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The Impact of Some Biostimulators on Tuber Yield and Quality of Two Potato Cultivars Planted at Two Densities

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ABSTRACT

Nowadays, biostimulants are increasingly being applied to potato crops to increase nutrient efficiency and better tolerate abiotic stress. Aiming to achieve sustainable potato crops, biostimulants have positive effects on crop yield. This research investigates the effects of foliar fertilization, planting density, and environmental conditions on yield and tuber quality (starch, protein, ash, dry matter content) in two potato cultivars, Darilena and Ultra, across two locations (Brașov and Codlea) in the year 2023 and 2024. The experiment involved five foliar fertilizer treatments: control (V1), two biostimulants - Genaktis (V2) and Irys (V3), a third biostimulant - Number One (V4) and a foliar fertilizer with biostimulant properties - Wuxal Macromix (V5). Results showed that Ultra at 53,000 plants/ha combined with biostimulants V4 and V5 achieved the highest yields, particularly in 2023. Darilena consistently recorded higher starch and protein content, especially in 2024 and under lower planting density. PCA and correlation analyses revealed that the yield was negatively associated with starch and dry matter, while starch strongly correlated with dry matter content. These results emphasize the need to align cultivar choice, fertilization strategy, and planting density with local environmental conditions to maximize tuber quality and yield.

Keywords: potato, yield, quality, fertilizer, density.

INTRODUCTION

One of the plants that changed the world is potato. It is cultivated on all continents, in over 170 countries (FAO, 2024). Potato is a plant easily available on the market, with many uses: direct consumption and food processing (chips, crisps, dried), starch for the agri-food and chemical industry (starch, glucose, maltodextrins, glucose syrups, modified starches, ethanol) or feed for farm animals (fresh tubers, dried potatoes, potato protein) (Javed et al., 2019; Zarzecka et al., 2022).

Potatoes are perceived as a staple food and have evolved in recent decades, becoming versatile and convenient for everyone, fitting into any diet, menu, or lifestyle (Fleming and Morris, 2024).

Starch is the main ingredient in potato tubers and is closely correlated with the amount of dry matter (Zarzecka et al., 2021). Potato starch is a polymeric carbohydrate consisting of large numbers of glucose units through glycosidic bonds, which is mainly formed with amylose and amylopectin (Tong et al., 2023).

The role of biostimulators is well defined by the European legislation, Regulation (EU) 2019/1009 (2023) being described as a product that stimulates plant nutritional processes regardless of the nutrient content of the product improving one or more of the following characteristics of the plant or the plant rhizosphere: (a) nutrient use efficiency; (b) tolerance to abiotic stress; (c) quality traits; (d) availability of confined nutrients in soil or rhizosphere (Sîrbu et al., 2022, 2025).

Plant biostimulators are various non-toxic substances, mostly of natural origin, that improve and stimulate plant life processes in a different way than fertilizers or

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phytohormones (Jenaru and Ion, 2024). Biostimulants are products capable of acting on the metabolic and enzymatic processes of plants, improving crop productivity and yield quality (Meluca et al., 2022). They have positive effects on plant growth, stress reduction and disease prevention, so their use contributes to increasing plant production, yield and quality (Xu and Geelen, 2018). Improving the effects of abiotic stress is the most commonly mentioned benefit of using biostimulants (Rouphael et al., 2017). Biostimulants are increasingly integrated into production systems with the goal of modifying physiological processes within the plants (Yakhin et al., 2017).

The use of biostimulants in potato cultivation is justified by increasing the size and quality of the yield. Their action is to stimulate the development of leaves, stems and roots of plants, to supplement the deficiency of nutrients during the growing season caused by, among others, drought or agrotechnical errors (Mystkowska, 2019).

Of the climate changes, and drought, influences and planning of adequate response are the biggest challenges today. Climate changes and drought occurrence influences negatively the plant development. These can be mitigated by finding appropriate measures (Bărbieru, 2022).

Improved stress resilience contributes to more robust tuber development, even in challenging growing environments.

To achieve reasonable yields and high-quality produce, growers use a wide range of fertilizers and pesticides, which account for up to 38 and 43% of total crop production costs, respectively. Abundant use of these synthetic chemicals can result in detrimental effects on non-target species and chemical contamination of soil, water supplies, and harvested products (Karak et al., 2023).

The aim of this paper is to present the effects of some biostimulators at tow potato cultivars planted at two densities on tuber yield and tuber quality.

MATERIAL AND METHODS

Fields experiments were conducted in the years 2023 and 2024 in two locations, respectively NIRDPSB Braşov and a private farm in Codlea town, using two potato cultivars (Darilena and Ultra). Five foliar fertilizers were tested under two planting densities (45,000 and 53,000 plants/ha). The treatments included a control variant (V1), three biostimulants (Genaktis, Irys, Number One), and a foliar fertilizer with biostimulant effect (Wuxal Macromix). Cultivation treatments were carried out in accordance with the principles of good agricultural practice. Chemical plant protection was used against the Colorado potato beetle and late blight.

Meteorological conditions

In the year 2023, the growing season was warm but no so dry. The temperatures between May and August was higher on average by 1.8°C, compared to multi annual average (MAA) and the rainfalls in June and August exceeded the MAA as volume, but significant rains fell in a short period of time

In the year 2024, the summer months (June-August) recorded higher temperatures than the MAA. Also, the volume of precipitation was much lower in all three months, establishing the phenomena of atmospheric and pedological drought (Table 1).

Table 1. Average monthly temperatures and amount of rainfall during the vegetation period (2023-2024)

Month	Temperature (°C)			Rainfall (mm)		
	Average of 2023	Average of 2024	MAA	Sum of 2023	Sum of 2024	MAA
April	7.3	12.2	8.5	83.1	43.5	50.0
May	13.8	13.8	13.6	77.5	42.7	82.0
June	17.6	21.1	16.5	111.0	54.5	96.7
July	20.5	22.2	18.1	59.1	79.4	99.8
August	20.9	21.2	17.5	77.5	28.9	76.4
September	16.9	15.9	13.6	11.0	48.7	52.5

The **Calcination method** was used to determine the ash content.

The potato tubers were washed, cleaned and cut into small pieces. A known amount of grated sample (1 g) was placed in a porcelain crucible, which was tare (m0) and reweighed (m1). The sample was placed in the calcination furnace, where it was maintained at 550°C for 3 hours, until a gray-white ash was obtained, without black particles (undecomposed carbon). After complete cooling in the desiccator, the crucible with ash was weighed (m2).

Total ash (%) = (m2 – m0)/(m1 – m0) x 100

where:

m0 = mass of empty crucible (g)

m1 = mass of crucible + ground sample (g)

m2 = mass of crucible + ash (g)

The **protein content** was analyzed according to the principle of the Kjeldahl method, which consists in determining the total organic nitrogen content of a sample by converting it into ammonium ions in an acidic medium, followed by distillation and titration. The nitrogen thus determined is used to calculate the crude protein (CP) content, using a standard conversion factor (F).

CP % = ((V1f1 -V2f2) x r x m1 x F)/m x 100

where:

V1 = the volume of 0.1 N sulfuric acid introduced into the collecting vessel is expressed in cm^3, depending on the amount of sample analyzed;

f1 = the factor of the 0.1 N sulfuric acid solution (determined by prior titration with a standard Na_2CO_3 or NaOH solution);

V_2 = the volume of the 0.1 N sodium hydroxide solution used in the titration, expressed in cm^3;

f_2 = the correction factor of the 0.1 N sodium hydroxide solution;

m_1 = the amount of nitrogen (g) corresponding to 1 cm^3 of 0.1 N sulfuric acid; the standard value used is 0.014008 g N/cm^3;

r = dilution ratio of the digestate, in this case r = 1 (without further dilution);

F - conversion factor nitrogen → crude protein, expressed as the ratio between the mass of crude protein and the mass of nitrogen determined. In the case of potato tubers, the value F = 5.7 is used;

m - mass of the sample used for analysis, expressed in grams (g).

Statistical analysis

Analysis of variance and multiple comparisons tests were carried out with the POLIFACT program, graphical representation and correlations with the EXCEL and Past 4.0.3 programs.

RESULTS AND DISCUSSION

Potato yield comparison across locations, varieties, densities and experimental years (Figure 1) indicate that at NIRDPSB Brașov location, the highest potato yields in 2023, were recorded for the Ultra variety, particularly at a planting density of 53,000 plants/ha, where the red colour indicates a yield approaching 44.9 t/ha. In contrast, yields in 2024, were significantly lower across all tested variants, with cool colours dominating, suggesting values around 14.4-24.6 t/ha. Based on the average over the two years, the Ultra variety at the higher density (53,000 plants/ha) showed superior performance (yellow), with estimated yields between 34.7 and 44.9 t/ha.

At Codlea location, similar trends are observed. The year 2023 was also favorable, especially for the Ultra variety at 53,000 plants/ha, where yield again reaches high levels, indicated by the intense red color (over 44 t/ha). In 2024, just like in the other location, yields dropped significantly, dominated by shades of blue and cyan, indicating lower values between 14.4 and 24.6 t/ha. When averaging the two years, the Ultra variety at 53,000 plants/ha once again stands out as the best performer, followed by the same variety at the lower density.

The experiment also evaluated the yield performance. The results, illustrated through a heatmap where cool colours (blue) represent lower yields and warm colours (yellow to red) represent higher yields, revealed significant differences across treatments, varieties, and locations. In general, the Ultra cultivar showed a stronger positive response to foliar fertilization compared to Darilena, particularly under the higher planting density of 53,000 plants/ha. The most effective treatments were V4 (Number One) and V5 (Wuxal Macromix), which consistently led to the highest yields, especially in NIRDPSB Brașov, where warm color zones were most prominent. In contrast, the control treatment (V1) resulted in the lowest yields across all conditions. Codlea location presented lower yield performance overall, with cooler colour patterns indicating limited effectiveness of treatments in that location. Moderate yield improvements were observed with V2 (Genaktis) and V3 (Irys), although they did not reach the performance levels of V4 and V5. These findings emphasize the importance of foliar fertilization, particularly with high-performance biostimulants, and highlight how planting density and environmental conditions interact with cultivar and treatment choice to influence potato yield.

Research conducted worldwide further highlights the beneficial impacts of biostimulants on potato yield. Positive results have been reported by Samy et al. (2014), and Anikin and Issayev (2023), confirming yield increases and improved tuber quality following the application of biostimulants (Barbaś et al., 2025).

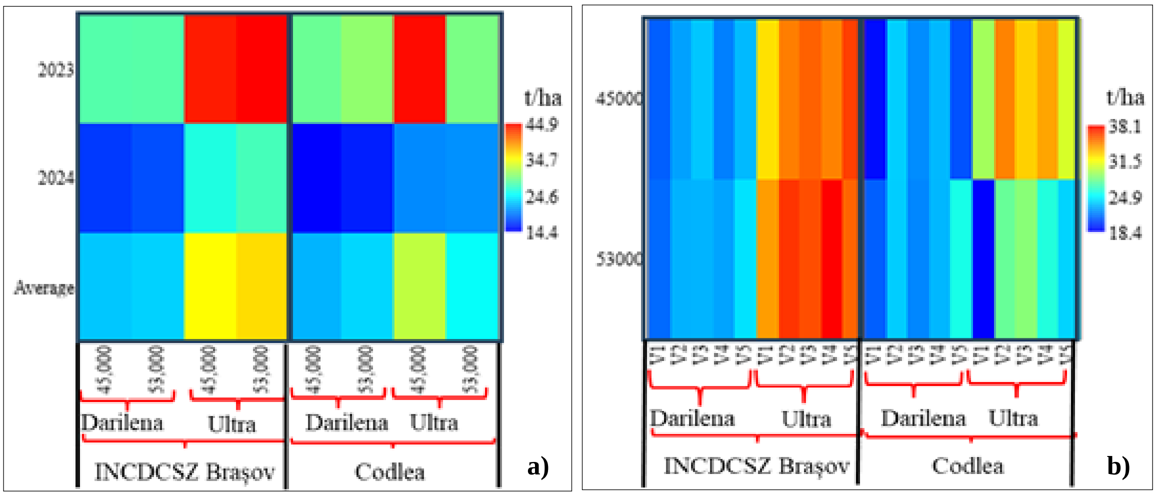

Figure 1. Potato yield comparison across locations, varieties, densities and experimental years (a) and across locations, varieties, fertilization treatment and densities (b)

Overall, the Darilena variety showed a higher starch content compared to Ultra variety, especially at the higher planting density of 53,000 plants/ha (Figure 2). These differences were observed in both locations, Brașov and Codlea, but were more pronounced in Codlea, where Darilena at 53,000 plants/ha in 2024 recorded the highest starch content, highlighted by the intense red color.

The year 2024 appears to have been more favorable for starch accumulation compared to 2023, across most of the tested combinations.

On the other hand, the combination of Ultra variety at 53,000 plants/ha in Codlea location, during the year 2023, resulted in the lowest starch content, shown by the blue color, which may indicate that this variety is more sensitive to agronomic practices.

The overall averages confirm the same trends, with Darilena showing more stable and higher starch content, particularly at higher planting density and in Codlea location.

The second heatmap illustrates the starch content (%) in potato tubers for the varieties Darilena and Ultra, grown under two planting densities (45,000 and 53,000 plants/ha) and treated with four foliar fertilization products (V2-V5), in the locations Brașov and Codlea. The color gradient ranges from cool colors (blue) indicating lower starch content, to warm colors (yellow to red) indicating higher starch content. The data show that Brașov (right panel) generally recorded higher starch content than Codlea (left panel), with particularly high values under V1 (control) and V2 (Genaktis) treatments for the Darilena variety, highlighted by red and orange shades. These values exceeded 14%, indicating a positive environmental influence on starch accumulation in Brașov. Conversely, Ultra recorded lower starch percentages, especially under V3-V5, where blue tones dominate the color spectrum in both locations. In Codlea, the starch content remained relatively stable across treatments and densities, with values mostly ranging from 12.5 to 13.5%, as indicated by green to yellow tones. Planting density had a modest effect on starch content; differences between the 45,000 and 53,000 plants/ha were minor, suggesting that starch accumulation is more influenced by variety and location than by planting density. Overall, Darilena, especially in Brașov, showed the highest starch accumulation, while Ultra exhibited more modest levels across all treatments. This suggests that Darilena may be better suited for starch-oriented production, particularly when grown in more favorable environments and with limited or targeted foliar input.

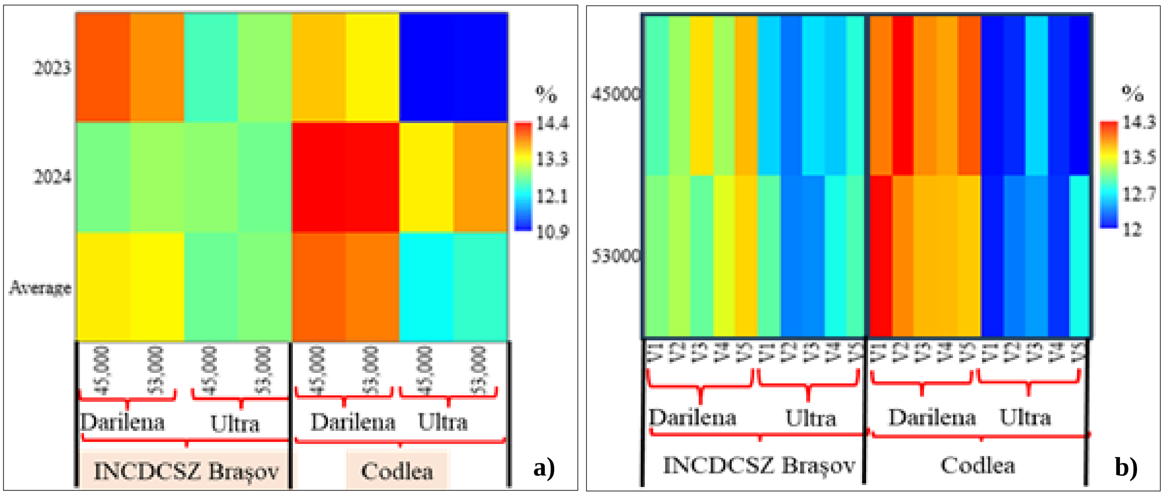

Figure 2. Potato starch comparison across locations, varieties, densities and experimental years (a) and across locations, varieties, fertilization treatment and densities (b)

Studies by other researchers indicate higher starch yields after the application of biostimulants (Mystkowska, 2019).

Rymuza et al. (2015) and Trawczyński, (2020) also showed that dry years with higher air temperature also had a more positive effect on the accumulation of dry matter and starch in tubers than wet and cool years.

Figure 3 shows the protein content (%) in potato tubers as influenced by variety (Darilena and Ultra), planting density (45,000 and 53,000 plants/ha), location (NIRDPSB Brașov and Codlea), and year (2023 and 2024).

At NIRDPSB Brașov location, variety Darilena planted at 45,000 plants/ha in the year 2024 recorded the highest protein content, as shown by the intense red color. In contrast, Ultra planted at 45,000 plants/ha in the year 2023 had the lowest protein content, indicated by the dark blue color.

The year 2024 generally favored higher protein accumulation, particularly at Brașov, where all treatments showed warmer colors compared to 2023. This suggests that environmental conditions in 2024 were more conducive to protein synthesis.

In the Codlea location, the protein content remained moderate across both years, with fewer extreme values. However, Ultra variety planted at both densities in 2024 showed a slight increase in protein content, reflected by the shift to orange hues. The 2023 values at

Codlea were uniformly low for all treatments.

Overall, the Darilena variety tended to accumulate more protein than Ultra variety, especially at lower planting densities and at Brașov location. The averages confirm that location and year played a significant role, with Brașov in 2024 producing the highest protein values.

In terms of fertilizer treatments, the results highlights that in Brașov (left panel), Darilena at the lower density (45,000 plants/ha) treated with V3 (Irys) reached the highest protein level, indicated by the intense red color, suggesting a strong stimulative effect of this biostimulant. Meanwhile, Ultra in Brașov showed generally lower protein content, especially under treatments V2 and V3, as reflected by blue and green colors. In Codlea (right panel), the highest protein contents were again observed in Darilena, especially under V1 (control) and V4 (Number One) at the higher planting density, where warm tones dominate. Ultra in Codlea displayed moderate to low protein levels, with blue and green tones across most treatments, except for a slight increase under V5 (Wuxal Macromix). Interestingly, V1 (control) sometimes resulted in high protein content, which may suggest a stress-induced concentration effect. Overall, Darilena showed consistently higher protein accumulation compared to Ultra, and biostimulant treatments V3 and V4 appeared to be the most effective in enhancing protein content in specific combinations of location and density. Planting density had variable effects, with both densities capable of supporting higher protein content when matched with suitable foliar treatments and growing conditions.

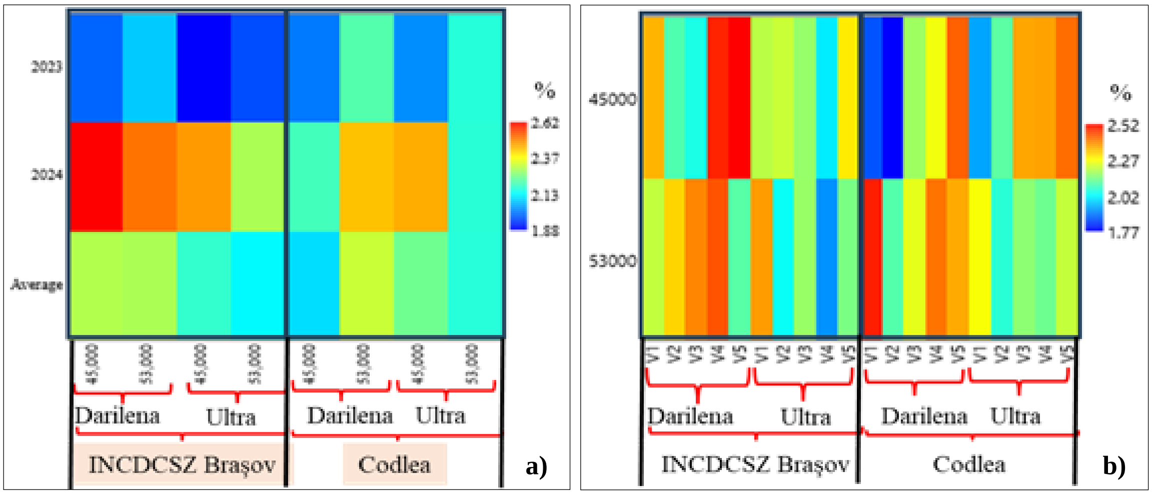

Figure 3. Potato protein comparison across locations, varieties, densities and experimental years (a) and across locations, varieties, fertilization treatment and densities (b)

The ash content in potato tubers was influenced by multiple factors, including cultivar, planting density, location, year, and fertilization strategy (Figure 4). In the year 2023, the ash content was generally lower, particularly in Brașov location, where most cultivar and density combinations were associated with cool color tones, indicating reduced values. Codlea, on the other hand, showed greater variability in the same year, with some combinations displaying warmer tones and higher ash accumulation. In the year 2024, a general increase in ash content was observed, especially for the cultivar Darilena planted at a lower density (45,000 plants/ha) in Brașov location, where the values reached some of the highest levels. Across both years, Darilena consistently recorded higher ash content compared to Ultra, particularly at lower planting densities, suggesting that it is more responsive to environmental conditions. Ultra appeared more stable, with consistently lower ash values regardless of density or location. The fertilization treatments also had a notable impact, especially for Darilena in Brașov location, where the application of Genaktis (V2), Number One (V4), and Wuxal Macromix (V5) resulted in increased ash content, as indicated by warmer color tones. In contrast, the Irys biostimulant (V3) was associated with reduced ash levels in Ultra, particularly in Codlea location, where it resulted in the lowest values among all treatments. Interestingly, the control variant (V1) in Codlea location led to high ash content for Darilena. Overall, the findings indicate that both genotype and agronomic practices, including planting density and fertilization, interact with local environmental conditions to shape the mineral composition of potato tubers.

The PCA graph illustrates the distribution of observations based on the first two principal components, where PC1 explains 97.56% of the total data variation, while PC2 accounts for only 1.89%. This indicates that PC1 is the main factor differentiating the observations, whereas PC2 contributes to a much lesser extent.

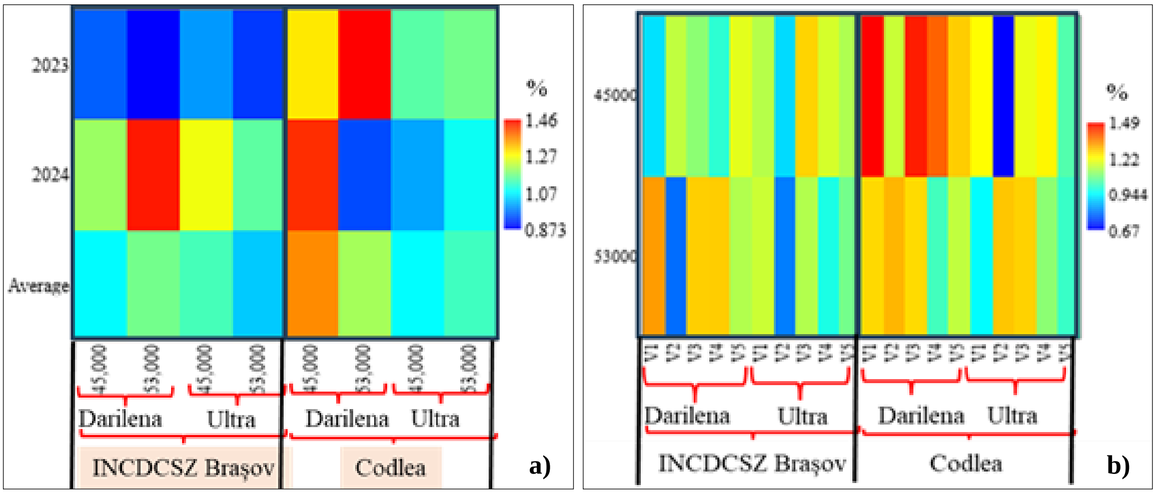

Figure 4. Potato ash comparison across locations, varieties, densities and experimental years (a) and across locations, varieties, fertilization treatment and densities (b)

The observations are represented by black dots labeled in blue text, and they are coded as follows: L1 and L2 indicate the experimental locations, G1 and G2 represent the genotypes used, D1 and D2 correspond to different planting densities, and foliar fertilizer treatments are marked as V1, V2, V3, V4, and V5. The clustering of these observations in different areas of the graph suggests that certain combinations of location, genotype, density, and fertilization influence the measured characteristics in distinct ways.

In the graph, the green vectors represent the original variables, including yield (production), protein content, starch content, dry matter (DM), and ash content. Yield has a significant influence on PC1, being strongly aligned with this axis, which suggests that variations in production are the primary factor separating the observations. On the other hand, DM and starch are more aligned with PC2, indicating a lesser contribution to the overall data variation.

The distribution of the points suggests that observations from L1 and L2 are distinctly grouped, indicating differences between locations. Additionally, there is a clear differentiation between genotypes G1 and G2, and foliar fertilizer treatments influence the measured characteristics in varying ways. The crop density (D1 or D2) may also contribute to this separation, depending on its combination with the other factors.

The PCA analysis shows that yield is the main factor driving the separation of observations along PC1, while DM and starch contribute more to PC2. Furthermore, location, genotype, planting density, and foliar fertilizer treatments significantly impact data variation, which can help identify the optimal combinations for maximizing yield and crop quality.

The correlation matrix based on Pearson coefficients highlights the relationships between different characteristics of potato tubers, such as yield, starch content, protein, ash, and dry matter (DM**).** A strong negative correlation between yield and starch (-0.61**)** suggests that higher yield is associated with lower starch content. Additionally, yield shows moderate negative correlations with ash (-0.31) and dry matter (-0.29)**,** indicating a potential decrease in mineral content and dry matter in high-yielding tubers. On the other hand, there is a strong positive relationship between starch and dry matter (0.64)**,** suggesting that tubers with higher dry matter also tend to have a higher starch content. Ash content is moderately positively correlated with starch (0.43)**,** meaning that starch-rich tubers may also have higher mineral content. Meanwhile, protein does not show significant correlations with either ash (-0.04) or dry matter (0.13), indicating independence between these characteristics. High yield tends to associate with lower starch, dry matter, and mineral content, while starch and dry matter are strongly correlated**,** which can be useful in selecting genotypes for various purposes, whether maximizing production or improving nutritional quality.

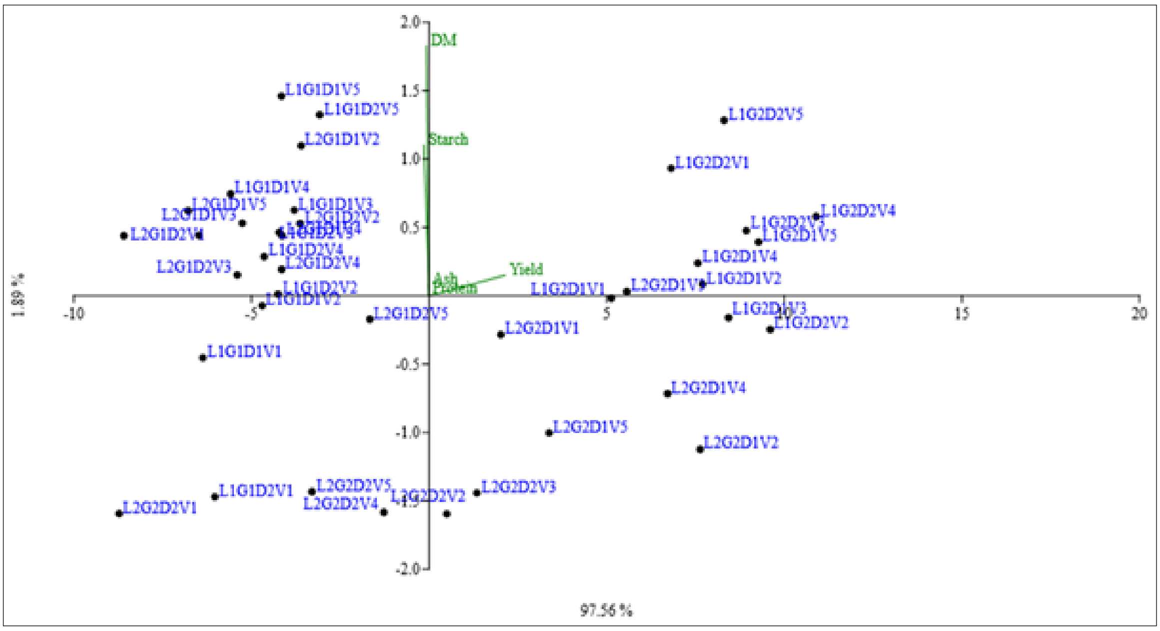

Figure 5. PCA analysis for yield and quality in potato

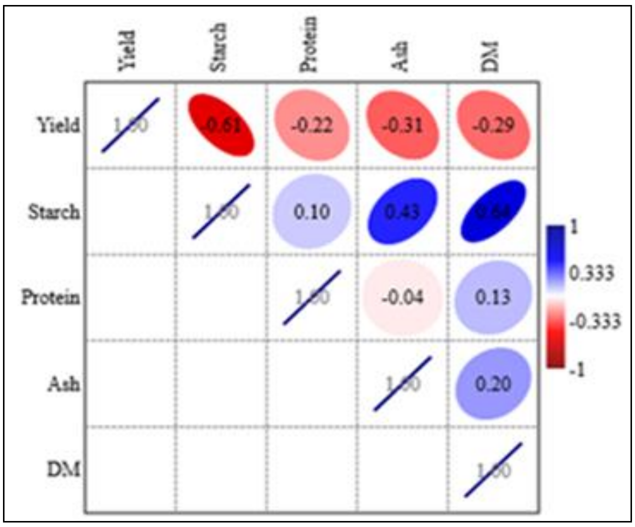

Figure 6. Pearson correlation matrix showing the relationships between yield, protein, starch, ash, and dry matter (DM) in potato

CONCLUSIONS

Potato yield was strongly influenced by location, year, variety, planting density, and foliar fertilization treatments.

Among foliar fertilization treatments, Number One and Wuxal Macromix produced the highest yields, while control consistently showed the lowest performance.

The Darilena variety accumulated more starch than Ultra variety, especially at higher planting density and exhibited higher protein content than Ultra variety, but especially at lower planting density.

Environmental conditions in 2024 favoured starch accumulation, suggesting different environmental conditions enhanced tuber carbohydrate synthesis.

Planting density had only a minor effect on starch content, indicating that starch accumulation is more genetically and environmentally determined.

Protein accumulation was strongly influenced by year and location.

Yield was the dominant factor in data variability (PC1 = 97.56%), separating the treatments and varieties most clearly.

The PCA also confirmed clear separation based on location, variety, and foliar treatments, underlining the complex interactions between environmental and agronomic factors.

A negative correlation between yield and starch content (-0.61) suggests a trade-off between productivity and starch accumulation.

Protein content showed weak or no correlation with ash, dry matter, or yield, suggesting it is relatively independent and may be more strongly influenced by genotype and stress conditions than by productivity.

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