

Genotype and Growing-Year Effects on Yield Stability and Tuber Quality in Potato Varieties

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ABSTRACT

Potato (*Solanum tuberosum* L.) is an important food and industrial crop, whose productivity and tuber quality are strongly influenced by genotype-environment interactions. Increasing climatic variability, particularly elevated temperatures and irregular precipitation, represents a major challenge for potato production, especially under non-irrigated conditions. Therefore, the evaluation of varietal performance under specific pedoclimatic conditions is essential for identifying genotypes with stable yield and desirable quality characteristics. In this context, the present study investigated the agronomic performance and tuber quality of 12 potato varieties under the pedoclimatic conditions of Braşov, Romania, during two contrasting growing seasons (2024-2025). Both seasons were characterized by pronounced climatic stress, particularly high temperatures and low precipitation. Tuber yield and the protein, ash, and dry matter contents were analysed. Analysis of variance (ANOVA) was performed to assess the significance of differences among varieties, while Linear Discriminant Analysis (LDA) was applied to discriminate the varieties based on the four investigated indicators. Significant genotypic variation was observed for yield, protein, ash, and dry matter contents. Mean yield was relatively stable between years, increasing slightly from 16.79 t ha⁻¹ in 2024 to 17.25 t ha⁻¹ in 2025. Azaria and Ervant consistently showed high yielding performance in both years, while Cosiana recorded the lowest yield. Cosiana was distinguished by the highest protein and ash contents and a high dry matter content, indicating a contrasting yield-quality profile. Protein content decreased from 2.15% in 2024 to 1.91% in 2025, whereas ash and dry matter contents increased from 1.15 to 1.45% and from 19.04 to 21.12%, respectively. The results demonstrate substantial genotypic variability and a significant influence of environmental conditions on the expression of quality traits.

Keywords: potato, dry matter, protein, ash, variability.

INTRODUCTION

Potato (*Solanum tuberosum* L.) represents the most widely cultivated non-cereal crop, with a major role in global food and nutritional security. Potato production and breeding programmes increasingly focus not only on improving tuber yield but also on enhancing nutritional, technological, and processing quality (Naeem et al., 2021; Kaur et al., 2026).

Tuber yield is a complex quantitative trait determined by the genetic potential of the variety and its interaction with environmental and agronomic conditions. Potato quality and processing characteristics are strongly influenced

by environmental conditions (Naeem et al., 2021). At the same time, potato varieties differ considerably in their capacity to respond to environmental conditions, resulting in differences in both yield potential and yield stability (Haverkort and Struik, 2015; Kleinwechter et al., 2016). Recent studies have further demonstrated that the productivity of potato varieties may vary considerably among locations and growing seasons (Scavo et al., 2023; Tatarowska et al., 2024; Pszczółkowski et al., 2025). Therefore, the identification of varieties capable of combining productivity with stable performance under specific pedoclimatic conditions remains an important

objective of potato research and varieties evaluation.

Among the quality characteristics, dry matter content is particularly important because it influences tuber texture, storage behaviour, marketability, and suitability for industrial processing. High dry matter content is generally associated with improved processing efficiency and product quality, while also representing an important trait in potato breeding programmes (Kaur et al., 2026). However, dry matter content is influenced by both genetic factors and environmental conditions, and considerable differences can occur among varieties, locations, and growing seasons (Leonel et al., 2017; Scavo et al., 2023). Recent studies conducted under different agroecological conditions have also emphasized the importance of variety adaptation and environmental variability in determining dry matter accumulation and the technological value of potato tubers (Tatarowska et al., 2024; Pszczółkowski et al., 2025).

Protein content also contributes to the nutritional value of potato tubers. Although potato is not generally considered a high-protein crop, its proteins are characterized by a relatively favourable amino acid composition and contribute to the nutritional quality of the human diet (Camire et al., 2009). Considerable genotypic variability in tuber protein concentration has been reported, indicating opportunities for the selection and development of varieties with improved nutritional characteristics (Naeem et al., 2021). High-protein genotypes are preferred in breeding programs aimed at special nutrition, such as foods for infants or vulnerable populations (Krauss et al., 2006). Similarly, ash content, which provides an overall indication of the mineral fraction of potato tubers, may vary depending on genotype and environmental conditions. Differences in mineral accumulation among potato genotypes have been reported in association with substantial phenotypic and genetic variation, (Pandey et al., 2023).

The expression of potato yield and quality traits is not determined exclusively by the genetic background of the variety. Previous

studies have demonstrated that growing conditions can significantly influence the chemical composition of potato tubers, including dry matter, protein, and mineral contents (Leonel et al., 2017). Genotype $\times$ environment interactions may substantially affect the expression and stability of important tuber yield and quality characteristics, meaning that the relative performance and ranking of varieties can vary across locations and growing seasons (Scavo et al., 2023; Tatarowska et al., 2024; Yousaf et al., 2026). Environmental variation represents an important determinant of potato productivity (Kleinwechter et al., 2016; Pszczółkowski et al., 2025). Consequently, varieties evaluation under specific pedoclimatic conditions is essential for identifying genotypes that are well adapted to particular production environments and that combine favourable yield and quality characteristics (Hussen, 2019).

Potato breeding plays an important role in increasing productivity and improving nutritional quality on existing agricultural land (Lindqvist-Kreuze et al., 2023). Studies based on the evaluation of diverse potato germplasm have demonstrated considerable variation in agronomic, nutritional, and quality-related traits, including tuber yield, dry matter content, mineral composition, and other yield components (Gowda et al., 2025).

The simultaneous evaluation of yield and several quality-related traits provides a more comprehensive characterization of potato varieties than the analysis of individual traits separately. In this context, multivariate statistical approaches can complement conventional analysis of variance by identifying patterns of variation and discriminating varieties according to their overall agronomic and physicochemical profiles. Multivariate analyses have previously been successfully applied to characterize differences among potato varieties based on their physicochemical characteristics, yield components, and cultivation conditions (Bombik et al., 2023; Gowda et al., 2025). These methods may therefore contribute to a more integrated interpretation of variety performance and

facilitate the identification of groups of genotypes with similar or contrasting production and quality profiles.

Therefore, the present study aimed to evaluate the performance of potato varieties under the pedoclimatic conditions of the experimental area over two consecutive growing seasons, focusing on tuber yield, protein, ash, and dry matter content. The study assessed genotypic variability and the influence of the growing season on these traits. In addition to analysis of variance, Linear Discriminant Analysis (LDA) was used to differentiate varieties based on their combined yield and quality characteristics, contributing to the identification of genotypes with favourable and relatively stable production potential and distinctive nutritional and technological quality profiles.

The selection of potato varieties combining high productivity with yield stability may contribute to improved food security at national and international levels (Mbuma et al., 2024).

MATERIAL AND METHODS

A field experiment was conducted at National Institute for Research and Development for Potato and Sugar Beet (NRDPSB) Braşov during two growing seasons, 2024 and 2025 in a non-irrigated field conditions, in order to evaluate the yield and quality of 12 potato varieties under the pedoclimatic conditions of Braşov, Romania. Yield, protein, ash, and dry matter contents were analysed. The potato varieties included in the study comprised the semi-early varieties: Azaria, Ervant, Darilena, Sarmis, Castrum, Cezarina, Marvis, Braşovia, Asinaria, Sevastia, and the semi-late varieties Cosiana and Foresta.

After harvest, tuber yield was determined for each of the 12 potato varieties and expressed in $t\ ha^{-1}$. Laboratory analyses were subsequently performed for each variety in three replicates to determine dry matter content using the oven-drying method, crude protein content using the Kjeldahl method, and ash content using the incineration method.

Determination of dry matter content

Dry matter content was determined by the oven-drying method. Tuber samples were dried in an oven at 105°C until constant weight was achieved. The dry matter content was subsequently calculated as the percentage of the constant dry weight relative to the initial fresh weight of the sample.

Determination of crude protein content

The crude protein content of tubers from the 12 potato varieties was determined using the Kjeldahl method. Tuber samples were ground and subjected to digestion with concentrated sulfuric acid in the presence of a catalyst, converting organic nitrogen into ammonium nitrogen. The digest was subsequently alkalized, and the released ammonia was distilled and quantified by titration. Total nitrogen content was calculated based on the amount of acid used in the titration, while crude protein content (%) was obtained by multiplying the nitrogen content by the conversion factor of 5.7.

Determination of ash content

The ash content of potato tubers was determined by incineration until the complete removal of organic matter. A known amount of the sample was subjected to combustion in a muffle furnace at 500-600°C until a constant mass was obtained. The crude ash content, representing the inorganic residue remaining after the complete combustion of organic matter, was expressed as a percentage of the initial sample mass and reflects the total mineral content present in the potato tubers.

Statistical data analysis

Statistical analyses were performed to evaluate the variability among the 12 potato varieties for yield and quality traits. Analysis of variance (ANOVA) was performed using POLIFACT software, and the significance of differences between variety means was assessed at the 5%, 1%, and 0.1% probability levels. The least significant difference (LSD) test was used for mean comparisons. Linear Discriminant Analysis (LDA) was subsequently performed using PAST 5 software to evaluate

the discriminatory capacity of the four investigated indicators (yield, protein, ash, and dry matter) and to assess the differentiation of potato varieties based on their combined characteristics. Graphical representations of the experimental results and statistical outputs were generated using Microsoft Excel.

RESULTS AND DISCUSSIONS

During the potato growing season (April-September), both experimental years were characterized by higher than normal temperatures compared with the multi-year average. The mean temperature exceeded the multi-year average by 1.18°C in the first year and by 0.55°C in the second year, indicating generally warmer conditions during the growing season (Table 1).

The first year was characterized by a more pronounced water deficit, with total precipitation being 150.6 mm below the multi-year average. The most unfavorable conditions occurred during July, August, and September, when temperatures exceeded the multi-year average by up to 5°C. In August, this thermal stress was aggravated by low

precipitation, with only 29 mm recorded compared with 76 mm in the multi-year average. These combined conditions of high temperature and insufficient water availability were particularly unfavorable for potato development.

The second year was also characterized by above-average temperatures, particularly in July, August, and September. Water availability was also below normal, with a total precipitation deficit of 85.44 mm. Notably, June recorded relatively normal temperatures but experienced a precipitation deficit of more than 90 mm, affecting crop development during an important stage of the growing season.

The two years were characterized by warmer and drier conditions than the multi-year average, with the first year showing the more pronounced climatic stress. The combination of elevated temperatures and insufficient precipitation, particularly during the summer months, affected potato growth, yield formation, and tuber quality. These climatic conditions may also explain part of the differences observed among the 12 potato varieties tested, as varieties can differ considerably in their tolerance to heat and water stress.

Table 1. Monthly mean air temperature and rainfall recorded during potato growing season compared with multi-year average (Braşov, 2024-2025)

Temperature and rainfall	Year	Month						Potato growing season
		IV	V	VI	VII	VIII	IX	(IV-IX)
Monthly temperatures average (°C)	2024	12.19	13.83	21.15	22.17	21.25	16.10	17.78
	2025	9.67	11.91	16.38	20.35	20.96	15.83	15.85
	MYA*	8.5	13.6	16.5	18.1	17.5	13.6	14.6
Monthly rainfall amount (mm)	2024	43.53	42.65	54.50	79.36	29.00	57.80	306.83
	2025	24.28	149.39	2.90	117.80	18.60	59.00	371.96
	MYA*	50	82	96.7	99.8	76.4	52.5	457.4

*multi-year average

The analysis of variance (ANOVA) (Table 2), based on the F-test values, revealed different responses of the four traits to the experimental factors year (Y) and genotype (G) and to their interaction (Y × G). Statistical significance was assessed according to the conventional probability levels, where * indicates significant effects ($p < 0.05$), ** indicates highly significant effects ($p < 0.01$), and *** indicates very

highly significant effects ($p < 0.001$). Overall, genotype factor (G) had a very highly significant effect on all four agronomic traits. A variable influence, ranging from non-significant for Yield to very highly significant for ash content was identified for the year factor (Y). Importantly, the Y × G interaction was very highly significant for all four traits, demonstrating that the effects of the two factors were not independent.

Source of variation	Yield	Protein	Ash	Dry matter
Year (Y)	0.13	125.70**	1481.16***	24.12*
Genotype (G)	36.09***	48.89***	37.64***	34.73***
Year x Genotype (Y x G)	5.46***	12.26***	28.99***	5.52***

mean at $P < 0.001$, whereas Marvis and Sarmis showed significant positive deviations at $P < 0.01$ and $P < 0.05$, respectively. Conversely, Cosiana recorded the lowest yield (8.22 t ha^{-1}), significantly below the mean ($P < 0.001$). In 2025, Ervant (25.99 t ha^{-1}), Castrum (25.01 t ha^{-1}), and Azaria (23.64 t ha^{-1}) were the most productive genotypes, with highly significant differences from the annual mean. Cosiana (7.23 t ha^{-1}) and Sevastia (7.84 t ha^{-1}) again showed the lowest yields, both being significantly below the mean at $P < 0.001$. These results indicate relatively stable high yielding ability of Azaria and Ervant across the two years, whereas the performance of Marvis and Castrum was more dependent on the growing year.

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Year	Genotype	Yield		Protein		Ash		Dry matter	
		(t/ha)	Significance	(%)	Significance	(%)	Significance	(%)	Significance
2024	Average	16.79	Ct.	2.15	Ct.	1.15	Ct.	19.04	Ct.
	AZARIA	25.41	***	2.25	ns	1.05	ns	21.29	***
	ERVANT	23.96	***	1.8	000	1.2	ns	16.68	000
	DARILENA	12.41	0	1.95	0	1.26	ns	20.17	*
	SARMIS	21.15	*	1.82	000	0.92	0	18.04	ns
	CASTRUM	15.52	ns	2.13	ns	1.32	ns	9.47	ns
	CEZARINA	14.74	ns	2.05	ns	0.9	0	18.49	ns
	MARVIS	21.59	**	1.79	000	1.1	ns	20.12	*
	COSLANA	8.22	000	2.95	***	1.39	*	19.98	ns
	BRAȘOVIA	12.92	0	2.38	*	1.09	ns	18.45	ns
	ASINARIA	17.7	ns	2.26	ns	1.04	ns	19.61	ns
	FORESTA	14.74	ns	2.55	***	1.29	ns	17.09	000
SEVASTIA	13.08	0	1.94	0	1.19	ns	19.08	ns	
2025	Average	17.25	Ct.	1.91	Ct.	1.45	Ct.	21.12	Ct.
	AZARIA	23.64	***	2.11	*	2.19	***	22.43	*
	ERVANT	25.99	***	1.49	000	0.96	000	17.43	000
	DARILENA	14.28	ns	1.92	ns	1.77	**	21.77	ns
	SARMIS	18.04	ns	1.55	000	1.08	000	20.7	ns
	CASTRUM	25.01	***	1.78	ns	1.16	00	22.23	*
	CEZARINA	17.29	ns	1.56	000	1.19	00	22.9	**
	MARVIS	16.74	ns	2.02	ns	1.11	000	22.03	ns
	COSLANA	7.23	000	2.5	***	2.52	***	23	***
	BRAȘOVIA	16.01	ns	2.1	*	1.08	000	20.47	ns
	ASINARIA	20.2	ns	1.81	ns	1.79	***	22.63	**
	FORESTA	14.68	ns	1.86	ns	0.88	000	18.8	000
SEVASTIA	7.84	000	2.24	***	1.69	*	19	000	
LSD (p 5%)		3.50		0.17		0.19		1.02	
LSD (p 1%)		4.69		0.22		0.26		1.37	
LSD (p 0.1%)		6.14		0.29		0.34		1.79	
Note: ns, not significant; “*”,0” for P value < 0.05; “***”, for P value < 0.01; “****”, 000” for P value <0.001 compared with the average of 12 genotypes (Ct.) within the same year (2024 or 2025)									

The protein content varied considerably among genotypes, with an overall decrease in the annual mean from 2.15% in 2024 to 1.91% in 2025. In 2024, Cosiana had the highest protein content (2.95%), significantly exceeding the mean at $P < 0.001$, followed by Foresta (2.55%) and Braşovia (2.38%). In contrast, Ervant (1.80%), Sarmis (1.82%), Marvis (1.79%), and Sevastia (1.94%) showed significantly lower protein contents than the annual mean. A similar genotypic pattern was observed in 2025, when Cosiana again recorded the highest protein content (2.50%; $P < 0.001$), while Sevastia (2.24%), Azaria (2.11%), and Braşovia (2.10%) also exceeded the annual mean significantly. Ervant, Sarmis, and Cezarina had significantly lower values. The consistently high protein concentration of Cosiana, combined with its low yield, suggests a potential negative association between productivity and protein concentration.

The ash content showed an opposite annual trend, increasing from 1.15% in 2024 to 1.45% in 2025. In 2024, Cosiana had the highest ash content (1.39%; $P < 0.05$), whereas Sarmis (0.92%) and Cezarina (0.90%) had significantly lower values. Genotypic differences were more pronounced in 2025. Cosiana exhibited the highest ash content (2.52%; $P < 0.001$), followed by Azaria (2.19%; $P < 0.001$), Asinaria (1.79%; $P < 0.001$), Darilena (1.77%; $P < 0.01$), and Sevastia (1.69%; $P < 0.05$). In contrast, Ervant, Sarmis, Marvis, Braşovia, and Foresta showed significantly lower ash contents than the annual mean. The marked increase in ash content observed for Cosiana and Asinaria in 2025 indicates a pronounced genotype $\times$ year response for this trait.

Dry matter content increased from an average of 19.04% in 2024 to 21.12% in 2025. In 2024, Azaria recorded the highest dry matter content (21.29%; $P < 0.001$), while Darilena (20.17%) and Marvis (20.12%) also significantly exceeded the annual mean. Ervant (16.68%) and Foresta (17.09%) had significantly lower values. In 2025, the highest dry matter content was recorded for Cosiana (23.00%; $P < 0.001$), followed by Cezarina (22.90%; $P < 0.01$),

Asinaria (22.63%; $P < 0.01$), Azaria (22.43%; $P < 0.05$), and Castrum (22.23%; $P < 0.05$). Ervant, Foresta, and Sevastia showed significantly lower dry matter contents than the annual mean.

The LDA biplot (Figure 1) revealed a clear differentiation among potato varieties according to yield and tuber quality traits, as well as their response to the contrasting environmental conditions recorded in 2024 and 2025. The first two axes explained 83.29% of the total variation, with Axis 1 accounting for 49.03% and Axis 2 for 34.26%, indicating that the biplot provides a reliable representation of the main differences among varieties and growing years. Yield was strongly oriented towards the positive direction of Axis 2, indicating a close association between this axis and productive performance. Varieties positioned in the upper part of the biplot, particularly Azaria in 2024 and Castrum and Azaria in 2025, were therefore associated with higher yield performance. In contrast, varieties positioned towards the lower part of the biplot showed a weaker association with yield.

Dry matter (DM) was oriented towards the negative direction of Axis 1 and the positive direction of Axis 2. This positioning indicates that varieties located in the upper-left region, such as Marvis in both years and Braşovia in 2025, were more closely associated with dry matter content.

Temperature and protein content were oriented mainly towards the positive direction of Axis 1. Consequently, varieties distributed on the right side of the biplot, particularly several varieties evaluated in 2024, showed a closer association with these characteristics. Ash content, being positioned close to the origin, appeared to have a comparatively lower contribution to the differentiation of varieties within the first two axes.

A clear separation between the two experimental years can also be observed. The 2025 varieties were predominantly distributed on the negative side of Axis 1, whereas most of the 2024 varieties were positioned on the positive side of Axis 1.

This pattern suggests that the environmental conditions prevailing in the two growing seasons had an important influence on variety performance and tuber quality. The greater dispersion of the varieties

between years also indicates that their agronomic response was not uniform, highlighting differences in adaptability to environmental conditions.

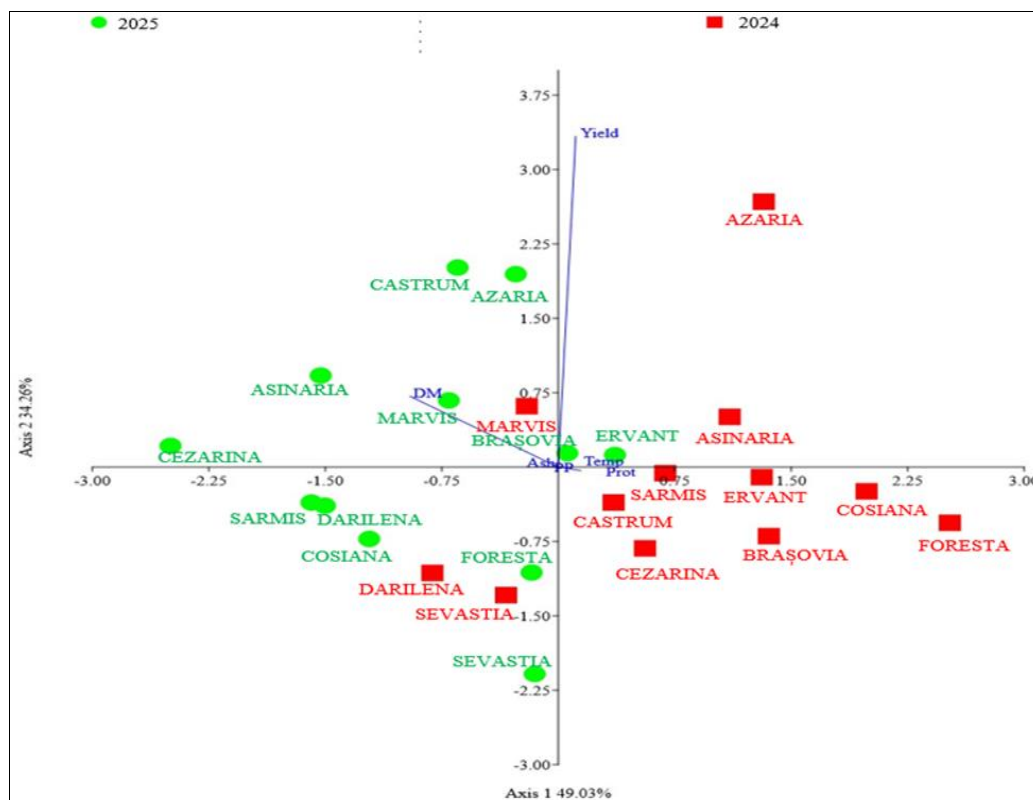


Figure 1. Linear Discriminant Analysis (LDA) in 12 potato varieties based on yield, protein, ash and dry matter content

The position of Azaria, as it was located in the positive direction of Axis 2 in both years, with the 2024 sample showing a particularly strong association with yield. Similarly, Castrum showed a favourable position in 2025, being located in the upper part of the biplot and therefore closer to the yield vector.

CONCLUSIONS

The study demonstrated significant genotypic variability among the 12 potato varieties evaluated under the pedoclimatic conditions of Braşov during 2024 and 2025. Yield performance was relatively stable between years, with Azaria and Ervant showing the most consistent high productivity, while Cosiana recorded the lowest yield. In contrast, Cosiana was characterized by the highest protein and ash contents and a high dry matter content,

highlighting a distinct yield–quality profile. The differences observed between years, particularly for protein, ash, and dry matter, indicate a considerable environmental influence on quality traits. Overall, the results confirm that the simultaneous assessment of yield and quality parameters is essential for identifying potato varieties with superior performance and adaptation to the pedoclimatic conditions of the Braşov area.

Variety performance was influenced by both genetic characteristics and growing-year conditions. The differentiation observed in the biplot indicates that some varieties were more closely associated with high yield, whereas others were characterized by higher dry matter or by traits related to temperature and protein content. These results emphasize the importance of selecting varieties not only according to their yield potential, but also according to their adaptability, yield stability,

and tuber quality under contrasting environmental conditions. Such characteristics are particularly relevant for potato production under increasingly variable climatic conditions.

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