Research Article **Open Access**

The impact of mineral and organic fertilizers on potato yield, quantitative and qualitative indicators, and functional value

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Submission Date: July 25th, 2024; **Acceptance Date:** August 16th, 2024; **Publication Date:** August 22nd, 2024

Please cite this article as: Martirosyan H., Galstyan M., Aloyan T., Gasparyan N., Terteryan K., Sahakyan N., Avagyan G. The Impact of Mineral and Organic Fertilizers on Potato Yield Quantitative, Qualitative Indicators, and Functional Value. *Functional Food Science* 2024; 4(8): Page 309-324. DOI: https://doi.org/10.31989/ffs.v4i8.1400

ABSTRACT

Background: Potatoes are a crucial component of the human diet, often referred to as the "second bread." The food security and safety of a country are significantly influenced by the volume of potato production, highlighting its strategic importance. As a staple crop worldwide, the potato is not only a versatile and delicious food, but also a rich source of nutrients and bioactive compounds, positioning it as a functional food with the potential to improve health and aid in the prevention and management of various chronic diseases.

As potato cultivation technologies progress, it is important to select appropriate fertilizers, as these can significantly impact tuber quality and their status as a functional food. The potential accumulation of harmful compounds in potato tubers poses risks to consumer health, making careful fertilizer selection essential.

Objective: The objective of this research is to assess the impact of both mineral and organic fertilizers on the quantitative and qualitative parameters of potato tubers, with the aim of evaluating their potential as a raw material for functional food production.

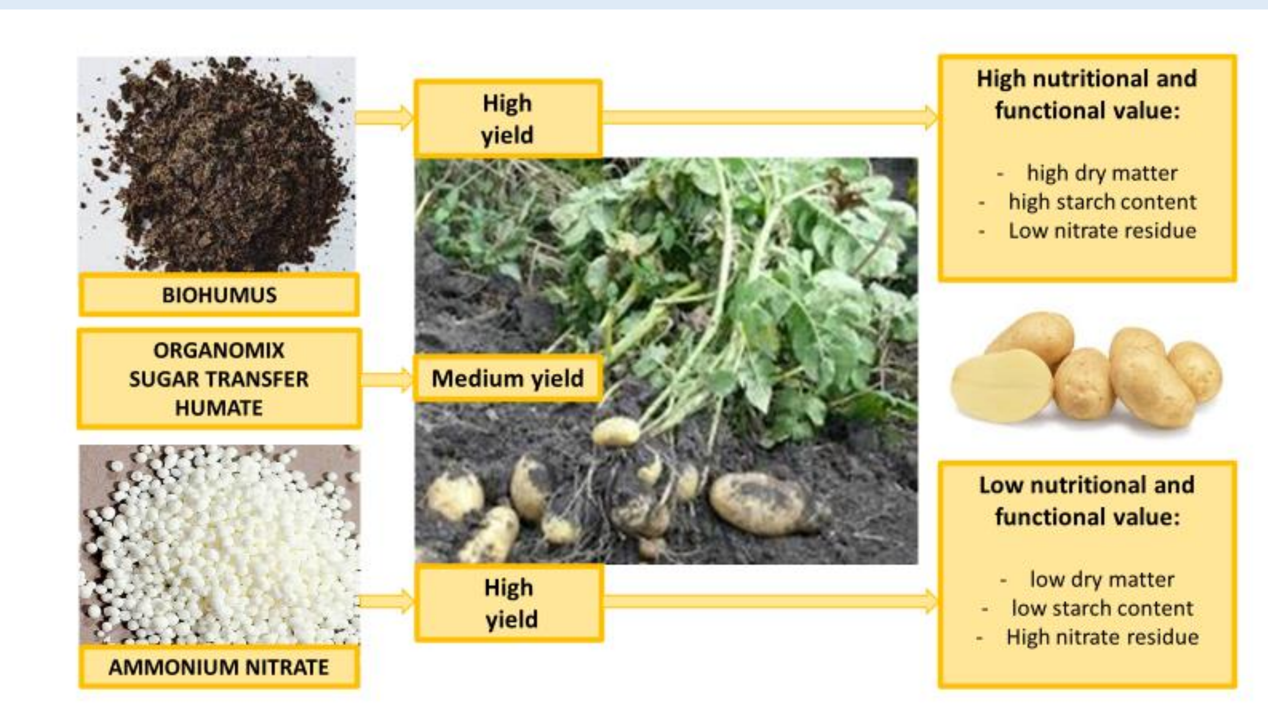
Methods: Investigations were conducted from 2021 to 2023 in the Stepanavan community of the Lori region, Republic of Armenia, using mineral (ammonium nitrate) and various organic fertilizers (Sugar Transfer, Humate, Biohumus, and

Organomix). The experiments followed a randomized complete block design comprising 5 variants and 4 replications. Each experimental plot covered an area of 25 m². During the vegetation period, phenological observations were carried out, and the effects of the applied nitrogen and organic fertilizers on the growth capacity of the above-ground organs, crop yield, and quality indicators of tubers were measured. The chemical composition and functional value of the tubers were determined and evaluated by laboratory analysis in the state-certified FDI laboratory.

Results: The findings from three-year studies revealed that the utilization of organic fertilizers not only enhances tuber yield but also increases dry matter and starch content, while significantly reducing the accumulation of residual nitrogen in the tuber's chemical composition. Among the tested organic fertilizers, Biohumus exhibited remarkable performance, yielding 41.9 t ha^{-1} and producing high-quality tubers with a residual nitrogen content of 57.4 mg kg^{-1}, which is 2.6 mg kg^{-1} below the specified permissible norm. In contrast, the application of ammonium nitrate resulted in a slightly higher tuber yield of 42.6 t ha^{-1}, however the residual nitrogen content was 72.7 mg kg^{-1}, exceeding the specified permissible norm by 12.7 mg kg^{-1}. Therefore, it is recommended to apply Biohumus into the furrow during potato planting. Additionally, foliar nutrition with a 0.2% solution should be provided at the beginning of the first soil loosening and during the blooming stage (how does the study support this result?).

Conclusion: The utilization of organic fertilizers, particularly Biohumus, in potato cultivation emerges as a promising technology for sustainable agriculture. It offers the potential to achieve high yields of tubers with elevated functional and nutritional value, while also mitigating the risk of residual nitrogen accumulation in the tubers.

Keywords: Potato, organic and mineral fertilizers, yield, functional and nutritional value residual nitrogen



INTRODUCTION

Agriculture currently plays a pivotal role in human nutrition. As consumers take more initiative to eat healthy to improve their health, manufacturers are developing innovative products, such as functional foods, that cater to these evolving demands [1–3]. Functional foods, containing bioactive compounds, offer health benefits beyond basic nutrition. Functional foods have the potential to enhance physiological functions and mitigate the risk of chronic disease [6]. With increasing interest in preventive healthcare and personalized nutrition, functional foods providetargeted solutions supported by rigorous scientific evidence, making them central to modern approaches to nutrition [2, 4, 5].

Potato (*Solanum tuberosum* L.) is one of the most important food crops in the world. According to the Food and Agriculture Organization of the United Nations (FAO) estimates in 2021 [7], over 376 million metric tons of potatoes were produced worldwide (up 17 percent compared with 2000). Potatoes are a crucial and irreplaceable component of the human diet, playing a vital role in the country's food safety and security [8]. In terms of human consumption, potato ranks third after rice and wheat [9]. Despite being commonly associated with starchy carbohydrates, potatoes are also rich inessential nutrients such as potassium, vitamin B6, vitamin C, minerals, and dietary fiber, which support immune function, maintain electrolyte balance, and promote overall health [10-14]..

Potassium is essential for maintaining healthy blood pressure and nerve function [15]. Vitamin B6 is vital for brain development and metabolism. (maybe define the role of vitamin C?) Dietary fiber aids digestion and promotes gut health. This diverse nutrient profile makes potatoes a valuable contributor to overall health and well-being. Additionally, potatoes contain significant amounts of antioxidants, such as flavonoids and carotenoids, which help reduce oxidative stress and inflammation in the body and boost immunity [16]. Furthermore, the resistant starch found in potatoes acts as a prebiotic, nourishing beneficial gut bacteria and supporting digestive health [17]. Resistant starch also contributes to satiety and may aid in weight management by promoting feelings of fullness and reducing calorie intake. Therefore, these beneficial properties contribute to various health benefits, highlighting the value of potatoes in a balanced diet. Consequently, ongoing research aims to explore the functionality and maximize the utilization of potato components, as well as to develop new products based on this versatile crop [12].

The potato was selected not only for its nutritional value but to also improve potato cultivation technology to increase yields (inclusion of a sentence to connect the paragraphs). Based on statistical data from 2022 [18], the potato sowing area in the Republic of Armenia (RA) was 19.2 thousand hectares, with a gross harvest of 251.4 thousand tons. According to data provided by the FAO, the acreage of irrigated lands has been steadily increasing worldwide, contributing to rising yields and overall production of potatoes despite a slight decline in the global harvested area for potatoes [19]. However, a significant portion of potato fields remains under rain-fed agriculture [20]. In such conditions improving agricultural technology, especially focusing on enhancing the culture of the fertilization system and supplementing it with the safest fertilizers, plays a crucial role in increasing potato production volume and improving product quality as functional food. Increasing the efficiency of potato cultivation requires a precise definition of the fertilization system during the entire growth period as part of a successful agronomic strategy, especially during the early stages of growth and development of the plants. This approach promotes the formation of robust, lush plants, which is one of the key factors in guaranteeing a high yield with high nutritional value [21].

Many authors suggest that achieving a rich and high-quality potato yield is often observed when the soil has a light mechanical composition and is fertilized with organic fertilizers. Applying organic preparations rich in macro and microelements through extra-root nutrition during the vegetative growth stage may promote optimal growth and development of potato plants [22-25].

In contrast, the excessive application of traditionally used mineral fertilizers can result in reduced soil fertility and increased contamination with heavy metals, potentially contributing to the development of carcinogenic diseases in humans [26-28]. Nitrogen, while essential for crop growth and development, requires careful management to avoid adverse effects. Insufficient nitrogen fertilization can result in significant yield losses [29, 30]. However, excessive nitrogen in the soil can disrupt the uptake and balance of other critical nutrients, such as calcium and zinc [31]. High nitrogen levels can also negatively affect the synthesis of bioactive compounds in potatoes, including antioxidants [32]. Additionally, elevated residual nitrogen can lead to nitrate accumulation in potato tubers, which, when ingested, can convert to nitrites and subsequently to nitrosamines—carcinogenic compounds that pose a serious health risk [33, 34]. As a result, high nitrate levels can diminish the health benefits of potatoes, reducing their value as a functional food.Therefore, to address this issue traditional mineral fertilizers are repla (ced with organic fertilizers as they have no negative effects on either the soil or the plants [23, 35]. In addition to fertilizing the soil by replenishing it with macro and micronutrients, organic fertilizersalso minimize the risk of soil salinization and alkalization [36]. Moreover, the combined application of chemical/organic and biological fertilizers can increase the tuber and the protein yields of potatoes by balancing the soil elements, reducing soil acidity, and mitigating the effects of stresses [37].

The objective of this study is to assess the impact of both mineral and organic fertilizers on the quantitative and qualitative parameters of potato tubers, with the aim of evaluating their potential as a raw material for functional food production.

MATERIALS AND METHODS

Experimental site description: The impact of organic (Sugar Transfer, Humate, Biohumus, Organomix) and nitrogen fertilizers (Ammonium nitrate) on the growth, development, and efficiency indicators of the Impala potato variety yield was studied under rain-fed agriculture conditions in the Stepanavan region of Lori Marz, RA. Stepanavan, characterized by its thick forests and alpine meadows, is situated at an average elevation of 1375 meters above sea level. The region has a humid continental climate, classified as Dfb in the Köppen climate classification [41]. Winters are cold with relatively low precipitation, while spring and summer experience significant rainfall. The region also receives an annual precipitation of 683 mm, with notably snowy winters, making rain-fed cultivation of potato plants possible (the sentence above stating that winters have low precipitation contradicts this sentence). The average temperature in January is -4.2°C; in July, it reaches 16.7°C (I think you should describe the average temperature in July to maintain consistency with the rest of the sentence), and the average yearly temperature is 6.6°C.

Potato variety description: The Impala potato (*Solanum tuberosum* L. *cv. Impala*) is an intensive, high-yielding variety of Dutch origin, renowned for its medium to large tubers and exceptional taste qualities. The Impala potato is distinguished by its large size (80-160 g) and its oval leveled shape. The skin is thin, light, and nearly transparent, while the pulp exhibits a creamy or light-yellow color.

Experimental Design: The experiments were conducted during 2021-2023 in a randomized complete block design (RCBD) in 5 variants with 4 replications. The area of each experimental plot was 25 m² [42]. The soil solution used was comprised of meadow-steppe black soils with a sandy-loam texture and a humus content of 4.1%. These soils, which dominate the Stepanavan region, exhibit a low availability of mobile nitrogen but are rich in phosphorus and potassium. The pH of the soil solution ranges from 6.8 to 6.9. Organic and mineral fertilizers were applied to the plants using both root and extra-root nutrition methods throughout the growing season. In all variants, potato planting was conducted with preliminary light-sprouted tubers.

Over the three years of the experiments, potato planting consistently took place in the third decade of April, following the same optimal planting scheme (70x30 cm) and a depth of 12 cm for the Impala variety. During the vegetation period, phenological observations were conducted by averaging data from 25 plants to determine the duration of growth and developmental stages of the potato plants, overall duration of the vegetation period [43, 44]. Additionally, the effects of the applied nitrogen and organic fertilizers on the growth capacity of the above-ground organs, crop yield, quality indicators, and functional value of the tubers were measured.

Description of the applied fertilizers:

Sugar Transfer is a liquid organic fertilizer containing free amino acids, organic nitrogen (N), and magnesium (Mg). Sugar Transfer is utilized to address magnesium deficiency in agricultural crops. This fertilizer was applied to potato plants at a rate of 2.5 l ha^{-1} during the germination stage. Additionally, the fertilizer was provided as extra-root nutrition twice during the tuber formation stage, at a rate of 2.0 l $ha^{-1}$and an interval of 15-20 days [45].

Humate is a liquid organic complex fertilizer enriched with valuable macro and microelements. Humate, which contains humic acids, can be applied as root and extra-root nutrition, while serving as a disinfectant, suggesting its significant benefits to soil and plant health. The potato plants received two applications of root nutrition treatments with Humate: the first at the fourth leaf stage and the second before flowering. Each root nutrition treatment was applied at a rate of 3.5 l ha^{-1}. Additionally, a single foliar nutrition treatment was applied at the flowering stage, with a concentration of 0.02% [46].

Organomix is a biologically active, environmentally friendly organic fertilizer composed of a macro and microelement complex, including a mixture of peat and compost. This fertilizer contains essential nutrients such as N, P, K, Ca, Mg, and sulfate (SO_4), which promote plant growth and increase yield. Additionally, Organomix positively affects the chemical composition of crops and enhances plant resistance to diseases and pests. It was applied twice during the vegetation period in the form of foliar nutrition before flowering with an interval of 15-20 days, with a concentration of 0.2% [47].

Biohumus **(**worm-compost**)** is an organic fertilizer produced through the processing of organic waste and the recycling of manure by Californian red worms. As the organic matter passes through the worms' intestines, the fertilizer acquires a special spherical structure. Biohumus is rich in organic matter and essential nutrients, including N, P, K, Ca, Mg, and SO_4. 200 grams of Biohumus is applied into the furrow when planting the potatoes. Additionally, at the beginning of the first soil loosening and during the blooming stage, foliar nutrition is provided with a 0.2% solution of Biohumus water extract [48].

Ammonium nitrate (NH_4NO_3) is a white, granulated, nitrogenous mineral fertilizer containing approximately 34% of the active substance. It was applied twice to potato bushes, with a total of N_{45} before the plant flowering stage.

All fertilizers were applied according to technical specifications and recommended application schedules.

Statistical Assessment of the Experimental Results:

Statistical analysis was conducted using a single-factor Analysis of Variance (ANOVA) to compare the means across various experimental treatments. Mean values and standard deviation error bars were generated using MS Excel. The Least Significant Difference (LSD) test was applied to assess the statistical significance of differences among treatment means, with a significance threshold of $p<0.05$. Treatment effects were considered significant when $p \leq 0.05$, allowing for precise differentiation of means while controlling for Type I error.

RESULTS AND DISCUSSION

Indicators of the effectiveness of mineral and organic fertilizers on the Impala potato variety, based on three-year averaged data, are presented in both tabular and graphical formats. Figure 1 provides a detailed presentation of the results illustrating the impact of fertilizers on the growth and development stages of potatoes.

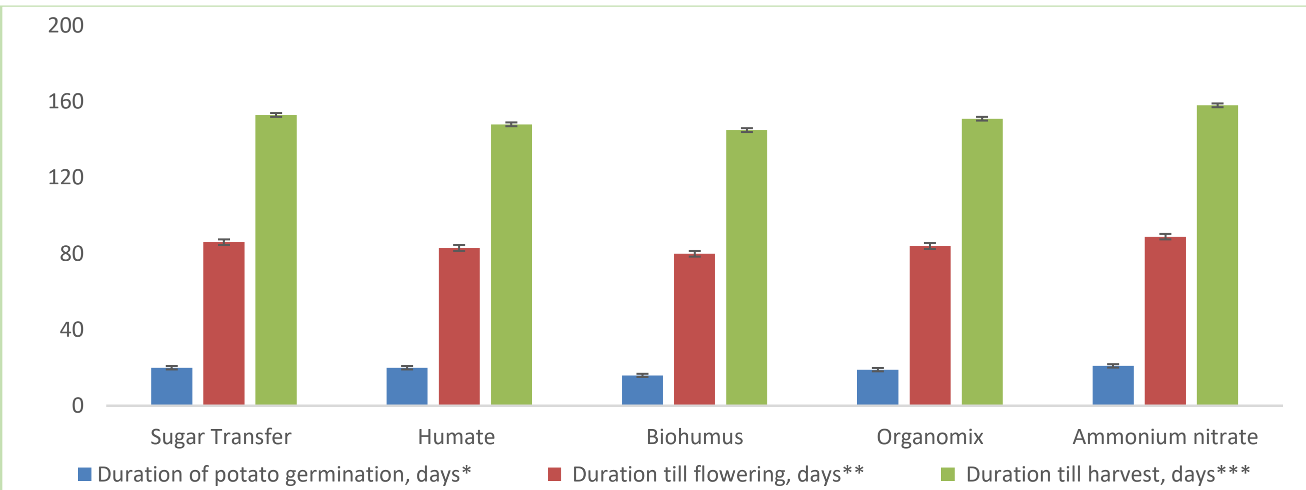


Figure 1. The impact of organic and mineral fertilizers on the duration of potato developmental stages. Error bars correspond to standard deviation (SD): * LSD_{05}=2.5; **LSD_{05}=5.7;***LSD_{05}=6.6

The duration of potato phenological stages differed significantly among the experimental options, primarily influenced by the choice of fertilizers applied. All experimental options had similar conditions regarding the tuber planting dates, planting schemes, and quality parameters of the planting material used. Given that only preliminary light-sprouted tubers were employed as planting material during the experiments, the germination period was expected to be notably shortened. This trend is clearly evidenced in the table data. Notably, in the Biohumus treatment, germination occurred over a span of 16 days, whereas in other treatments utilizing both mineral and organic fertilizers applied via root and foliar nutrition during the vegetative phase, the germination stage was extended by 3-5 days compared to Biohumus, totaling 19-21 days.

From the flowering stage onward, after the plants had been nourished through fertilization, the durations of growth and developmental stages in potatoes varied significantly. The Biohumus variant showed the earliest and shortest flowering stage, occurring 80 days after tuber planting. In contrast, the mineral fertilizer variant extended the flowering stage by 9 days. The other organic fertilizer variants lengthened this stage by only 3-6 days compared to the Biohumus variant

In the Biohumus variant, a notable increase in soil organic matter (due to fertilization during planting) is evident, leading to an enhancement in soil structure. This improvement contributes to the accelerated germination of tubers (a new graph/table measuring soil organic matter content may be included).

The applied fertilizers also had a significant impact on the duration of the vegetation period of the plants. The shortest vegetation periods were observed in the Biohumus and Humate versions, lasting 145 and 148 days, respectively. The variants using Organomix and Sugar Transfer fertilizers showed slightly longer durations, ranging from 151 to 153 days for the vegetation period. In contrast, with the application of ammonium nitrate, the vegetation period was extended by 13 days compared to the Biohumus treatment, totaling 158 days (a new graph/table representing duration of the vegetation period may be included).

Fertilization of potatoes also had a significant impact on the growth intensity of above-ground organs, as illustrated in Figure 2 and detailed in Table 1.

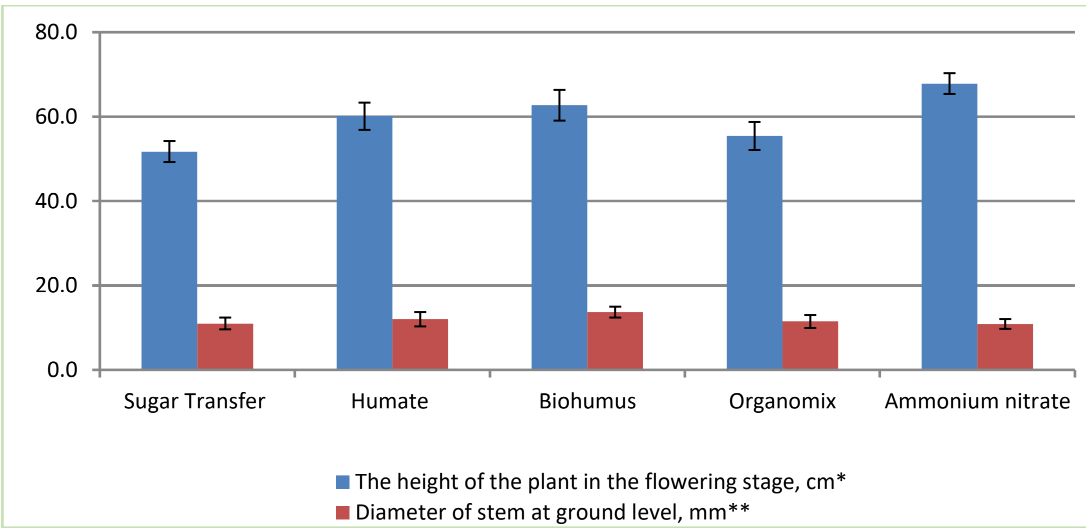


Figure 2. The effect of organic and mineral fertilizers on the growth intensity of potato above-ground organs. Error bars correspond to standard deviation (SD): * $LSD_{05}=4.7$; ** LSD_{05}=1.6

The robust growth of the plants was particularly evident in the variant where nitrogen fertilizer was used, with an average plant height reaching 67.8 cm, surpassing the Biohumus variant by 5.1 cm, and the other organic fertilizer application variants by 7.7 to 16.1 cm (see Figure 2). Moreover, in the Biohumus variant, the plants exhibited thick stems with a diameter of 13.7 mm, exceeding that of the Ammonium nitrate variant by 2.8 mm. All variants with the application of organic fertilizers showed greater improvement in stem thickness, ranging from 11.0 to 13.7 mm, compared to the variants treated with ammonium nitrate by 0.1 to 2.8 mm (maybe describe the stem thickness of the variants treated with ammonium nitrate for consistency).

The Biohumus variant had the greatest number of stems per plant with an average of3.7 stems, exceeding the NH_4NO_3 variant by 0.19 stems (see Table 1). Our findings are consistent with Miskoska-Milevska et al. [35], who reported a statistically significant difference in the average leaf area of potato plants treated with Biohumus compared to the untreated control. The variant with Sugar Transfer had the fewest number of stems, with 3.05 stems. However, the nitrogen fertilizer variant had the greatest branch number, leaf count, and leaf surface area, promoting intensive vegetative growth. Alimkhanov et al. demonstrated that the application of mineral fertilizers significantly enhances plant height, number of main stems, and leaf count per plant in potatoes compared to the control group [49].

Table 1. The effect of organic and mineral fertilizers on the growth intensity of potato above-ground organs

Fertilizer	**Potato above-ground organs per one bush**			
	Number of stems, pcs.	Number of branches, pcs.	Number of the leaves, pcs.	Surface of the leaves, cm^2
Sugar Transfer	3.05	3.15	49.8	5840
Humate	3.41	4.15	55.8	6215
Biohumus	3.74	4.32	59.0	6423
Organomix	3.24	3.72	51.6	6050
Ammonium nitrate	3.55	4.40	59.7	6490
LSD_{05}	0.44	0.09	1.88	11.3

Fertilization significantly influenced the growth of both above-ground organs and stolons, which are modified slender underground stems. Figure 3 shows that Biohumus had the most pronounced effect on stolon growth. The length of stolons applied with Biohumus exceeded those treated with ammonium nitrate by 0.8 cm and other tested organic fertilizers by 2.7-4.1 cm. A similar trend was observed for stolon diameter (can provide numerical values here for consistency). This can be attributed to Biohumus stimulating the growth of underground plant organs and improving soil structure, thereby enhancing soil lightness, looseness, and aeration. These factors facilitate the free and vigorous development of stolons.

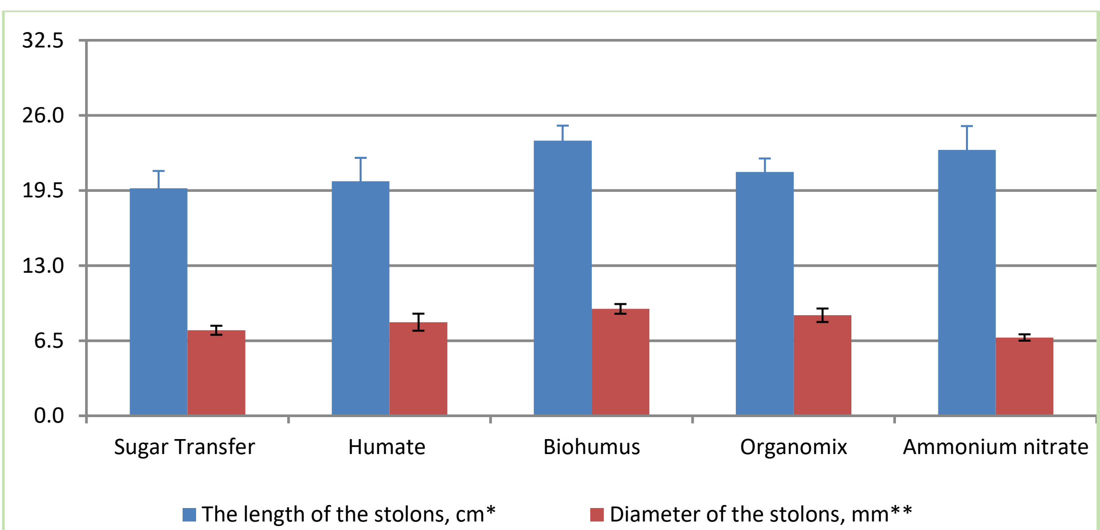


Figure 3. Comparative effects of potato fertilization on stolon growth. Error bars correspond to standard deviation (SD): * LSD_{05}=1.7; ** LSD_{05}=0.94

The habitus form of the potato plant is influenced by the development of its stolons. When Biohumus was used, providing plants with essential nutrients throughout the entire growth period, a cylindrical and less scattered bush form was observed, clearly demonstrating this effect. In contrast, plants treated with other organic fertilizers displayed various forms: compact and clustered (Sugar Transfer application), oval-shaped (Humate), and oval-shaped but scattered (Organomix). Plants treated with ammonium nitrate exhibited a compact growth habitus. Therefore, the Biohumus application variant should be considered advantageous due to its positive impact on both above-ground and underground plant organs.

It is well known that achieving a high yield of tubers is largely influenced by the indicators of harvest structural elements, particularly the number of tubers obtained from one plant and their weight [50]. Therefore, we also investigated the effect of organic and mineral fertilizers on these structural elements of the potato crop (see Table 2).

Table 2. Effect of organic and mineral fertilizers on structural elements of potato crop

Fertilizer	Number of tubers per plant, pce.	Weight of the tubers per plant, g				Total tuber harvest, t ha^{-1}
		total	big	medium	small	
Sugar Transfer	10.9	915.7	590.3	188.7	136.7	33.4
Humate	12.5	1084.3	690.2	271.4	122.7	38.9
Biohumus	13.1	1174.3	707.4	348.4	118.9	41.9
Organomix	11.7	985.7	647.0	210.4	128.3	35.8
Ammonium nitrate	14.9	1294.7	770.3	321.5	202.9	42.6
LSD_{05}	1.0	0.94	1.57	1.41	1.26	1.73

In the experimental variants where organic fertilizers were applied, the number of tubers formed per plant is significantly lower than in the variant with ammonium nitrate (14.9), averaging 1.8-4.0 tubers. In terms of the weight of tubers per plant, the NH_4NO_3-using variant exceeded the versions with the use of organic fertilizers by 120.4-379.0 g. The total mass of the harvested crop was categorized into product groups: large, medium, and small tubers. In terms of the weight of commercial tubers, the variant fertilized with ammonium nitrate (770.3 g) was notable, exceeding the Biohumus variant by 62.9 g in the weight of large tubers. However, in terms of medium-sized tubers, the variant fertilized with ammonium nitrate was inferior to Biohumus by 26.9 g. It should be noted that the tubers intended for planting material constituted a substantial portion (202.9 g or 15%) of the yield in the NH_4NO_3 variant compared to the Biohumus variant, where the tubers constituted 118.9g or 10%. This amount was 84g less than the tubers in the NH_4NO_3 variant and 3.8 to 17.8g less than the tubers in other organic fertilizer variants.

Regarding the structural elements of the yield, the lowest results were observed in the Sugar Transfer and Organomix variants, with 10.9 and 11.7 tubers per plant, respectively., The specific weights of small tubers treated with Sugar Transfer and Organomix were higher compared to other organic fertilizer variants. Among the organic fertilizer variants, the number of tubers formed per plant was significantly lower than in the ammonium nitrate variant, averaging between 1.8 and 4.0 tubers per plant. Additionally, the weight of tubers per plant in the NH_4NO_3-utilized variant exceeded that of the organic fertilizer variants by 120.4 to 379.0 g.

The experimental variant fertilized with ammonium nitrate outperformed all organic fertilizer-tested variants in terms of actual yield. These research findings align with other studies indicating that the application of mineral fertilizers, particularly nitrogen, significantly increases both the total tuber yield and average tuber number in potatoes compared to control groups [37, 49, 51, 52]. In our experiments, the yield in the ammonium nitrate-utilized variant, at 0.7 t ha^{-1}, exceeded that of the Biohumus variant and surpassed the remaining organic fertilizers by 3.7-9.2 t ha^{-1}. These results are consistent with findings from other studies, which demonstrated that the application of either organic or inorganic fertilizers—whether used individually or in combination—significantly improves potato yield, growth parameters, and yield components (such as tuber number and average tuber weight) [8, 29]. Furthermore, the use of biological organic fertilizers has been shown to enhance productivity, increase potato production, and improve farmers' profits [53].

It is noteworthy that the Biohumus variant nearly matched the yield of the variant fertilized with ammonium nitrate. The high yield associated with Biohumus is primarily attributed to its significant improvement of the soil's mechanical content, structure, and physicochemical properties, which are crucial for promoting intensive stolon formation and, consequently, achieving high yields. Additionally, Biohumus enhances soil aeration and water retention, thereby enriching the soil with essential macro and micro-elements and beneficial bacteria for plants. Moreover, organic fertilizers improve nutrient availability and promote better nutrient uptake by potato plants. This can result in higher concentrations of beneficial nutrients in the tubers. The enhanced nutritional profile of potatoes, facilitated by proper fertilization, includes elevated levels of vitamins, minerals, and bioactive compounds. These improvements make potatoes more effective in contributing to health benefits and solidify their role as a functional food. Regarding the Humate-utilizing variant, notable outcomes were observed in terms of tuber number (12.5 pcs), tuber weight per plant (1084.3g), and total tuber harvest (38.9 t ha^{-1}), closely following ammonium nitrate and Biohumus. This aligns with research by Ahmed Ali Mosa [54], indicating that humic substances (HS) enhance moisture retention in the root zone and nutrient availability in soil, thereby boosting fertilizer use efficiency and improving both quantitative and qualitative tuber characteristics. Our findings are consistent with several other studies [55–57], highlighting the positive impact of potassium humate on various aspects of potato production, such as seed germination, tuber yield, and overall productivity. Notably, potassium humate proves to be a cost-effective choice for potato growers, supporting sustainable agricultural practices even in water-deficient conditions by enhancing crop yield and resilience. These insights highlight the potential of humic substances to advance agricultural sustainability and ensure food security, particularly in arid and semi-arid climates.

Additionally, increased dosages of Organomix organic fertilizer enhance potato growth, development, tuber accumulation, and overall yield [58]. Furthermore, organic potato production using Biohumus and other organic fertilizers could be a viable alternative to conventional methods [59].

In agricultural and functional food science, it is important to obtain results that measure the quantitative, qualitative, and functional values of the product, especially if the product is for food consumption. [60, 61]. Therefore, our study examined the impact of the tested mineral and organic fertilizers on the quality indicators and chemical composition of the potato tuber crop. The chemical composition of the tubers was analyzed in the state-certified FDI laboratory located in Abovyan, Kotayk Marz, RA. The results are summarized in Table 3.

The quality of potato tubers is largely influenced by their end-use purposes [62]. Potatoes generally have a water content that varies from 75 to 85% with the rest as dry matter containing the nutrients that support potato growth. Thus, for potatoes intended for fresh consumption, important internal quality traits to consider include tuber dry matter, and starch content [63]..

Table 3. The effect of organic and mineral fertilizers on the chemical composition of potato tubers

Fertilizer	**Chemical composition of potato tubers**			
	Dry matter, %	Starch, %	Protein, %	Nitrate residues, mg kg^{-1}
Sugar Transfer	22.7	20.9	2.05	60.5
Humate	23.9	21.1	2.08	58.5
Biohumus	24.8	22.1	1.95	57.4
Organomix	23.2	21.9	2.00	59.8
Ammonium nitrate	21.4	18.7	2.87	72.7

The applied fertilizers had a significant impact on the dry matter content of potato tubers. The Biohumus variant had a dry matter content of 24.8%, surpassing the ammonium nitrate variant by 3.4% and other organic fertilizer variants by 1.6-2.1%. Potatoes with high dry matter content tend to have a higher concentration of essential nutrients such as vitamins, minerals, and antioxidants. High dry matter content indicates a higher concentration of carbohydrates, providing a significant energy source that is slowly released, which can be particularly beneficial for maintaining steady energy levels [64]. Potatoes with higher dry matter content can have a lower glycemic index, which helps improve blood sugar regulation. In addition, the dry matter content is an important quality criterion for processed potatoes, such as French fries or crisps. High dry matter content within the tuber ensures lower oil absorption [65]. Thus, high dry matter potatoes are ideal for creating functional food products that require specific textures and consistencies.

The use of Biohumus also had a beneficial effect on the starch content in the tubers, increasing the content by 22.1%, which exceeded the ammonium nitrate variant by 3.4% and the other organic fertilizer options by 0.2-1.2%.Starch is a complex carbohydrate that provides a steady and sustained release of energy, making it an excellent source of fuel for daily activities. Previous research demonstrated that a daily intake of 30 grams of raw potato starch over 12 weeks increased levels of Bifidobacteria and improved glycemic responses among elderly participants. Therefore, resistant starch in potatoes acts as a prebiotic, promoting the growth of beneficial gut bacteria, which can enhance gut health and contribute to the prevention of digestive disorders [66]. Resistant starch also provides health benefits such as glycemic control, control of fasting plasma triglyceride and cholesterol levels, and absorption of minerals. Native quality of starch, processing techniques, and storage temperatures affect the resistant starch content in food [67].

It is widely recognized that an increase in protein content in potato tubers can adversely impact their organoleptic and qualitative properties, rendering them unsuitable for cooking purposes. Since the Impala potato variety is cultivated primarily for food consumption, maintaining a protein content below 2% is essential. This is clearly evidenced in the ammonium nitrate experimental variant, where the protein content in the tuber's chemical composition reached its maximum value

(2.87%), surpassing the Biohumus variant by 0.92%. However, it is important to note that when other organic fertilizers were used, this indicator remained within the permissible limit, not exceeding 2.08%.

Residual nitrogen from mineral fertilizers, such as ammonium nitrate, can pose several risks to the chemical composition of potatoes, potentially compromising their status as a functional food. Elevated nitrate levels may be detrimental to human health as they can convert to nitrites in the body, which are associated with the formation of nitrosamines, compounds linked to cancer risk [68].

High nitrogen levels can lead to lower concentrations of certain vitamins and minerals [69], bioactive compounds in potatoes, such as antioxidants and phytochemicals diminishing the tuber's health benefits [70].

According to the norms established by The Food Safety Inspectorate of the Republic of Armenia, the residual nitrogen content in food should not exceed 60 mg kg^{-1}. In this context, the used organic fertilizers have fully met this requirement. Chemical analysis of the potato tubers revealed that the Biohumus variant had the lowest nitrate residue, measuring 57.4 mg kg^{-1}, which is below the permissible limit. Conversely, the application of ammonium nitrate resulted in nitrate levels exceeding the established norm by 12.7 mg kg^{-1}.

Overall, the application of organic fertilizers yielded excellent results regarding residual nitrogen content. Notably, the variant with Humate application achieved a low residual nitrogen level of 58.5 mg kg^{-1}, which is almost identical to the Biohumus variant, differing by only 1.1 mg kg^{-1}.

These findings are consistent with El-Sayed et al., who reported that plants treated with organic fertilizers, or a combination of mineral and bio-fertilizers exhibited lower nitrate content in potato tubers compared to those treated with conventional mineral fertilizers [22]. Additionally, the use of Biohumus and other organic fertilizers in potato production effectively reduces nitrate content in tubers while enhancing soil nutrient availability [59]. Furthermore, our results are aligned with other research demonstrating that both organic manure and inorganic fertilizers impact potato growth, yield, and quality. However, regarding environmental impact and sustainable development, organic manures are more significant compared to inorganic fertilizers [8].

In summary, the chemical analysis of tubers indicates that the use of organic fertilizers is highly recommended for food safety and security. Organic fertilizers not only enhance yields but also increase dry matter and starch levels while minimizing residual nitrogen. This combination improves the nutritional, functional, and health-promoting qualities of potatoes.

CONCLUSION

Summarizing the research findings on the use of different fertilizers in potato cultivation, organic fertilizers were found to significantly enhance both the yield and quality of potato tubers as functional food. Ammonium nitrate resulted in a tuber yield that was 0.7 t ha-1 higher compared to Biohumus. However, Biohumus was recognized as the best organic fertilizer among those tested, exceeding others in terms of all tuber quality indicators. It stands out by significantly reducing residual nitrogen, enhancing dry matter, and increasing starch content. Moreover, Biohumus effectively lowers the protein content in potato tubers to below 2%, a critical threshold for optimizing food quality. These improvements collectively enhance the overall functional and nutritional value of the tubers.

Therefore, it is recommended to apply 200 grams of Biohumus into the furrow during potato planting. Additionally, foliar nutrition with a 0.2% solution should be provided at the beginning of the first soil loosening and during the blooming stage.

The implementation of a fertilization system like this could serve as a primary assurance for the establishment of ecologically sound food production.

Abbreviations: FAO: Food and Agriculture Organization, HS: humic substances, RA: Republic of Armenia, RCBD: randomized complete block design.

Authors' contributions: HM - conceptualization, methodology, validation, resources, data curation, writing-original draft preparation, writing-review and editing; MG - methodology, data curation, writing-review and editing, TA - methodology, data curation, resources, writing-review and editing; NG - resources, writing-review and editing; KhT - resources, writing-review and editing; NS - resources, writing-review and editing; GA - conceptualization, methodology, validation, resources, data curation, writing-original draft preparation, writing-review, editing and supervision. All authors read and approved the final version of the manuscript.

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

Acknowledgement/Funding: Authors are thankful to the administration of the "Agrobiotechnology Scientific Center" Branch of Armenian National Agrarian University for supporting the research. The authors thank the reviewers whose constructive comments and suggestions improved the quality of the paper.

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