertilization ($N_{160}P_{160}K_{160}$ kg ha^{-1}) increased yields relative to the control but led to nitrate concentrations in potatoes and table beet exceeding the MPC, raising food safety concerns. Manure-only applications (35 t ha^{-1}) provided moderate yield improvements while maintaining nitrate levels below those observed under high mineral input.

These results demonstrate that integrating biohumus—either alone or in combination with reduced mineral fertilizers—can maximize crop productivity while minimizing nitrate accumulation, thereby improving both yield and food safety.

Table 1. Yield and nitrate content of vegetables under different fertilization systems (mean ± SD, n = 3). LSD values at $p < 0.05$ are included.

Fertilization	**Potato Yield (c ha^{-1})**	**Potato Nitrate (mg kg^{-1})**	**Table Beet Yield (c ha^{-1})**	**Table Beet Nitrate (mg kg^{-1})**	**Cabbage Yield (c ha^{-1})**	**Cabbage Nitrate (mg kg^{-1})**
Control	197.3 ± 3.2	95 ± 2.5	95.0 ± 2.0	90 ± 3.0	266.3 ± 4.0	205 ± 5.0
$N_{160}P_{160}K_{160}$	368.6 ± 4.5	360 ± 6.2	210.0 ± 3.5	280 ± 5.5	415.0 ± 6.0	416 ± 7.0
Manure (35 t ha^{-1})	330.2 ± 4.0	300 ± 5.5	200.0 ± 3.0	265 ± 4.5	405.0 ± 5.5	405 ± 6.5
Biohumus (8 t ha^{-1})	420.0 ± 4.2	190 ± 4.0	230.0 ± 4.0	200 ± 4.0	500.0 ± 5.0	220 ± 4.5
Manure (25 t ha^{-1}) + $N_{50}P_{50}K_{50}$	377.4 ± 4.3	200 ± 4.2	220.0 ± 3.8	210 ± 4.2	474.0 ± 5.2	240 ± 4.8
Biohumus (6 t ha^{-1}) + $N_{35}P_{35}K_{40}$	440.0 ± 4.5	185 ± 3.8	240.0 ± 4.5	190 ± 4.0	520.0 ± 5.5	210 ± 4.5
***LSD* (*p* < 0.05)**	12.5	15.0	10.8	14.2	16.5	18.0

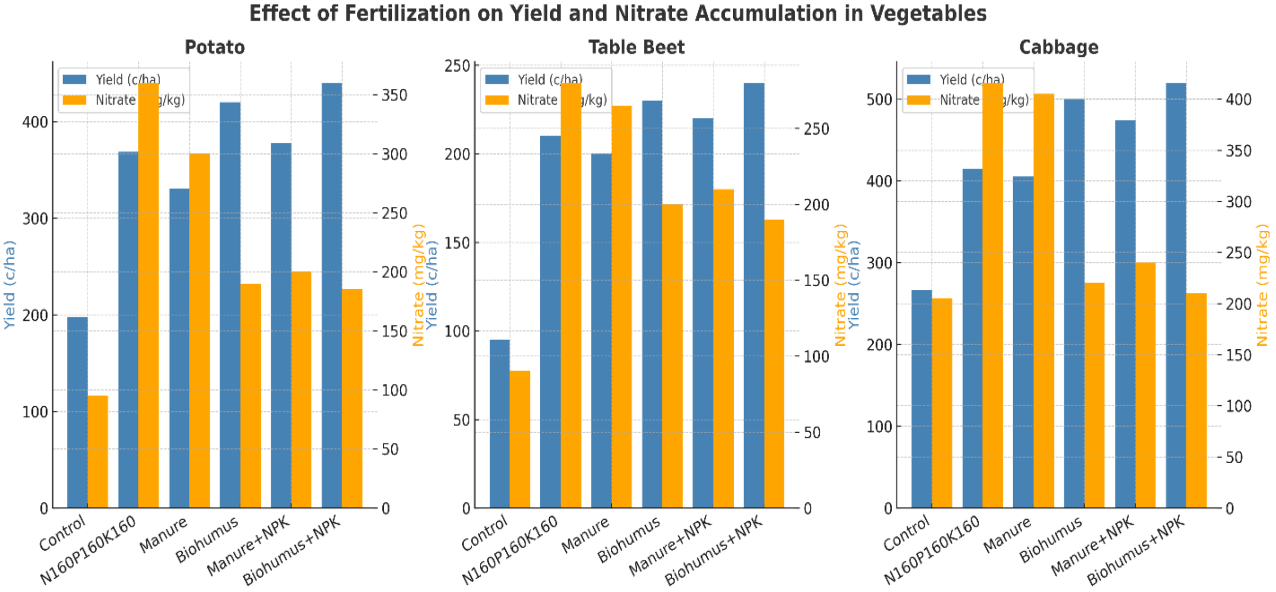


Figure 1. Effect of different fertilization treatments on yield and nitrate concentration in potato, table beet, and cabbage. Data represent mean ± SD (n = 3).

The combined evidence from Table 1 and Figure 1 underscores the dual role of fertilization in shaping yield and nitrate safety.

Post-Harvest Nitrate Reduction: Post-harvest handling significantly influenced nitrate concentrations in all studied vegetables (Table 2, Figure 2). Storage under controlled conditions (10 °C, 50% RH) for five months reduced nitrate content by approximately 46% in potatoes, 60.5% in table beetroot, and 21.0% in cabbage. Subsequent processing steps—including washing, peeling (where applicable), and boiling—resulted in an additional 30–70% reduction in nitrate levels, highlighting the effectiveness of integrated post-harvest management.

Note: Percentage reductions (in parentheses) indicate the decrease relative to the initial after-harvest nitrate concentration and are not cumulative.

Table 2. Nitrate content and reduction after post-harvest treatments (mg kg^{-1}; mean ± SD; n = 3)

Product	MPC (mg kg^{-1})	After Harvest	2-Month Storage	5-Month Storage	After Washing	After Peeling	After Boiling
Potato	250	185 ± 3.8	172 ± 3.0 (7%)	100 ± 3.0 (46%)	140 ± 2.5 (24%)	115 ± 2.0 (38%)	90 ± 3.0 (51%)
Table Beet	250	190 ± 4.0	180 ± 3.5 (5%)	75 ± 2.8 (61%)	150 ± 3.0 (21%)	–	110 ± 2.5 (42%)
Cabbage	400	210 ± 4.5	200 ± 3.8 (5%)	165 ± 3.2 (21%)	180 ± 3.0 (14%)	–	90 ± 3.0 (57%)

Peeling was not performed for the table beet and cabbage. Values represent mean ± standard deviation (SD) of three replicates (n = 3).

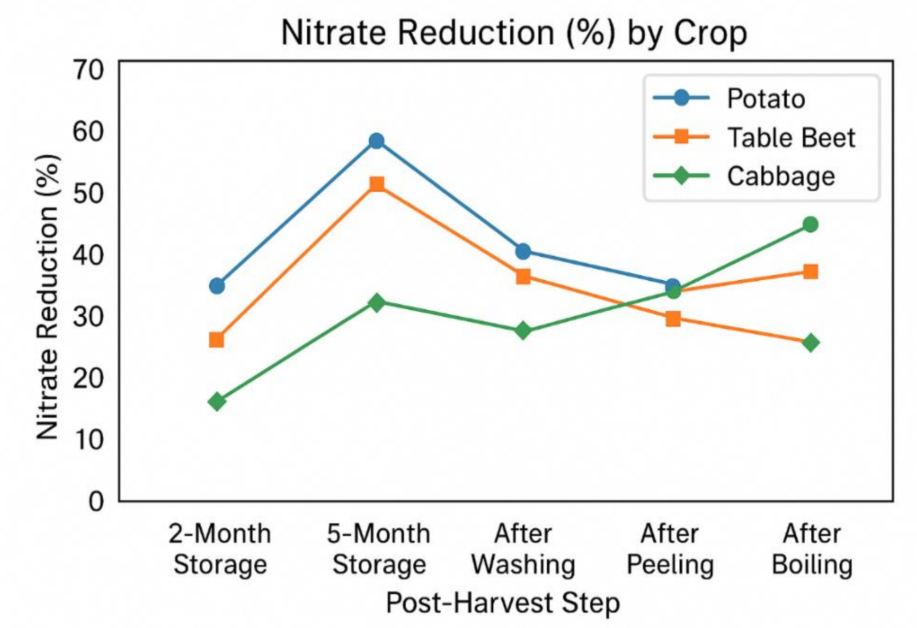


Figure 2. Changes in nitrate concentration of potato, table beet, and cabbage during storage and subsequent processing. Values represent mean ± SD (n = 3).

Figure 2 illustrates the progressive decline in nitrate concentration across storage and processing stages. Table beet exhibited the most pronounced reduction during storage, whereas cabbage showed a more moderate decrease. Additional sharp declines in nitrate levels occurred after washing, peeling, and boiling, confirming the efficacy of these post-harvest treatments in mitigating nitrate accumulation. Overall, these results emphasize that proper storage combined with post-harvest processing is essential to maintain nitrate concentrations within safe consumption limits, particularly in crops subjected to high nitrogen fertilization. Effective post-harvest management thus plays a critical role in ensuring both food safety and functional quality.

Crop Quality Indicators: Fertilization significantly affected the nutritional quality of potato, table beet, and cabbage, as reflected in DM, starch, vitamin C, and sugar content (Figure 3). All quality parameters improved with organic and combined fertilization compared to the control.

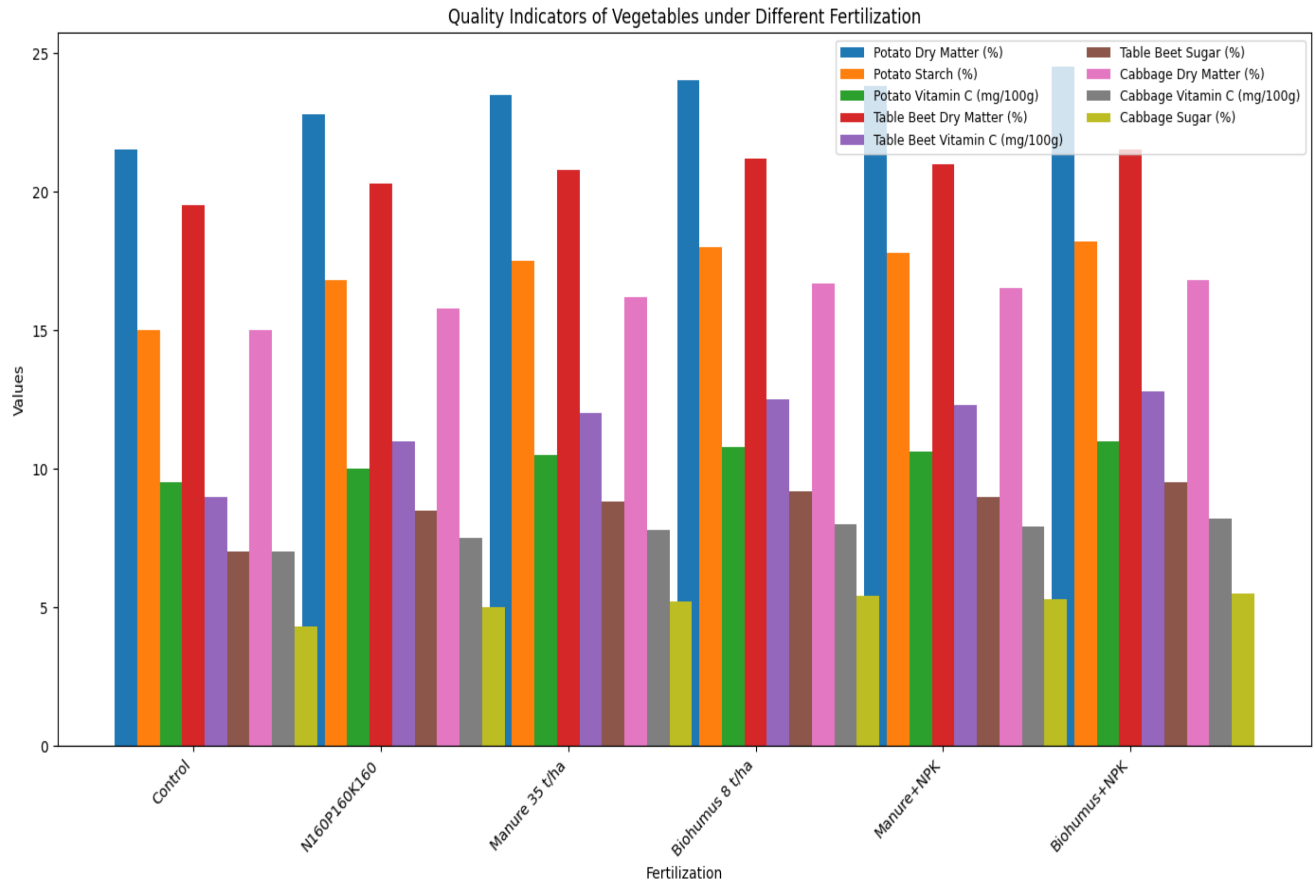


Figure 3. Nutritional quality indicators (DM, starch, Vitamin C, and Total sugar) of potato, table beet, and cabbage under selected fertilization treatments. Data represent mean ± SD (n = 3).

Potato responded positively to biohumus and biohumus + NPK fertilization, achieving maximum DM (24.5%), starch (18.2%), and vitamin C content (11.0 mg/100 g FW). Table beet exhibited similar trends, with the highest DM, vitamin C, and total sugar content under biohumus + $N_{35}P_{35}K_{40}$ kg ha^{-1}. Cabbage also showed enhanced DM (16.8%), vitamin C (8.2 mg/100 g FW), and total sugar (5.5%) under the combined biohumus + NPK treatment. Overall, biohumus-based fertilization, particularly when combined with reduced mineral NPK, consistently improved both yield and functional quality across all vegetables. These results highlight the effectiveness of integrated organic–mineral fertilization as a strategy for enhancing the nutritional properties of root and leafy vegetables under the studied conditions.

DISCUSSION

The present study demonstrated that fertilization type significantly influenced the yield, nitrate accumulation, and quality of potato, table beet, and cabbage grown in the Martuni district floodplain. Biohumus-based fertilization (8 t ha^{-1}), applied alone or in combination with reduced mineral fertilizers, consistently produced the highest yields across all tested crops. Potato, table beet, and cabbage achieved maximum yields of 440, 240, and 520 c ha^{-1}, respectively, highlighting the potential of biohumus to sustainably increase crop productivity. These findings are consistent with previous reports indicating that organic amendments improve soil fertility and nutrient availability, thereby promoting plant growth and yield performance [29-30].

In contrast, excessive mineral fertilization ($N_{160}P_{160}K_{160}$ kg ha^{-1}) increased yields compared to the control but also caused nitrate accumulation above the maximum permissible concentrations, particularly in root crops. This indicates a trade-off between maximizing yield and ensuring food safety [31]. Manure-only applications (35 t ha^{-1}) provided moderate yield improvements while maintaining comparatively lower nitrate levels, reflecting the slower nutrient release and reduced risk of nitrate over-accumulation characteristic of organic fertilizers. Therefore, balanced fertilization, combining organic and mineral sources, appears to optimize both productivity and food safety.

Post-harvest handling significantly reduced nitrate levels. Storage at 10 °C and ~50% relative humidity for five months reduced nitrate content significantly, with additional reductions observed after washing, peeling, and boiling. These results underscore integrated post-harvest management, especially for crops cultivated under high nitrogen inputs, to maintain nitrate concentrations within safe consumption limits [32-33].

Fertilization also strongly influenced crop quality parameters, including DM, starch, vitamin C, and total sugar content. As shown in Figure 3, biohumus-based treatments improved both yield and nutritional quality, with biohumus + $N_{35}P_{35}K_{40}$ kg ha^{-1} achieving the highest levels of all measured quality indicators. These results suggest that organic amendments not only enhance growth but also promote the accumulation of functional nutrients, potentially improving the health-promoting properties of vegetables [34–36]. The observed synergistic effect of combined biohumus and reduced mineral fertilizers indicates that partial mineral supplementation can complement organic inputs without compromising safety or quality [37].

Overall, the study confirms that sustainable fertilization strategies that integrate biohumus with moderate mineral inputs can maximize yield, maintain food safety, and improve the nutritional quality of vegetables. These findings have practical implications for the management of root and leafy crops under floodplain soil conditions in the Martuni district, emphasizing the importance of balanced fertilization and post-harvest handling to optimize both productivity and consumer safety.

Future Recommendations: Based on the findings of this study, sustainable vegetable production can be supported by optimizing fertilization strategies, identifying the most effective combination and timing of biohumus and mineral fertilizers to maximize yield, nutrient use efficiency, and accumulation of functional compounds. Long-term trials are recommended to assess the cumulative effects of different fertilization approaches on soil health, crop productivity, and environmental sustainability. Additionally, post-harvest management should be carefully evaluated, including storage, washing, and other processing methods, to ensure retention of bioactive compounds and production of safe, high-quality vegetables. The integration of precision agriculture and market studies is also encouraged, employing advanced technologies to optimize nutrient management and to assess consumer acceptance of organically enhanced crops. Together, these strategies provide a comprehensive approach for improving both productivity and functional quality in vegetable production systems.

Functional Food Implications: The findings of this study carry significant implications for the development of functional foods, which are conventionally defined as foods that provide health benefits beyond basic nutrition [38–39]. The vegetables examined—particularly those grown under biohumus-only or biohumus + $N_{35}P_{35}K_{40}$ kg·ha^{-1} fertilization—demonstrated notable improvements in key quality parameters, including increased DM, total sugar, and vitamin C content. Importantly, they also exhibited higher starch accumulation, a major determinant of potato quality. These enhancements indicate that the treated produce can serve as valuable functional food ingredients with superior nutritional and health-promoting properties [40–41].

The functional food potential of the tested vegetables—including potatoes—can be summarized in the following key areas:

Enhanced Nutritional Quality

***Vitamin C Content*:** Elevated vitamin C levels in tubers and vegetable heads reflect enhanced antioxidant capacity, contributing to reduced oxidative stress and better overall consumer health outcomes [42].

***Carbohydrate Quality (Starch Focus)*:** Increased starch content in potatoes, together with higher sugar levels in table beet and cabbage, indicates improved energy value and greater nutrient density, supporting their classification as nutrient-rich functional foods [43].

Food Safety Compliance

***Nitrate Reduction*:** The lower nitrate accumulation achieved through the combined biohumus–mineral fertilization system significantly enhances produce safety, meeting an essential requirement for functional food designation [44].

These outcomes are consistent with previous studies showing that organic or integrated fertilization can improve the bioactive compound profile of vegetables, for example, elevated phenolic levels in organically fertilized tomatoes [45] and enhanced nutritional quality in potatoes grown under combined biohumus/mineral fertilizer treatments [40]. Thus, targeted fertilization strategies can transform vegetables from basic calorie sources into functional foods that promote health and may help reduce the risk of diet-related diseases.

In accordance with the Functional Food Center's (FFC) 17-Step Functional Food Product Development Model [46], the present study aligns with several foundational phases of functional food research. The selection of potatoes, table beet, and cabbage as nutrient-dense vegetables, and the quantification of their key bioactive compounds—including vitamin C, sugars, DM, and starch—corresponds to Steps 1 and 2 (establishing a goal and determining relevant bioactive compounds). Evaluation of the effects of different fertilization systems on these compounds addresses Step 4 (establishing the appropriate time of consumption). The assessment of nitrate accumulation under various fertilization regimes and post-harvest nitrate-reduction methods fulfills Step 7 (choosing a suitable food vehicle), while the improvements in nutritional quality and reduced nitrate risks support Step 12 (educating the public). Collectively, these alignments indicate that the study contributes to the foundational stages of functional food development by enhancing both the nutritional value and safety profile of staple vegetables grown under Lake Sevan Basin conditions.

These findings are consistent with recent research emphasizing the importance of enhancing bioactive compounds and ensuring safety in plant-based functional foods [47-50].

CONCLUSION

The present study demonstrated that fertilization strategy significantly influenced the yield, nitrate accumulation, and nutritional quality of potatoes, table beet, and cabbage. Biohumus-based fertilization, applied alone or combined with reduced mineral fertilizers, consistently produced the highest yields and improved quality traits such as DM, starch, vitamin C, and total sugar content, whereas excessive mineral fertilization led to nitrate accumulation above safe limits. Importantly, the unique contribution of this research lies in its holistic and integrated approach. For the first time in the region, we link sustainable Biohumus-based fertilization systems to functional quality outcomes and practical post-harvest strategies for mitigating nitrate risk. This integrated system not only maximizes yield and nutritional quality but also provides a novel, fully verified solution for ensuring food safety—a critical insight for ecologically sensitive regions such as the Lake Sevan Basin.

Abbreviations: ANAU – Armenian National Agrarian University; ANOVA – Analysis of Variance; c ha^{-1} – Centners per hectare; DM – Dry Matter; LSD – Least Significant Difference; MPC – Maximum Permissible Concentration; mg kg^{-1} – Milligrams per kilogram; mg/100 g – Milligrams per 100 grams; NPK – Nitrogen–Phosphorus–Potassium; RH – Relative Humidity; Total Sugar – Total sugar content (%).

Competing interests: The authors declare no competing interests.

Authors' Contributions: MG: Conceptualization, methodology, validation, resources, data curation, writing—original draft preparation, writing—review and editing; GM: Methodology, data curation, writing—review and editing; AM: Methodology, data curation, writing—review and editing; GA: Methodology, data curation, writing—review and editing; TA: Methodology, data curation, resources, writing—original draft preparation, writing—review and editing; BVK: Resources, writing—review and editing; HM: Resources, writing—review and editing; MM: Resources, writing—review and editing; AMk: Resources, data curation, writing—review and editing; AH: Resources, writing—review and editing; AV: Conceptualization, methodology, validation, resources, data curation, writing—original draft preparation, writing—review and editing.

All authors have read and approved the final version of the manuscript.

REFERENCES

1. Dumitru EA, Berevoianu RL, Tudor VC, Teodorescu F-R, Stoica D, Giucă A, et al. Climate change impacts on vegetable crops: a systematic review. *Agriculture*. 2023; 13:1891. DOI: https://doi.org/10.3390/agriculture13101891
2. Martirosyan DM, Ekblad M. Functional foods classification system: exemplifying through analysis of bioactive compounds. *Functional Food Sci*. 2022;2(4):94–123. DOI: https://doi.org/10.31989/ffs.v2i4.919
3. Ierna A, Distefano M. Crop nutrition and soil fertility management in organic potato production systems. *Horticulturae*. 2024;10(8):886. DOI: https://doi.org/10.3390/horticulturae10080886
4. Nasiro K, Mohammednur T. Precision nutrient management amid climate change challenges: a review. *Science Frontiers*. 2024;5(3):110–122. DOI: https://doi.org/10.11648/j.sf.20240503.12
5. El Baroudi Y, Ouazzani C, Er Ramly A, Moustaghfir A, Essebbahi I, Dami A, et al. Nitrate contamination of different organic and non-organic vegetable varieties: a case study in Morocco. *Aust J Crop Sci*. 2023;17(6):531–538. DOI: https://doi.org/10.21475/ajcs.23.17.06.p3890
6. Dodocioiu AM, Buzatu G-D, Botu M. Nitrates and nitrites in vegetables and the health risk. *Foods*. 2025; 14:3037.

DOI: https://doi.org/10.3390/foods14173037

7. Nguyen NTT, Nguyen BX, Habibi N, Dabirimirhosseinloo M, Oliveira LdA, Terada N. et al., Effect of organic and synthetic fertilizers on nitrate, nitrite, and vitamin C levels in leafy vegetables and herbs. *Plants*. 2025; 14:917. DOI: https://doi.org/10.3390/plants14060917
8. Yao R, Bai R, Yu Q, Bao Y, Yang W. The effect of nitrogen reduction and applying bio-organic fertiliser on apple quality and soil enzyme activity. *Agronomy*. 2024; 14:345. DOI: https://doi.org/10.3390/agronomy14020345
9. Toishimanov M, Suleimenova Z, Myrzabayeva N, Dossimova Z, Shokan A, Kenenbayev S, et al. Effects of organic fertilizers on the quality, yield, and fatty acids of maize and soybean in Southeast Kazakhstan. *Sustainability*. 2024; 16:162. DOI: https://doi.org/10.3390/su16010162
10. Lin S, Pi Y, Long D, Duan J, Zhu X, Wang X, et al. Impact of organic and chemical nitrogen fertilizers on the crop yield and fertilizer use efficiency of soybean–maize intercropping systems. *Agriculture*. 2022; 12:1428. DOI: https://doi.org/10.3390/agriculture12091428
11. Zhai J, Zhang G, Zhang Y, Xu W, Xie R, Ming B, et al. Effect of the rate of nitrogen application on dry matter accumulation and yield formation of densely planted maize. *Sustainability*. 2022; 14:14940. DOI: https://doi.org/10.3390/su142214940
12. Feng W, Xue W, Zhao Z, Shi Z, Wang W, Bai Y, et al. Nitrogen fertilizer application rate affects the dynamic metabolism of nitrogen and carbohydrates in kernels of waxy maize. *Front Plant Sci*. 2024; 15:1416397. DOI: https://doi.org/10.3389/fpls.2024.1416397
13. Pacier C, Martirosyan D. Vitamin C: optimal dosages, supplementation and use in disease prevention. *Funct Foods Health Dis*. 2015;5(3):174. DOI: https://doi.org/10.31989/ffhd.v5i3.174
14. Hemkemeyer M, Schwalb SA, Berendonk C. Potato yield and quality are linked to cover crop and soil microbiome, respectively. *Biol Fertil Soils*. 2024; 60:525–545. DOI: https://doi.org/10.1007/s00374-024-01813-0
15. Galstyan M, Melikyan A, Melyan G, Martirosyan H, Aloyan T, Markosyan M, et al. Effects of microfertilizer application methods on potato productivity and nutritional quality in the Gegharkunik region. *Bioactive Comp Health Dis*. 2025;8(7):243–256. DOI: https://doi.org/10.31989/bchd.8i7.1696
16. Al Nawaiseh FY, Mashal RH. Nitrate in raw and cooked vegetables: content, variation and influence of cooking methods. *Afr J Food Agric Nutr Dev*. 2025;25(1):25596–25618. DOI: https://doi.org/10.18697/ajfand.138.25335
17. FAO. World reference base for soil resources. Rome: FAO; 2015.
18. Gomez KA, Gomez AA. Statistical procedures for agricultural research. 2nd ed. New York: Wiley; 1984.
19. Horneck DA, Miller RO. Determination of plant nutrients. In: Soil testing laboratory manual. Corvallis: Oregon State University; 1998.
20. AOAC. Official methods of analysis of AOAC International. 21st ed. Gaithersburg, MD: AOAC Int.; 2019.
21. Cataldo DA, Maroon M, Schrader LE, Youngs VL. Rapid colorimetric determination of nitrate in plant tissue by nitration of salicylic acid. *Commun Soil Sci Plant Anal.* 1975;6(1):71–80. DOI: https://doi.org/10.1080/00103627509366547
22. ISO 6635:1984. Fruits, vegetables and derived products—determination of nitrate content—spectrometric method.
23. WHO/FAO. Codex Alimentarius: general standard for contaminants and toxins in food and feed. 2022.
24. International Organization for Standardization. Fruits, vegetables and derived products—determination of nitrite and nitrate content—molecular absorption spectrometric method; ISO 6635:1984.
25. AOAC Method 934.01. Moisture in dried fruits. AOAC International; 2019.
26. Hedge JE, Hofreiter BT. Methods in carbohydrate chemistry. Vol. 17. New York: Academic Press; 1962.
27. Sadasivam S, Manickam A. Biochemical methods. 3rd ed. New Delhi: New Age International; 2008.
28. Lane JH, Eynon L. Determination of reducing sugars by Fehling's solution. *J Soc Chem Ind*. 1923; 42:32T–37T.
29. Khujamshukurov N, Eshkobilov ShA, Aliqulov SM, Normatov AM, Boboev D, et al. Effect of biohumus on agrochemical properties of soil, fertility and plant productivity in greenhouse conditions. *Int J Curr Microbiol Appl Sci*. 2022;11(12):119–145. DOI: https://doi.org/10.20546/ijcmas.2022.1112.013
30. Melyan G, Galstyan M, Avagyan G, Aloyan T, Vahramians Khosravizad B, Hakobjanyan I, et al. Influence of nutrient medium components on in vitro tuberization of Solanum tuberosum L. and subsequent minituber production in aeroponic and greenhouse conditions. *Life*. 2025; 15:241. DOI: https://doi.org/10.3390/life15020241
31. Hosseini M-J, Dezhangah S, Esmi F, Gharavi Nakhjavani MS, Hashempour Baltork F, Mirza Alizadeh A. A worldwide systematic review, meta-analysis and modelling study of

nitrate and nitrite in vegetables and fruits. *Ecotoxicol Environ Saf*. 2023; 257:114934.
DOI: https://doi.org/10.1016/j.ecoenv.2023.114934

32. Dhandapani S, Philip VS, Nabeela Nasreen SAA, Tan AMX, Jayapal PK, et al. Effects of storage temperatures on nitrogen assimilation and remobilization during post-harvest senescence of Pak Choi. *Biomolecules*. 2023;13(10):1540. DOI: https://doi.org/10.3390/biom13101540
33. Luo F. Nitrate quantification in fresh vegetables in Shanghai. *Int J Environ Res Public Health*. 2022;19(21):14487. DOI: https://doi.org/10.3390/ijerph192114487
34. Liu S, Zhang X, Wang H. Effects of organic fertilizer combined with inorganic fertilizer on growth, yield and quality of potato. *Henan Agric Sci*. 2020;49(3):32–39. DOI: https://doi.org/10.15933/j.cnki.1004-3268.2020.03.005
35. Girma Z, Tadesse F, Alemu A. Integrated application of organic and blended mineral fertilizers improves potato productivity and income for smallholder farmers in acidic soils. *Environ Nat Resour Res*. 2020;10(3):45–56. DOI: https://doi.org/10.5539/enrr.v10n3p45
36. Suraganova E, Batyrova L, Kadyrova G. Effect of bio-organic mineral fertilizers on quality, yield, and safety indicators of potatoes under conditions of Akmola Region. *Open J Biophys Sci*. 2022; 12:1–9. DOI: https://doi.org/10.3844/ojbsci.2022.1.9
37. Oladele SO, Gould I, Varga S. Low carbon footprint organo mineral fertilizer increases potato yield, nitrogen uptake, and soil nutrient levels comparable to conventional fertilizer. *Potato Res*. 2025; 68:3505–3523. DOI: https://doi.org/10.1007/s11540-025-09871-z
38. Martirosyan D. Functional food science and bioactive compounds. *Bioactive Comp Health Dis*. 2025;8(6):218–229. DOI: https://doi.org/10.31989/bchd.v8i6.1667
39. Maurya VK, Shakya A, McClements DJ, Srinivasan R, Bashir K, et al. Vitamin C fortification: need and recent trends in encapsulation technologies. *Front Nutr*. 2023; 10:1229243. DOI: https://doi.org/10.3389/fnut.2023.1229243
40. Jhangiryan T, Hunanyan S, Markosyan A, Yeritsyan S, Eloyan A, et al. Assessing the effect of joint application of mineral fertilizers and biohumus on potato yield quality indicators. *Functional Food Sci*. 2024;4(12):508–520. DOI: https://doi.org/10.31989/ffs.v4i12.1528
41. Cardarelli M, El Chami A, Rouphael Y, Ciriello M, Bonini P, Erice G, et al. Plant biostimulants as natural alternatives to synthetic auxins in strawberry production: physiological and metabolic insights. *Front Plant Sci*. 2024; 14:1337926. DOI: https://doi.org/10.3389/fpls.2023.1337926
42. Zhang B, Murtaza A, Iqbal A, Zhang J, Bai T, Ma W, et al. Comparative study on nutrient composition and antioxidant capacity of potato based on geographical and climatic factors. *Food Biosci*. 2022; 46:101536. DOI: https://doi.org/10.1016/j.fbio.2021.101536
43. Rašovský M, Leňo M, Škvarla K, Dobrá V, Majorošová M. Quantity and quality changes in sugar beet (Beta vulgaris L.) under biostimulant application. *Plants*. 2022; 11:2222. DOI: https://doi.org/10.3390/plants11172222
44. Martirosyan G, Sargsyan G, Sarikyan K, Adjemyan G, Hakobyan A, et al. Impact of green manure plants on the yield and bioactive compounds content of lettuce. *Bioactive Comp Health Dis*. 2023;6(12):351–363. DOI: https://doi.org/10.31989/bchd.v6i12.1261
45. González-Coria J, Lozano-Castellón J, Jaime-Rodríguez C, Olmo-Cunillera A, Laveriano-Santos EP, et al. The effects of differentiated organic fertilization on tomato production and phenolic content in traditional and high-yielding varieties. *Antioxidants*. 2022; 11:2127. DOI: https://doi.org/10.3390/antiox11112127
46. Baghdasaryan A, Martirosyan D. Economic implications of functional foods. *Functional Food Sci*. 2024;4(6):216–227. DOI: https://doi.org/10.31989/ffs.v4i6.1379
47. Miyasaka K, Tanaka Y, Suzuki H, Yamamoto T, Ito R, Kobayashi M, *et al. Functional Food Health Dis*. 2025;15(8):506–518. DOI: https://doi.org/10.31989/ffhd.v15i8.1666
48. Rithi AT, Mitra A, Banerjee A, Ilanchoorian D, Marotta F, Radhakrishnan AK, *et al. Functional Food Sci*. 2023;4(1):11–28. DOI: https://doi.org/10.31989/ffs.v4i1.1271
49. Xie B, Chen P, Hong Y, Xu C, Zhang W, Li Q, *et al. Dietary Supplements Nutraceuticals*. 2025;4(6):1–11. DOI: https://doi.org/10.31989/dsn.v4i6.1621
50. Zakari AD, Audu GA, Egbeja TI, Aliyu AA, Adefila MA, Momoh TB, *et al. Agric Food Bioact Comp*. 2025;2(7):157–168. DOI: https://doi.org/10.31989/afbc.v2i7.1722