

Salykov Bulat Rakhimzhanovich* – Candidate of Technical Sciences, Associate Professor, Department of agricultural machinery and transport, Akhmet Baitursynuly Kostanay Regional University NLC, Republic of Kazakhstan, 110000, Kostanay, 2a Voinov Internatsionalistov Str., tel.: 87758190343, e-mail: salykovbulat@mail.ru.

Yskak Aliya – Candidate of Agricultural Sciences, Director of the Research Institute of Applied Biotechnology, Akhmet Baitursynuly Kostanay Regional University NLC, Kostanay, Republic of Kazakhstan, 110000, Kostanay, 123 Abai Str., tel.: 87058854684, e-mail: yskak_aliya@ksu.edu.kz.

Manuilov Nikolay Vladimirovich – Engineer, Department of software, Akhmet Baitursynuly Kostanay Regional University NJSC, Republic of Kazakhstan, 110005, Kostanay, 1 Geologicheskaya Str., tel.: 87772315458, e-mail: mnlv.nv.94@gmail.com.

Kabdusheva Almira Serikpayevna – PhD, Department of agricultural machinery and transport, Akhmet Baitursynuly Kostanay Regional University NLC, Republic of Kazakhstan, 110000, Kostanay, Nauryz micro district, 7–32, tel.: 87789791807, e-mail: 9.12.1989@mail.ru.

IRSTI 68.35.31; 68.35.29

UDC 635.21:631.811.98:620.3

<https://doi.org/10.52269/SEPT2631236>

EFFECTS OF ARTEMISIA ABSINTHIUM L. AQUEOUS EXTRACT AND BIOSYNTHESIZED IRON NANOPARTICLES ON THE YIELD AND QUALITY OF COLOMBO POTATO TUBERS

Seitkhanova K.K.* – PhD student, Toraighyrov University, Pavlodar, Republic of Kazakhstan.

Anikina I. N. – Candidate of Agricultural Sciences, Associate Professor, Toraighyrov University, Pavlodar, Republic of Kazakhstan.

The study evaluated the effects of foliar application of an *Artemisia absinthium* L. aqueous extract and a formulation containing biosynthesized iron nanoparticles (FeNPs) on the quality and tuber yield of the early-maturing potato cultivar 'Colomba' under field conditions of the Pavlodar region of Kazakhstan. The aqueous extract was prepared from dried aerial parts of *A. absinthium*, while FeNPs were synthesized using the plant extract and FeCl_3 as a precursor. Scanning electron microscopy confirmed the formation of nanoscale particles with irregular, predominantly rounded morphology and pronounced agglomeration; representative individual particle measurements were 35.99, 45.86, and 61.08 nm. Both formulations were applied by foliar spraying according to three schemes: once before flowering, once during flowering, or twice at both stages. Potato yield was evaluated separately in the 2024 and 2025 growing seasons. Two-way ANOVA showed significant effects of treatment on total tuber number ($F(6,126) = 4.603$, $p < 0.001$) and total tuber weight ($F(6,126) = 7.382$, $p < 0.001$), as well as significant effects of year on both parameters. No significant treatment $\times$ year interaction was detected. Planned comparisons with Holm adjustment showed that double application of the aqueous extract and double application of the FeNP-containing formulation significantly increased total tuber number compared with the control. Double-application of both formulations also significantly increased total tuber weight, while significant increases in tuber weight were additionally observed for single pre-flowering applications of both formulations and for the FeNP-containing formulation applied during flowering. In the 2025 crop, starch content ranged from 5.48 to 10.14%, vitamin C from 18 to 30 mg/100 g, nitrate content from 40.6 to 69.2 mg/kg, and dry matter from 14.65 to 19.60%; these biochemical differences were interpreted descriptively because statistical significance was not established for these parameters. No treatment-related deterioration in the assessed browning characteristics of raw or cooked tubers was observed. The results indicate that double foliar application of the *A. absinthium* aqueous extract or the FeNP-containing formulation was the most consistently effective application scheme for improving 'Colomba' potato yield under the conditions of this two-year field experiment.

Keywords: *Artemisia absinthium* L., biosynthesized iron nanoparticles, foliar application, potato, aqueous extract, tuber quality, green synthesis.

ARTEMISIA ABSINTHIUM L. СУ СЫҒЫНДЫСЫ МЕН БИОСИНТЕЗДЕЛГЕН ТЕМІР НАНОБӨЛШЕКТЕРІНІҢ «КОЛОМБО» СОРТТЫ КАРТОПТЫҢ ӨНІМДІЛІГІ МЕН ТҮЙНЕК САПАСЫНА ӨСЕРІ

Сейтханова К.К.* – докторант, «Торайғыров университеті» КЕАҚ, Павлодар қ., Қазақстан Республикасы.

Аникина И.Н. – ауыл шаруашылығы ғылымдарының кандидаты, қауымдастырылған профессор, «Торайғыров университеті» КЕАҚ, Павлодар қ., Қазақстан Республикасы.

Зерттеуде Қазақстанның Павлодар облысының далалық жағдайында *Artemisia absinthium* L. су сығындысы мен биосинтезделген темір нанобөлшектері (FeNPs) бар препаратты жапырақ арқылы

қолданудың ерте пісетін «Коломбо» картоп сортының өнімділігі мен түйнек сапасына әсері бағаланды. Су сығындысы *A. absinthium* өсімдігінің кептірілген жерүсті бөлігінен алынды, ал темір нанобөлшектері өсімдік сығындысын және прекурсор ретінде FeCl_3 пайдалану арқылы синтезделді. Сканерлеуші электрондық микроскопия нанобөлшектерді, пішіні дұрыс емес, негізінен дөңгелек және айқын агрегацияланған бөлшектердің түзілгенін растады; микрофотосуретте өлшенген жекелеген бөлшектердің репрезентативті өлшемдері 35,99; 45,86 және 61,08 нм болды. Екі препарат та жапырақ арқылы бүрку жолымен үш схема бойынша қолданылды: гүлденуге дейін бір рет, гүлдену кезінде бір рет және екі кезеңде екі рет. Картоп өнімділігі 2024 және 2025 жылдардағы вегетациялық кезеңдер бойынша жеке бағаланды. Екі факторлы дисперсиялық талдау өңдеу нұсқасының түйнектердің жалпы санына ($F(6,126) = 4,603$; $p < 0,001$) және жалпы массасына ($F(6,126) = 7,382$; $p < 0,001$), сондай-ақ жылдың екі көрсеткішке де статистикалық маңызды әсерін көрсетті. «Өңдеу нұсқасы × жыл» өзара әрекеттесуі статистикалық маңызды болған жоқ. Холм түзетуімен жүргізілген жоспарлы салыстырулар су сығындысын да, FeNPs бар препаратты да екі рет қолдану бақылаумен салыстырғанда түйнектердің жалпы санын статистикалық маңызды арттырғанын көрсетті. Екі препаратты екі рет қолдану түйнектердің жалпы массасын да статистикалық маңызды арттырды. Сонымен қатар, гүлденуге дейін екі препаратты бір рет қолданғанда және FeNPs бар препаратты гүлдену кезінде қолданғанда түйнектердің жалпы массасының статистикалық маңызды артуы байқалды. 2025 жылғы өнімде крахмал мөлшері 5,48-10,14%, С дәрумені 18-30 мг/100 г, нитраттар 40,6-69,2 мг/кг, ал құрғақ зат мөлшері 14,65-19,60% аралығында болды. Бұл биохимиялық көрсеткіштер бойынша статистикалық маңыздылық анықталмағандықтан, байқалған айырмашылықтар сипаттамалық тұрғыдан бағаланды. Өңдеулерге байланысты шикі немесе пісірілген түйнектердің зерттелген қараю көрсеткіштерінің нашарлауы байқалмады. Зерттеу нәтижелері осы екі жылдық далалық тәжірибе жағдайында *A. absinthium* су сығындысын немесе FeNPs бар препаратты екі рет жапырақ арқылы қолдану «Коломбо» сорты картобының өнімділігін арттырудың ең тұрақты тиімді схемасы болғанын көрсетті.

Түйінді сөздер: *Artemisiaabsinthium*L., биосинтезделген темір нанобөлшектері, жапырақ арқылы өңдеу, картоп, су сығындысы, түйнек сапасы, жасыл синтез.

ВЛИЯНИЕ ВОДНОГО ЭКСТРАКТА ARTEMISIA ABSINTHIUM L. И БИОСИНТЕЗИРОВАННЫХ НАНОЧАСТИЦ ЖЕЛЕЗА НА ПРОДУКТИВНОСТЬ И КАЧЕСТВО КЛУБНЕЙ КАРТОФЕЛЯ СОРТА КОЛОМБО

Сейтханова К.К.* – докторант, НАО «Торайгыров университет», г. Павлодар, Республика Казахстан.

Аникина И.Н. – кандидат сельскохозяйственных наук, ассоциированный профессор, НАО «Торайгыров университет», г. Павлодар, Республика Казахстан.

В исследовании оценивали влияние внекорневого применения водного экстракта *Artemisia absinthium* L. и препарата, содержащего биосинтезированные наночастицы железа (FeNPs), на продуктивность и качество клубней раннеспелого сорта картофеля «Коломбо» в полевых условиях Павлодарской области Казахстана. Водный экстракт получали из высушенной надземной части *A. absinthium*, а наночастицы железа синтезировали с использованием растительного экстракта и FeCl_3 в качестве прекурсора. Сканирующая электронная микроскопия подтвердила образование наноразмерных частиц неправильной, преимущественно округлой формы с выраженной агрегацией; репрезентативные размеры отдельных частиц на микрофотографии составляли 35,99; 45,86 и 61,08 нм. Оба препарата применяли путём внекорневого опрыскивания по трём схемам: однократно до цветения, однократно во время цветения и двукратно на обеих стадиях. Продуктивность картофеля оценивали отдельно в вегетационные сезоны 2024 и 2025 гг. Двухфакторный дисперсионный анализ выявил статистически значимое влияние варианта обработки на общее количество клубней ($F(6,126) = 4,603$; $p < 0,001$) и их общую массу ($F(6,126) = 7,382$; $p < 0,001$), а также значимое влияние года на оба показателя. Взаимодействие факторов «вариант обработки × год» статистически значимым не было. Плановые сравнения с поправкой Холма показали, что двукратное применение как водного экстракта, так и препарата с FeNPs статистически значимо увеличивало общее количество клубней по сравнению с контролем. Двукратное применение обоих препаратов также обеспечивало статистически значимое увеличение общей массы клубней. Кроме того, значимое увеличение массы клубней отмечено при однократном применении обоих препаратов до цветения и препарата с FeNPs во время цветения. В урожае 2025 г. содержание крахмала составляло 5,48-10,14%, витамина С – 18-30 мг/100 г, нитратов – 40,6-69,2 мг/кг, сухого вещества – 14,65-19,60%. Поскольку статистическая значимость различий этих биохимических показателей не была установлена, наблюдаемые различия интерпретировали описательно. Ухудшения исследованных показателей потемнения сырых и варёных клубней, связанного с обработками, не выявлено. Полученные результаты показывают, что двукратное внекорневое применение водного экстракта *A. absinthium* или препарата с FeNPs было наиболее стабильно эффективной схемой повышения продуктивности картофеля сорта «Коломбо» в условиях данного двухлетнего полевого эксперимента.

Ключевые слова: *Artemisia absinthium* L., биосинтезированные наночастицы железа, фолитарная обработка, картофель, водный экстракт, качество клубней, зелёный синтез.

Introduction. Potato (*Solanum tuberosum* L.) is one of the world's most important food crops and ranks fourth in global human consumption after maize, wheat, and rice [1, p.1]. Owing to its high content of carbohydrates, vitamins, and minerals, potato plays a crucial role in ensuring food security [2, p. 119]. In recent years, increasing attention has been paid not only to improving crop productivity but also to enhancing tuber quality, which determines the nutritional and biological value of potato. As a highly productive food crop, potato is characterized by intensive accumulation of dry matter and biologically valuable compounds. Consequently, starch, dry matter, and vitamin C contents are regarded as the principal quality indicators of potato tubers in food biotechnology [3, p. 487, 4, c. 533].

These characteristics are largely influenced by cultivar-specific traits, environmental conditions, and agronomic management practices [4]. Early-maturing potato cultivars generally contain relatively low starch levels and high tuber moisture content, limiting their suitability for industrial starch production. Nevertheless, they are highly valued for dietary and functional nutrition because of their desirable taste, tender flesh texture, and elevated content of biologically active compounds [5. pp. 823-825, 6. pp. 34-36].

Another important quality parameter is the nitrate content of potato tubers. Nitrate accumulation is closely associated with plant mineral nutrition, particularly nitrogen fertilization. Although nitrates are natural constituents of soils and are essential for plant growth, their excessive accumulation in agricultural products is considered undesirable. After ingestion, nitrates may be reduced to nitrites, which exhibit greater biological activity and may pose potential health risks. Therefore, monitoring nitrate concentrations is an important criterion for assessing the safety and quality of potato tubers [7, pp. 41-43].

The potato cultivar Colombo belongs to the group of early-maturing table cultivars [8. p.1] and is widely cultivated for early-season production. Therefore, evaluating its biochemical composition and food safety indicators is of considerable practical importance for both the food industry and the catering sector.

The research aim was to evaluate the effects of foliar application of an *Artemisia absinthium* L. aqueous extract and a preparation based on this extract containing biosynthesized iron nanoparticles (FeNPs) on potato yield, biochemical composition, and tuber quality of the early-maturing cultivar Colombo.

Research objective: To evaluate the effects of foliar application of an *Artemisia absinthium* L. aqueous extract and a biosynthesized iron nanoparticle (FeNP)-containing formulation, applied at different growth stages, on the productivity, biochemical characteristics, and technological quality of 'Colomba' potato tubers under field conditions.

Tasks: The study was designed to evaluate the effects of different foliar application schemes of *Artemisia absinthium* L. aqueous extract and the FeNP-containing formulation on the yield of 'Colomba' potato during two growing seasons; to assess changes in the biochemical characteristics of the tubers, including starch, vitamin C, nitrate, dry matter, and moisture contents; and to determine whether the studied treatments affected the technological quality of the tubers, as assessed by the resistance of raw and cooked tuber flesh to browning.

Materials and Methods. To study the effect of an *Artemisia absinthium* L. aqueous extract in its pure form and in combination with biosynthesized iron nanoparticles on potato yield and yield structure, a field experiment was established at the Arman farming enterprise in the Pavlodar Region. The study was conducted during the 2024-2025 growing seasons on the potato cultivar Colombo in accordance with the Methods of Field Experiment (Dospekhov B.A., 1979).

Potatoes were grown under open-field conditions in small experimental plots of 100 m² with four replications in compliance with the agronomic practices adopted for this crop. The experiment was carried out using agronomic practices corresponding to the Dutch potato cultivation technology. Planting was performed using a Kramer potato planter during the period from 1 to 5 May according to the 75 × 40 cm planting scheme.

Before planting, the tubers were treated with TMTD VSK at a rate of 5 L/t. During the growing season, pre-emergence treatment with Tornado herbicide was carried out at a rate of 7 L/ha. To maintain soil moisture in the active soil layer at not less than 80% of field capacity throughout the growing season, 5 to 8 irrigations were carried out depending on the weather conditions of the year, with an irrigation rate of 2500-3000 m³/ha. Irrigation was performed using a Valley Ranger sprinkler irrigation system. The experimental plots were harvested manually during the last ten days of July.

The *Artemisia absinthium* L. stock aqueous extract was prepared from dried plant material at a ratio of 10 g per 100 mL of distilled water (100 g L⁻¹). The plant material was extracted at 60-70 °C for 30 min, and the resulting extract was filtered. For the extract-only treatment, the stock extract was diluted with water at a ratio of 1:3 (v/v), resulting in a 25% (v/v) working extract, equivalent to 25 g of initial dry plant material per litre of working solution.

For preparation of the FeNP-containing formulation, 900 mL of the stock *A. absinthium* aqueous extract was mixed with 100 mL of 0.1 M FeCl₃ solution used as the iron precursor. The reaction mixture was allowed to react for 90 min and was subsequently diluted with 3 L of water to a final working volume of 4 L. The resulting formulation therefore contained 22.5% (v/v) of the initial plant extract, while the amount of FeCl₃ introduced during synthesis corresponded to a precursor equivalent of 2.5 mM when calculated for the final working

volume. The biosynthesized nanoparticles were not isolated or dried prior to field application; therefore, the mass concentration of FeNPs in the working formulation was not determined separately. The freshly prepared reaction mixture was used directly for foliar treatment.

The formation and morphology of FeNPs obtained using this synthesis protocol were confirmed by scanning electron microscopy (SEM). SEM analysis revealed nanoscale particles with irregular, predominantly rounded morphology and pronounced agglomeration. Representative measurements of individual particles shown in the SEM micrograph were 35.99, 45.86, and 61.08 nm (Figure 1).

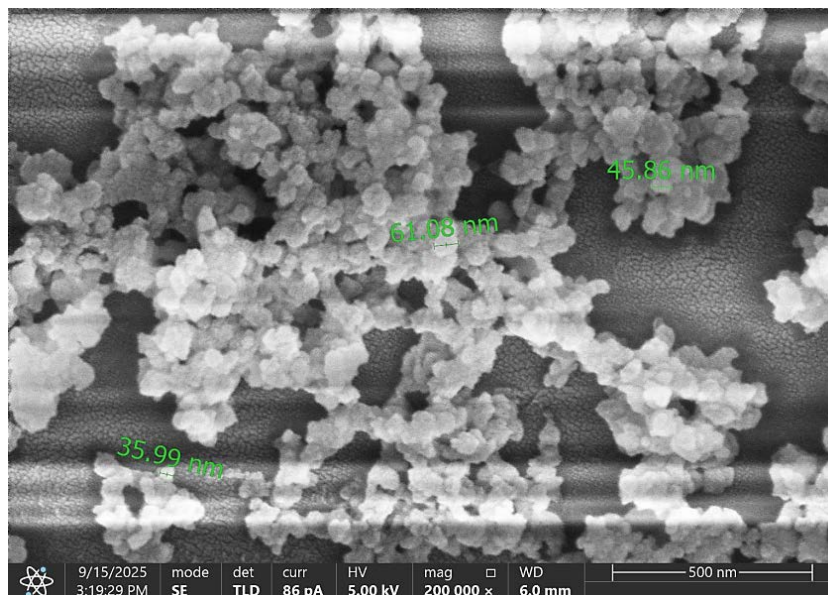


Figure 1 – SEM micrograph of iron nanoparticles biosynthesized using *Artemisia absinthium* L. aqueous extract. Representative particle measurements (35.99, 45.86, and 61.08 nm) are indicated in the image

Both the aqueous extract and the FeNP-containing formulation were applied exclusively by foliar spraying. The volume of working solution was adjusted according to plant developmental stage and canopy size to ensure uniform wetting of the leaf surface. Approximately 20-25 mL plant⁻¹ of working solution was applied during the pre-flowering treatment, whereas approximately 40-50 mL plant⁻¹ was applied during flowering. For treatments involving two applications, the plants were sprayed at both stages using the corresponding application volume.

Six treatment variants and a water-treated control were evaluated, comprising two formulations and three foliar application schemes. The *Artemisia absinthium* L. aqueous extract was applied as a single treatment before flowering (WE-BF), as a single treatment at flowering (WE-FL), or as a double treatment at both stages (WE-DA). The FeNP-containing formulation was applied according to the same schemes: a single treatment before flowering (FeNPs-BF), a single treatment at flowering (FeNPs-FL), or a double treatment at both stages (FeNPs-DA). Control plants were sprayed with water. The pre-flowering treatment was performed approximately 30 days after planting, and the flowering-stage treatment was carried out approximately 20 days after the first treatment.

Each treatment comprised 100 experimental plants. In each year of the study, 10 plants per treatment were selected for yield assessment using systematic sampling, with every tenth plant included in the sample. Thus, yield was assessed on 10 plants per treatment in 2024 and 10 plants per treatment in 2025. The number of tubers and total tuber weight were determined individually for each selected plant.

The obtained data were processed using IBM SPSS Statistics software. The effects of treatment and year on potato yield were evaluated using two-way analysis of variance (ANOVA), with treatment and year considered as fixed factors. The treatment × year interaction was also included in the model. The analysis was performed separately for total tuber number and total tuber weight per plant. Following ANOVA, planned comparisons between each treatment and the water-treated control were performed, with Holm adjustment for multiple comparisons. Differences were considered statistically significant at $p \leq 0.05$.

Along with total yield, the yield of marketable tubers was of considerable importance; according to the standard, tubers weighing more than 50 g were classified as marketable, those weighing 30-50 g as seed tubers, and those weighing less than 30 g as non-standard tubers, in accordance with the requirements of GOST R 7176-2017 "Food Potatoes. Specifications." The obtained data are presented in Table 1.

The chemical composition of potato tubers was analyzed at the Research Laboratory for Food Quality and Safety Assessment of Almaty Technological University on the basis of laboratory test reports.

Starch content was determined in accordance with the requirements of GOST 7194-81 "Fresh Potatoes. Acceptance Rules and Methods for Quality Determination." Vitamin C content was determined by the titrimetric

method according to GOST 24556-89 "Processed Fruit and Vegetable Products. Methods for the Determination of Vitamin C." Nitrate content was determined in accordance with GOST 29270-95 "Processed Fruit and Vegetable Products. Methods for the Determination of Nitrates."

Dry matter and moisture contents in potato tubers were determined at the Department using a RADWAG MAC 210 moisture analyzer in accordance with the manufacturer's instructions.

The technological properties of potato were evaluated by the resistance of tuber flesh to browning. The browning of raw potato flesh was evaluated by visual assessment of changes in the colour of the cut surface over time, based on the approaches and methods described in scientific publications by other authors and widely used in potato breeding and technological studies [2, p. 120,9. p. 208,10. p.9].

To evaluate the browning of raw tubers, the tubers were peeled, cut longitudinally into two halves (from the apical end to the stolon end), and placed in Petri dishes exposed to air. Visual assessment of the degree of flesh browning was carried out 30 min, 3 h, and 24 h after cutting the tubers. The intensity of browning was evaluated using a nine-point scale: 9 points – the flesh colour did not change; 7 points – slight change in flesh colour; 5 points – moderate browning; 3 points – severe browning; 1 point – very severe browning of the flesh [9. p.210,10 p.9].

The browning of cooked tubers was evaluated immediately after boiling (after 20 min) and repeatedly after 3 h and 24 h. For this purpose, 5 tubers from each treatment were boiled in their skins without allowing them to overcook, after which the tubers were peeled, cut into two halves, and one half of each tuber was left exposed to air on filter paper. The intensity of browning was evaluated at the stolon end and at the apical end of the tuber. The average browning score was calculated as the mean value of the two assessment times using the nine-point scale for evaluating the resistance of potato flesh to browning applied in similar studies [2, p. 120,10. p. 9].

Results and Discussion. The data obtained during the study on the total yield and yield structure of potato under the experimental treatments were summarized and are presented in Table 1

Table 1 – Effect of the studied treatments on the Colombo potato yield (mean for 2024-2025)

Treatment	Total tuber number (tubers plant ⁻¹), 2024	Total tuber number (tubers plant ⁻¹), 2025	Total tuber weight (g plant ⁻¹), 2024	Total tuber weight (g plant ⁻¹), 2025
WE-BF	18.30 ± 3.65	20.40 ± 3.24	1254.6 ± 307.1	1622.6 ± 226.1
WE-DA	21.00 ± 8.88	21.30 ± 3.20	1390.3 ± 472.1	1938.9 ± 572.7
WE-FL	17.40 ± 3.84	18.80 ± 3.65	1191.4 ± 337.4	1352.1 ± 203.8
FeNPs-BF	15.50 ± 2.59	17.00 ± 2.49	1203.2 ± 365.6	1872.3 ± 125.0
FeNPs-DA	21.30 ± 2.87	21.60 ± 4.50	1386.6 ± 410.3	2039.4 ± 503.3
FeNPs-FL	15.90 ± 3.25	19.50 ± 3.44	1220.5 ± 254.0	1574.5 ± 287.6
Control	16.10 ± 5.74	17.80 ± 3.12	1018.6 ± 207.4	1229.8 ± 233.4

Potato yield differed between the two years of the study, with generally higher values recorded in 2025 than in 2024 (Table 1). Two-way ANOVA confirmed a significant effect of year on both total tuber number ($F(1,126) = 4.800$, $p = 0.030$) and total tuber weight ($F(1,126) = 52.707$, $p < 0.001$). Treatment also had a significant effect on total tuber number ($F(6,126) = 4.603$, $p < 0.001$) and total tuber weight ($F(6,126) = 7.382$, $p < 0.001$). However, the treatment × year interaction was not significant for either total tuber number ($F(6,126) = 0.362$, $p = 0.902$) or total tuber weight ($F(6,126) = 1.754$, $p = 0.114$), indicating that although the absolute yield differed between years, the overall pattern of treatment responses was comparable.

Among the treatments, double foliar application produced the most consistent increase in yield. For the *Artemisia absinthium* L. aqueous extract (WE-DA), the mean number of tubers was 21.00 tubers plant⁻¹ in 2024 and 21.30 tubers plant⁻¹ in 2025, compared with 16.10 and 17.80 tubers plant⁻¹, respectively, in the control. The corresponding total tuber weights were 1390.3 and 1938.9 g plant⁻¹ for WE-DA, compared with 1018.6 and 1229.8 g plant⁻¹ in the control. Planned comparisons with Holm adjustment confirmed that WE-DA significantly increased both total tuber number (adjusted $p = 0.008$) and total tuber weight (adjusted $p < 0.001$) relative to the control.

A similar response was observed for the FeNP-containing formulation. Double application (FeNPs-DA) resulted in 21.30 and 21.60 tubers plant⁻¹ in 2024 and 2025, respectively, with corresponding total tuber weights of 1386.6 and 2039.4 g plant⁻¹. Compared with the control across the two-year dataset, FeNPs-DA significantly increased both total tuber number (adjusted $p = 0.005$) and total tuber weight (adjusted $p < 0.001$). The other application schemes did not significantly affect tuber number relative to the control. For total tuber weight, significant increases were also detected for WE-BF (adjusted $p = 0.016$), FeNPs-BF (adjusted $p = 0.001$), and FeNPs-FL (adjusted $p = 0.030$), whereas the difference for WE-FL was not significant (adjusted $p = 0.186$).

The observed response to the aqueous plant extract is consistent with the general concept that plant-extract-based biostimulants may influence crop productivity through complex mixtures of biologically active plant metabolites. A large field-trial meta-analysis showed that plant extracts were among the most effective categories of non-microbial biostimulants, although the magnitude of the response varied according to crop, environmental conditions, application method, dose, and frequency [15, pp. 4-6]. In potato, hormonal regulation

is closely associated with tuber initiation and development. Auxin-related processes have been shown to affect assimilate influx, starch biosynthesis, tuber size, tuber weight, and tuber development [11, p. 3].

The positive effect of the FeNP-containing formulation may also be associated with the physiological role of iron in plant metabolism. Iron is involved in electron transport, photosynthesis, respiration, and chlorophyll synthesis [12, p. 24]. Experimental evidence further indicates that iron oxide nanoparticles can influence plant growth and photosynthetic processes and may improve iron availability in plant tissues [12., p. 3].

Plant extracts contain various phytochemicals, including phenolic compounds, reducing sugars, ascorbic acid, and other polyphenolic constituents, which may act as reducing and stabilizing agents during green nanoparticle synthesis [14, p. 2].

Overall, double application of either the *A. absinthium* aqueous extract or the FeNP-containing formulation produced the most consistent response, increasing both tuber number and tuber weight. The absence of a significant treatment $\times$ year interaction indicates that the relative pattern of treatment effects was maintained across the two growing seasons despite differences in absolute yield between years. This finding is also compatible with published evidence showing that biostimulant effectiveness depends strongly on application management and environmental conditions rather than being constant across all cultivation situations [15, pp. 4-6].

Table 2 – Quality characteristics of the 2025 potato crop

Treatment	Code	Starch content (%)	Vitamin C content (mg/100 g)	Nitrate content (mg/kg)	Dry matter/Moisture content (% of fresh weight)
WE-BF	5.97	18 $\pm$ 0.2	67.8 $\pm$ 1.02	15.157/84.843	
2	WE-DA	6.71	23 $\pm$ 0.3	61.3 $\pm$ 0.92	14.655/85.345
3	WE-FL	9.98	27 $\pm$ 0.4	45.8 $\pm$ 0.50	15.314/84.686
4	FeNPs-BF	7.42	25 $\pm$ 0.3	58.9 $\pm$ 0.88	19.603/80.397
5	FeNPs-DA	10.14	28 $\pm$ 0.5	40.6 $\pm$ 0.57	17.542/82.458
6	FeNPs-FL	5.48	30 $\pm$ 0.3	69.2 $\pm$ 0.90	15.784/84.216
7	Control	9.68	23 $\pm$ 0.3	49.7 $\pm$ 0.87	15.450/84.550

The biochemical characteristics of 'Colomba' potato tubers varied among the studied treatments (Table 2). Starch content ranged from 5.48 to 10.14%, while dry matter content ranged from 14.65 to 19.60%. For comparison, reference values reported for the 'Colomba' cultivar are 10.9% starch and 16.7% dry matter [8]. Vitamin C content ranged from 18 to 30 mg/100 g, with the highest value recorded for FeNPs-FL (30 mg/100 g), followed by FeNPs-DA (28 mg/100 g) and WE-FL (27 mg/100 g), whereas the control contained 23 mg/100 g. Nitrate content ranged from 40.6 to 69.2 mg/kg, with the lowest value recorded for FeNPs-DA (40.6 mg/kg), compared with 49.7 mg/kg in the control. The highest dry matter content was recorded for FeNPs-BF (19.60%), compared with 15.45% in the control. Moisture content varied inversely with dry matter content and ranged from 80.40 to 85.35%. Since statistical significance was not established for these biochemical parameters, the observed differences should be interpreted as treatment-associated variation rather than as statistically confirmed treatment effects.

The observed variation in tuber biochemical composition may reflect changes in plant physiological and metabolic processes associated with the treatments. Iron is involved in chlorophyll biosynthesis, photosynthesis, chloroplast development, dark respiration, and the activity of several respiratory enzymes [13. p. 3]. Iron nanoparticles may also affect iron availability in plant tissues and thereby influence plant physiological processes [13. p. 3]. Nevertheless, the present results do not establish a direct mechanistic relationship between FeNP application and changes in individual biochemical characteristics of potato tubers.

Overall, the studied treatments did not result in a consistent deterioration of the main biochemical quality characteristics of the tubers, although treatment-dependent variation was observed for individual parameters.

Table 3 – Technological properties of potato (mean values for two years)

Preparation	Treatment	Browning score, points					
		Cooked tubers			Raw tubers		
		20 min	3 h	24 h	30 min	3 h	24 h
Artemisia absinthium aqueous extract	WE-BF	9	9	9	9	8	6
	WE-DA	9	9	9	9	8	6
	WE-FL	9	9	9	9	8	6
Artemisia absinthium extract + FeNPs	FeNPs-BF	9	9	9	9	8	6
	FeNPs-DA	9	9	9	9	8	6
	FeNPs-FL	9	9	9	9	8	6
Control (water)	Control	9	9	9	9	8	6

The assessment of technological properties showed no differences in flesh browning scores among the studied treatments (Table 3). Cooked tubers retained the maximum score of 9 points throughout the observation period, indicating the absence of visible flesh darkening under the conditions of the test. In raw tubers, the browning score was 9 points 30 min after cutting, decreased to 8 points after 3 h, and reached 6 points after 24 h. The same pattern was observed in all treatment groups, including the water-treated control, indicating that foliar application of either the *Artemisia absinthium* L. aqueous extract or the FeNP-containing formulation did not alter the resistance of tuber flesh to browning.

Flesh browning is an important technological quality characteristic of potato tubers because changes in colour after peeling, cutting, or cooking may affect their suitability for processing and consumer acceptance. Enzymatic browning of raw potato tissue is primarily associated with polyphenol oxidase activity and the oxidation of phenolic compounds following tissue damage [16, p. 233; 17, p. 1]. In the present study, the identical browning scores observed among the treatments indicate that the changes in yield and biochemical characteristics associated with the studied preparations were not accompanied by detectable changes in this technological quality parameter. Thus, under the conditions of the present experiment, both the *A. absinthium* aqueous extract and the FeNP-containing formulation maintained the browning characteristics observed in the untreated 'Colomba' control.

Conclusions. The results of the two-year field study showed that foliar application of the *Artemisia absinthium* L. aqueous extract and the FeNP-containing formulation affected the yield of 'Colomba' potato, with the magnitude of the response depending on the application scheme. Two-way ANOVA demonstrated significant effects of treatment on both total tuber number ($F(6,126) = 4.603$, $p < 0.001$) and total tuber weight ($F(6,126) = 7.382$, $p < 0.001$). A significant year effect was also observed for tuber number ($F(1,126) = 4.800$, $p = 0.030$) and tuber weight ($F(1,126) = 52.707$, $p < 0.001$), whereas the treatment $\times$ year interaction was not significant for either parameter.

Double foliar application produced the most consistent yield response. The *A. absinthium* aqueous extract applied twice (WE-DA) increased both total tuber number (adjusted $p = 0.008$) and total tuber weight (adjusted $p < 0.001$) compared with the water-treated control across the two-year dataset. Similarly, double application of the FeNP-containing formulation (FeNPs-DA) significantly increased total tuber number (adjusted $p = 0.005$) and total tuber weight (adjusted $p < 0.001$). Significant increases in total tuber weight were also observed for WE-BF (adjusted $p = 0.016$), FeNPs-BF (adjusted $p = 0.001$), and FeNPs-FL (adjusted $p = 0.030$), whereas the remaining differences were not statistically significant.

The studied treatments were not associated with a consistent deterioration in the measured biochemical quality characteristics of the tubers. Starch, vitamin C, nitrate, dry matter, and moisture contents showed treatment-associated variation; however, statistical significance was not established for these biochemical parameters. Likewise, no differences in flesh browning scores were observed among the treatments and the water-treated control: cooked tubers retained a score of 9 points throughout the observation period, while raw tubers showed the same pattern of 9, 8, and 6 points after 30 min, 3 h, and 24 h, respectively.

Overall, the results indicate that double foliar application of either the *A. absinthium* aqueous extract or the FeNP-containing formulation was the most consistently effective application scheme for improving the yield of 'Colomba' potato under the conditions of the present two-year field experiment without detectable deterioration in the measured tuber quality parameters. Because the study was conducted using a single potato cultivar and under the agroclimatic conditions of the Pavlodar Region, further studies involving additional cultivars, environments, and growing seasons are required before broader recommendations for potato production can be made.

Conflict of interest: The authors declare no conflict of interest.

REFERENCES:

1. Ahmadu T., Abdullahi A., Ahmad K. The role of crop protection in sustainable potato (*Solanum tuberosum* L.) production to alleviate global starvation problem: An overview. IntechOpen, 2021. DOI: 10.5772/intechopen.100058.
2. Pityurina I.S., Vinogradov D.V., Novikova A.V. Produktivnost' i tehnologicheskie pokazateli kachestva klubnej sortov kartofelya, vy'rashhenny'h v usloviyah Nechernozemnoj zony' [Productivity and technological quality indicators of potato tubers grown under conditions of the Non-Chernozem zone]. *Vestnik Krasnoyarskogo gosudarstvennogo agrarnogo universiteta*, 2021, no. 1 (166), pp. 118-125. DOI: 10.36718/1819-4036-2021-1-118-125. (In Russian)
3. Ezekiel R., Singh N., Sharma S. et al. Beneficial phytochemicals in potato – a review. *Food Research International*, 2013, vol. 50, no. 2, pp. 487-496. DOI: 10.1016/j.foodres.2011.04.025.
4. Burgos G., Auqui S., Amoros W. et al. Ascorbic acid concentration of native Andean potato varieties as affected by environment, cooking and storage. *Journal of Food Composition and Analysis*, 2009, vol. 22, no. 6, pp. 533-538. DOI: 10.1016/j.jfca.2008.05.013.
5. Camire M.E., Kubow S., Donnelly D.J. Potatoes and human health. *Critical Reviews in Food Science and Nutrition*, 2009, vol. 49, no. 10, pp. 823-840. DOI: 10.1080/10408390903041996.

6. Sergeeva Z.F., Sinitsyna S.M., Lyskova I.V. et al. **Ocenka sortov kartofelya po urozhainosti i biohimicheskim pokazatelyam v usloviyah Kirovskoj oblasti** [Evaluation of potato varieties by yield and biochemical parameters under conditions of the Kirov region]. *Agrarnaya nauka Evro-Severo-Vostoka*, 2018, no. 3 (64), pp. 34-38. DOI: 10.30766/2072-9081.2018.64.3.34-38. (In Russian)
7. Tivo P.F., Saskevich L.A., But E.A. **Problema nitrátov v rastenievodstve** [Nitrate problem in crop production]. *Melioraciya*, 2016, no. 3, pp. 41-48. (In Russian)
8. **Colomba: rannespelyj stolovyj sort kartofelya s rano nastupayushhim urozhajem** [Colomba: early-maturing table potato variety with early yield]. PotatoPro. Available at: <https://www.potatopro.com/potato-varieties/colomba> (accessed 29 January 2026).
9. Cherezov S.N., Gizatullina A.T., Stashevski Z. **Ocenka selekcionnogo materiala kartofelya: opredelenie prigodnosti klubnej dlya promy'shlennoj pererabotki** [Evaluation of potato breeding material: determination of tuber suitability for industrial processing]. *Ucheny'e zapiski Kazanskogo universiteta. Seriya Estestvenny'e nauki*, 2010, vol. 152, no. 2, pp. 207-216. (In Russian)
10. Gordeeva A.V., Udalova E.Yu. **Ocenka kulinaryh kachestv gibridov kartofelya po priznaku potemneniya myakoti sy'ry'h i varen'yh klubnej** [Evaluation of cooking qualities of potato hybrids by browning of raw and cooked tuber flesh]. *Vestnik Marijskogo gosudarstvennogo universiteta. Seriya "Sel'skhozaystvenny'e nauki. E'konomicheskie nauki"*, 2017, vol. 3, no. 3 (11), pp. 7-12. (In Russian)
11. Kondhare K.R., Patil A.B., Giri A.P. **Auxin: An emerging regulator of tuber and storage root development**. *Plant Science*, 2021, vol. 306, art. 110854. DOI: 10.1016/j.plantsci.2021.110854.
12. Feng Y., Cui X., He S. et al. **Effects of iron oxide nanoparticles (Fe₃O₄) on growth, photosynthesis, antioxidant activity and distribution of mineral elements in wheat (*Triticum aestivum*) plants**. *Plants*, 2022, vol. 11, no. 14, art. 1894. DOI: 10.3390/plants11141894.
13. Li Y., Zhang W., Niu J. et al. **Application and mechanisms of metal-based nanoparticles in the control of bacterial and fungal crop diseases**. *Pest Management Science*, 2023, vol. 79, no. 1, pp. 21-36. DOI: 10.1002/ps.7218.
14. Jain R., Mendiratta S., Kumar L., Srivastava A. **Green synthesis of iron nanoparticles using *Artocarpus heterophyllus* peel extract and their application as a heterogeneous Fenton-like catalyst for the degradation of Fuchsin Basic dye**. *Current Research in Green and Sustainable Chemistry*, 2021, vol. 4, art. 100086. DOI: 10.1016/j.crgsc.2021.100086.
15. Li J., Van Gerrewey T., Geelen D. **A meta-analysis of biostimulant yield effectiveness in field trials**. *Frontiers in Plant Science*, 2022, vol. 13, article 836702. DOI: 10.3389/fpls.2022.836702.
16. Snoeck D., de Jesus Raposo M.F., De Moraes A.M.M.B. **Polyphenol oxidase activity and colour changes of peeled potato (cv. Monalisa) in vacuum**. *International Journal of Postharvest Technology and Innovation*, 2011, vol. 2, no. 3, pp. 233-242. DOI: 10.1504/IJPTI.2011.043329.
17. Bobo G., Arroqui C., Virseda P. **Natural plant extracts as inhibitors of potato polyphenol oxidase: The green tea case study**. *LWT*, 2022, vol. 153, art. 112467. DOI: 10.1016/j.lwt.2021.112467.
18. Sui X. et al. **Enzymatic browning and polyphenol oxidase control strategies**. *Current Opinion in Biotechnology*, 2023, vol. 81, art. 102921. DOI: 10.1016/j.copbio.2023.102921.

Received: 03 August 2026. **Accepted:** 03 September 2026. **Published:** 30 September 2026.

Information about the authors:

Seitkhanova Kumiszhana Kabdyluakhitkyzy* – Master of Agricultural Sciences, PhD student, "Biotechnology" educational program, Republic of Kazakhstan, 140000, Pavlodar, Toraighyrov University, 64 Lomov Str., tel.: 87182673641 (ext. 1295), e-mail: seyt.k@inbox.ru.

Anikina Irina Nikolayevna – Candidate of Agricultural Sciences, Professor, Department of biotechnology, Toraighyrov University, Republic of Kazakhstan, 140000, Pavlodar, 64 Lomov Str., tel.: 87182673641 (ext. 1295), e-mail: anikina.i@mail.ru.

Сейтханова Күмісжан Қабдылуахитқызы* – ауыл шаруашылығы ғылымдарының магистрі, «Биотехнология» білім беру бағдарламасының докторанты, «Торайғыров университеті» КЕАҚ, Қазақстан Республикасы, 140000, Павлодар қ., Ломов көш, 64, тел.: 87182673641 (ішкі 1295), e-mail: seyt.k@inbox.ru.

Аникина Ирина Николаевна – ауыл шаруашылығы ғылымдарының кандидаты, «Биотехнология» кафедрасының профессоры, «Торайғыров университеті» КЕАҚ, Қазақстан Республикасы, 140000, Павлодар қ., Ломов көш, 64, тел.: 87182673641 (ішкі 1295), e-mail: anikina.i@mail.ru.

Сейтханова Кумисжан Кабдылуахитқызы* – магистр сельскохозяйственных наук, докторант образовательной программы «Биотехнология», НАО «Торайғыров университет», Республика Казахстан, 140000 г. Павлодар, ул. Ломова, 64, тел.: 87182673641 (вн. 1295), e-mail: seyt.k@inbox.ru.

Аникина Ирина Николаевна – кандидат сельскохозяйственных наук, профессор кафедры биотехнологии, НАО «Торайғыров университет», Республика Казахстан, 140000, г. Павлодар, ул. Ломова, 64, тел.: 87182673641 (вн. 1295), e-mail: anikina.i@mail.ru.