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Interactions Effects of Cultivation Year, Cultivation Method and Cultivar on Potato Growth and Minituber Production under Aeroponic and Conventional Systems

Andreea Tican*, Carmen Chelmea, Mihaela Cioloca, Monica Popa

National Institute of Research and Development for Potato and Sugar Beet Brașov, Brașov County, Romania
*Corresponding author. E-mail: tican_andreea@yahoo.com

ABSTRACT

The cultivation method represented the main factor influencing vegetative growth and minituber production, with the aeroponic system resulting in higher plant height, higher minituber number, and greater minituber weight than conventional cultivation. The positive effect of aeroponics was observed in both experimental years, although its magnitude varied among cultivars, suggesting differential genotypic responses to the cultivation environment. Among the cultivars evaluated, Azaria, Brașovia, and particularly Cosiana exhibited higher vegetative development and tuberization potential compared with the control cultivar Cezarina. The variations observed between years for certain cultivar × cultivation method combinations, under constant aeroponic technology, may reflect biological variability and the differential response of genotypes to the specific conditions of each experimental cycle. The very strong correlation between minituber number and minituber weight (r = 0.972) confirms the close association between tuberization intensity and total biomass accumulation, while the correlation between vegetative development at two months and minituber weight (r = 0.814**) suggests that greater vegetative vigor is associated with higher production potential. These findings highlight the importance of cultivation system and cultivar selection for improving potato minituber production under aeroponic conditions.**

Keywords: potato, minituber production, aeroponic, conventional cultivation, tuberization, cultivar.

INTRODUCTION

Feeding a growing global population sustainably will require producing more food with the same or fewer resources while reducing waste, and potato is expected to play a central role in this transition (Devaux et al., 2021). Climate change, water scarcity, soil degradation and the increasing demand for high-quality planting material have stimulated the development of innovative crop production systems (Tunio et al., 2020; Balasundram et al., 2023). In conventional seed potato production, the multiplication rate is low (1:6) and present other several bottlenecks: accumulation of degenerative diseases, perishability, bulkiness, and a slow process of generating 100% healthy seed stock (Sadawarti et al., 2026).

Controlled environment agriculture, including hydroponic and aeroponic systems, has gained attention as an approach for increasing productivity while reducing resource use and environmental constraints (Benke and Tomkins, 2017). These systems save time, land, fertilizer, and water in an environment-friendly manner and give higher and uniform yields as compared to the conventional method (Sinha et al., 2025) Soilless culture is now a major technological component of the modern greenhouse industry (Savvas and Gruda, 2018), and the integration of sensors and automated nutrient management enables precise control of the growing conditions (Balasundram et al., 2023).

In aeroponic systems, plant roots are suspended in air and periodically supplied with a nutrient mist, which improves root-zone oxygenation and nutrient availability (Lakhiar et al., 2018; Eldridge et al., 2020). Compared with conventional cultivation, aeroponics considerably reduces water (Kannan et al., 2022). It has been shown to increase the multiplication rate of potato minitubers (Ritter et al., 2001; Buckseth et al., 2016; Çalışkan et al., 2021) and to support the production of disease-free planting material (Tunio et al., 2020).

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Aeroponics also allows successive harvests during the vegetation period (Broćić et al., 2022; Borstel et al., 2026), and multiple harvests increased the total number of tubers by 36% in Indonesian conditions (Dianawati et al., 2025). Planting density and harvesting interval further influence minituber yield (Farran and Mingo-Castel, 2006).

Aeroponic performance depends strongly on genotype. The crop response was shown to be influenced by the interaction between cultivar, planting date and planting density (Singh et al., 2025). According to Buckseth et al. (2024), the genotype and material type for planting (plant origin) had a significant impact on the total number of minitubers generated by the plant, minituber mass, and the overall production of potato growth that takes place in the aeroponic system. Aeroponic evaluation also revealed differences among varieties in root morphology, nitrogen use efficiency and yield traits (Tiwari et al., 2022; Cheema et al., 2024). In addition, early vegetative growth indicators were related to final minituber production (Silva Filho et al., 2024).

In Romania, hydroponic cultivation gave better results than the conventional method (Tican, 2018; Tican et al., 2018a, 2025), whereas the first aeroponic systems were inefficient and did not reach international standards (Tican et al., 2018b). More recently, minituber production in an aeroponic system was evaluated across different cultivation periods (Tican et al., 2026a).

The aim of this study was to evaluate the effects and interactions of cultivation year, cultivation method (aeroponic vs. conventional) and cultivar (Azaria, Brașovia, Cosiana and Cezarina, the latter as control) on plant height, and on the number and weight of minitubers per plant, and to assess the relationships among these traits. We hypothesized that improved root-zone aeration and nutrient availability in the aeroponic system would enhance growth and minituber production, with a differentiated response among cultivars. Previous results obtained at NIRDPSB Brașov for the same four cultivars compared aeroponic, hydroponic and conventional systems in a single year (Tican et al., 2026b) and examined aeroponic minituber production across different cultivation periods (Tican et al., 2026a). The effect of cultivation year and its interactions with method and cultivar, however, have not been tested.

MATERIAL AND METHODS

The experiments were carried out in two consecutive cultivation years (2025 and 2026) at the National Institute of Research and Development for Potato and Sugar Beet (NIRDPSB) Brașov, Romania. Four potato (*Solanum tuberosum* L.) cultivars were evaluated: Azaria, Brașovia, Cosiana and Cezarina, the latter used as the control. Virus-free plantlets of all cultivars were obtained by *in vitro* propagation and subsequently transferred either to the aeroponic system or to pots containing a peat-perlite mixture for conventional minituber production. Data from the 2025 cycle, comprising the aeroponic and conventional treatments for the same four cultivars, were previously reported in a comparison of aeroponic, hydroponic and conventional systems (Tican et al., 2026b). In that study, the 2025 data were analyzed as a single-year experiment that also included a hydroponic treatment. In the present paper, the 2025 data are reanalyzed together with the 2026 cycle in a combined three-factor analysis of variance (year × cultivation method × cultivar), which allows the year effect and its interactions with method and cultivar to be tested for the first time.

The experiment was a three-factorial trial with cultivation year: 2025 (control) and 2026, cultivation method (aeroponic, conventional) and cultivar (Azaria, Brașovia, Cosiana, and Cezarina) as factors. Aeroponic and conventional cultivation represented the two levels of the cultivation-method factor, while the four cultivars constituted the levels of the cultivar factor. Cezarina served as the control cultivar, and conventional cultivation served as the reference method for comparing cultivation systems. The data were analyzed by three-way analysis of variance (ANOVA), with cultivation year, cultivation method, and cultivar as fixed factors. The analysis included

all three main effects, all two-way interactions, and the three-way interaction (year × method × cultivar). Differences among means were assessed using the least significant difference (LSD) test at significance levels of $p \leq 0.05$, $p \leq 0.01$, and $p \leq 0.001$. Statistical analyses were performed using POLYFACT, Microsoft Excel, and SPSS.

Pearson's correlation coefficients (r) were calculated to evaluate the linear relationships among plant height measured at one and two months, minituber number, and total minituber weight. Statistical significance was assessed using the corresponding significance tests.

RESULTS AND DISCUSSION

Analysis of variance (ANOVA) was performed to evaluate the effects of cultivation year, cultivation method, and cultivar on four traits: plant height at one and two months after transfer, number of minitubers per plant, and minituber weight per plant. The analysis considered the three main effects, all two-way interactions, and the three-way interaction among cultivation year, cultivation method, and cultivar (Table 1).

Table 1. Analysis of variance for plant height (one and two months after transfer), number of minitubers per plant and minituber weight per plant

Source of variation	SS	df	MS	*F*	Sig.	*p*
For plant height one month after transfer						
Cultivation year (a)	156.64	1	156.64	144.09	**	0.007
Cultivation method (b)	226.59	1	226.59	70.31	**	0.001
a × b	258.40	1	258.40	80.18	**	0.004
Cultivar (c)	514.73	3	171.58	15.49	***	8.11×10^{-6}
a × c	82.05	3	27.35	2.47	ns	0.086
b × c	14.55	3	4.85	0.44	ns	0.728
a × b × c	18.20	3	6.07	0.55	ns	0.654
For plant height two months after transfer						
Cultivation year (a)	0.97	1	0.97	0.149	ns	0.740
Cultivation method (b)	39,131.20	1	39,131.20	737.59	***	1.09×10^{-5}
a × b	133.90	1	133.90	2.52	ns	0.187
Cultivar (c)	9,386.89	3	3,128.96	114.85	***	2.27×10^{-14}
a × c	92.77	3	30.92	1.14	ns	0.355
b × c	4,955.08	3	1,651.69	60.27	***	2.40×10^{-11}
a × b × c	18.65	3	6.21	0.23	ns	0.880
For the number of minitubers per plant						
Cultivation year (a)	87.80	1	87.80	6.40	ns	0.127
Cultivation method (b)	13,244.81	1	13,244.81	476.16	***	2.61×10^{-5}
a × b	4.64	1	4.64	0.17	ns	0.700
Cultivar (c)	4,662.50	3	1,554.17	205.37	***	2.70×10^{-12}
a × c	1,689.43	3	563.14	74.14	***	2.69×10^{-12}
b × c	7,125.82	3	2,375.27	313.87	***	2.21×10^{-19}
a × b × c	1,651.80	3	550.60	72.76	***	3.43×10^{-12}
For minituber weight per plant						
Cultivation year (a)	9,883.42	1	9,883.42	9.61	ns	0.090
Cultivation method (b)	938,944.40	1	938,944.40	554.72	***	1.93×10^{-5}
a × b	202.58	1	202.58	0.12	ns	0.747
Cultivar (c)	512,362.50	3	170,787.50	187.97	***	8.47×10^{-17}
a × c	98,095.85	3	32,698.62	35.90	***	4.81×10^{-9}
b × c	399,594.70	3	133,198.20	146.60	***	1.45×10^{-15}
a × b × c	92,025.20	3	30,675.06	33.76	***	8.93×10^{-9}

*Statistical significance: ns (not significant): $p > 0.05$; * significant: $p \leq 0.05$; ** distinctly significant: $p \leq 0.01$; *** highly significant: $p \leq 0.001$.*

Plant height one month after transfer was significantly influenced by cultivation year, cultivation method and the year × method interaction, and highly significantly by cultivar. Plant height two months after transfer was significantly influenced by cultivation method and cultivar and by their interaction, with no significant effect of cultivation year. The number of minitubers per plant and minituber weight per plant (Table 1) were both highly significantly influenced by cultivation method and cultivar, as well as by the year × cultivar, method × cultivar and year × method × cultivar interactions; the main effect of cultivation year was not significant for either trait.

Plant height one month after transfer was significantly higher in 2026 (21.88 cm) than in 2025 (18.27 cm), with a distinctly significant difference of 3.61 cm ($p \leq 0.01$). Plant height two months after transfer, the number of minitubers per plant and minituber weight per plant showed no significant differences between the two cultivation years (Table 2).

The cultivation method significantly influenced all four traits analyzed, with the aeroponic system producing higher values than the conventional system for plant height at both dates and for minituber number and weight (Table 3). Biologically, the aeroponic system favored more vigorous vegetative growth, which may be attributed to the continuous availability of water, nutrients, and oxygen at the root level, thereby facilitating nutrient uptake and plant development. This interpretation is consistent with previous studies reporting enhanced growth and minituber production under aeroponic conditions (Buckseth et al., 2024). As the growing period progressed, the advantage of aeroponics over the conventional cultivation method became increasingly evident, particularly in plant height two months after transfer, when all cultivars exhibited highly significant gains under the aeroponic system. The absence of significant differences between years under aeroponic cultivation, when the technology and cultivation parameters were maintained consistently, suggests that the controlled growing conditions may have reduced the influence of year-specific environmental variation on vegetative development. The favorable effect of aeroponics also extended to tuberization, as the continuous supply of oxygen and nutrients to the root system may have contributed to the higher number and weight of minitubers recorded under this system. These effects were particularly pronounced in cultivars such as Cosiana, Brașovia, and Azaria, which may reflect differences in their genetic potential for minituber production. Also, Çalışkan et al. (2021) reported a much higher number of tubers per m² with aeroponics compared to the conventional system.

The cultivar significantly influenced all four traits, with highly significant positive differences recorded for Azaria and Brașovia compared with the control cultivar Cezarina (Table 4). The differential response among cultivars indicates that tuberization potential and vegetative vigor were controlled mainly by genotype, and that this genetic potential was further amplified or constrained by the cultivation method. Two months after transfer, the genetic characteristics of the cultivars had a stronger influence on growth than the variation between cultivation years, since Azaria, Brașovia and Cosiana maintained a high and stable vegetative vigor irrespective of the year, while Cezarina consistently showed a slower growth rate. The maintenance of constant aeroponic parameters across the two years may also have contributed to reducing the variability associated with cultivation year, allowing the genotype-specific response to the cultivation method to be expressed more clearly. According to Tierno et al. (2014) plants in the aeroponic system showed increased growth and their vegetative cycle extended between 12 and 36 % compared to the plants cultivated in greenhouse beds.

One month after transfer, plant height under aeroponic cultivation was 8.25 cm higher in 2026 than in 2025 ($p \leq 0.01$); under the conventional method the difference between years was not significant (Table 5).

Two months after transfer, aeroponically grown plants reached 92.82 cm in 2026 and 89.76 cm in 2025, both highly significantly greater than the conventional method; the difference between years was not significant for either method (Table 6).

Table 2. Effect of cultivation year on plant height at one and two months, number of minitubers per plant and minituber weight per plant

Year	Height 1 month (cm)	Diff./Sig.	Height 2 months (cm)	Diff./Sig.	Minitubers/ plant (no.)	Diff./Sig.	Minituber weight/ plant (g)	Diff./Sig.
2026	21.88 A	3.61 **	62.60 A	-0.28 ns	23.67 A	2.70 ns	186.50 A	-28.70 ns
2025 (control)	18.27 B	-	62.88 A	-	20.97 A	-	215.19 A	-

LSD height 1 month (cm): *p* 5% = 1.29; *p* 1% = 2.99; *p* 0.1% = 9.51. LSD height 2 months (cm): *p* 5% = 3.17; *p* 1% = 7.32; *p* 0.1% = 23.30. LSD minitubers/*p*lant: *p* 5% = 4.60; *p* 1% = 10.62; *p* 0.1% = 33.79. LSD minituber weight (g): *p* 5% = 39.80; *p* 1% = 91.92; *p* 0.1% = 292.51.

Table 3. Effect of cultivation method on plant height at one and two months, number of minitubers per plant and minituber weight per plant

Culture method	Height 1 month (cm)	Diff./Sig.	Height 2 months (cm)	Diff./Sig.	Minitubers/ plant (no.)	Diff./Sig.	Minituber weight/ plant (g)	Diff./Sig.
Aeroponic	22.25 A	4.35 **	91.29 A	57.10 ***	38.93 A	33.22 ***	340.71 A	279.72 ***
Conventional (control)	17.90 B	-	34.19 B	-	5.71 B	-	60.98 B	-

LSD height 1 month (cm): p 5% = 1.44; p 1% = 2.38; p 0.1% = 4.46. LSD height 2 months (cm): p 5% = 5.85; p 1% = 9.67; p 0.1% = 18.10. LSD minitubers/plant: p 5% = 4.23; p 1% = 7.00; p 0.1% = 13.11. LSD minituber weight (g): p 5% = 33.02; p 1% = 54.63; p 0.1% = 102.26.

Table 4. Effect of cultivar on plant height at one and two months, number of minitubers per plant and minituber weight per plant

Cultivar	Height 1 month (cm)	Diff./Sig.	Height 2 months (cm)	Diff./Sig.	Minitubers/ plant (no.)	Diff./Sig.	Minituber weight/ plant (g)	Diff./Sig.
Azaria (c1)	20.98 B	5.81 ***	67.03 B	28.12 ***	23.52 B	14.84 ***	226.07 B	187.55 ***
Brașovia (c2)	24.32 A	9.14 ***	70.83 AB	31.92 ***	20.67 C	11.99 ***	213.21 B	174.69 ***
Cosiana (c3)	19.83 B	4.66 **	74.17 A	35.26 ***	36.40 A	27.72 ***	325.58 A	287.06 ***
Cezarina (c4) (control)	15.17 C	-	38.92 C	-	8.68 D	-	38.52 C	-

LSD height 1 month (cm): *p* 5% = 2.80; *p* 1% = 3.80; *p* 0.1% = 5.09. LSD height 2 months (cm): *p* 5% = 4.39; *p* 1% = 5.97; *p* 0.1% = 7.99. LSD minitubers/*p*lant: *p* 5% = 2.31; *p* 1% = 3.14; *p* 0.1% = 4.21. LSD minituber weight (g): *p* 5% = 25.35; *p* 1% = 34.46; *p* 0.1% = 46.15.

At one month, Azaria and Brașovia cultivars were very significantly taller than Cezarina in 2026. Azaria showed a highly significant increase in 2026 compared with 2025 (7.79 cm); Brașovia, Cosiana and Cezarina did not differ significantly between years (Table 7).

At two months, Brașovia, Cosiana and Azaria remained significantly taller than Cezarina in both years, and none of the four cultivars differed significantly between 2025 and 2026 (Table 8).

One month after transfer, plants grown aeroponically were generally taller than those grown conventionally, with the difference being distinctly significant for Cosiana (6.25 cm) and significant for Azaria (3.71 cm) and Cezarina (3.79 cm) (Table 9).

Two months after transfer, the advantage of the aeroponic system was more pronounced for every cultivar, with highly significant differences ranging from 29.15 cm (Azaria) to 80.83 cm (Brașovia); the highest values were obtained by Brașovia (111.25 cm) and Cosiana (109.89 cm) under aeroponic cultivation (Table 10).

The aeroponic system favored early vegetative growth for all cultivars. Height increases from 2025 to 2026 under aeroponic cultivation were highly significant for Azaria (13.67 cm), distinctly significant for Brașovia (9.73 cm) and non-significant for Cosiana and Cezarina (Table 11).

Table 5. Year × cultivation method interaction - plant height (cm) one month after transfer

Method	2026 (a1)	Diff./Sig.	2025 (a2)	Diff./Sig.	a1-a2/Sig.
Aeroponic (b1)	26.38	8.99 ***	18.12	-0.29 ns	8.25 **
Conventional (b2, control)	17.39	-	18.42	-	-1.03 ns
		LSD: *p* 5% = 2.04; *p* 1% = 3.37; *p* 0.1% = 6.31.			LSD: *p* 5% = 1.90; *p* 1% = 3.56; *p* 0.1% = 8.64.

Table 6. Year × cultivation method interaction - plant height (cm) two months after transfer

Method	2026 (a1)	Diff./Sig.	2025 (a2)	Diff./Sig.	a1-a2/Sig.
Aeroponic (b1)	92.82	60.44 ***	89.76	53.76 ***	3.06 ns
Conventional (b2, control)	32.38	-	36.00	-	-3.63 ns
		LSD: *p* 5% = 8.27; *p* 1% = 13.68; *p* 0.1% = 25.60.			LSD: *p* 5% = 6.57; *p* 1% = 11.55; *p* 0.1% = 24.80.

Table 7. Year × cultivar interaction - plant height (cm) one month after transfer

Cultivar	2026 (a1)	Diff./Sig.	2025 (a2)	Diff./Sig.	a1-a2/Sig.
Azaria (c1)	24.88	9.01 ***	17.08	2.60 ns	7.79 **
Brașovia (c2)	26.25	10.39 ***	22.38	7.90 ***	3.87 ns
Cosiana (c3)	20.54	4.68 *	19.13	4.64 *	1.42 ns
Cezarina (c4) (control)	15.86	-	14.49	-	1.38 ns
		LSD: *p* 5% = 3.96; *p* 1% = 5.38; *p* 0.1% = 7.21.			LSD: *p* 5% = 3.60; *p* 1% = 5.12; *p* 0.1% = 7.83.

Table 8. Year × cultivar interaction - plant height (cm) two months after transfer

Cultivar	2026 (a1)	Diff./Sig.	2025 (a2)	Diff./Sig.	a1-a2/Sig.
Azaria (c1)	66.99	27.24 ***	67.08	29.00 ***	-0.10 ns
Brașovia (c2)	71.92	32.17 ***	69.75	31.67 ***	2.17 ns
Cosiana (c3)	71.74	31.99 ***	76.61	38.53 ***	-4.88 ns
Cezarina (c4) (control)	39.75	-	38.08	-	1.67 ns
		LSD: *p* 5% = 6.21; *p* 1% = 8.44; *p* 0.1% = 11.30.			LSD: *p* 5% = 6.04; *p* 1% = 9.02; *p* 0.1% = 15.76.

*Table 9***.** Cultivation method × cultivar interaction - plant height (cm) one month after transfer

Cultivar	Aeroponic (b1)	Diff./Sig.	Conventional (b2)	Diff./Sig.	b1-b2/Sig.
Azaria (c1)	22.83	5.76 **	19.13	5.85 **	3.71 *
Brașovia (c2)	26.13	9.06 ***	22.50	9.22 ***	3.63 ns
Cosiana (c3)	22.96	5.89 **	16.71	3.43 ns	6.25 **
Cezarina (c4) (control)	17.07	-	13.28	-	3.79 *
		LSD: *p* 5% = 3.96; *p* 1% = 5.38; *p* 0.1% = 7.21.			LSD: *p* 5% = 3.70; *p* 1% = 5.16; *p* 0.1% = 7.28.

Table 10. Cultivation method × cultivar interaction - plant height (cm) two months after transfer

Cultivar	Aeroponic (b1)	Diff./Sig.	Conventional (b2)	Diff./Sig.	b1-b2/Sig.
Azaria (c1)	81.61	19.19 ***	52.46	37.04 ***	29.15 ***
Brașovia (c2)	111.25	48.83 ***	30.42	15.00 ***	80.83 ***
Cosiana (c3)	109.89	47.47 ***	38.46	23.04 ***	71.43 ***
Cezarina (c4) (control)	62.42	-	15.42	-	47.00 ***
	LSD: *p* 5% = 6.21; *p* 1% = 8.44; *p* 0.1% = 11.30.			LSD: *p* 5% = 7.85; *p* 1% = 11.76; *p* 0.1% = 18.98.	

Table 11. Year × cultivation method × cultivar interaction - plant height (cm) one month after transfer

Cultivar	2026 (a1)					2025 (a2)					a1-a2/Sig.	
	Aero.(b1)	Diff./Sig	Conv.(b2)	Diff./Sig	b1-b2/Sig	Aero.(b1)	Diff./Sig	Conv.(b2)	Diff./Sig	b1-b2/Sig	b1	b2
Azaria (c1)	29.67	10.17 **	20.08	7.86 **	9.58 **	16.00	1.36 ns	18.17	3.83 ns	-2.17 ns	13.67 ***	1.92 ns
Brașovia (c2)	31.00	11.50 ***	21.50	9.28 **	9.50 **	21.27	6.63 *	23.50	9.17 *	-2.23 ns	9.73 **	-2.00 ns
Cosiana (c3)	25.33	5.83 *	15.75	3.53 ns	9.58 **	20.58	5.95 *	17.67	3.33 ns	2.92 ns	4.75 ns	-1.92 ns
Cezarina (c4)	19.50	-	12.22	-	7.28 *	14.64	-	14.33	-	0.30 ns	4.86 ns	-2.11 ns

LSD cultivar: *p* 5% = 5.60; *p* 1% = 7.61; *p* 0.1% = 10.19. LSD method: *p* 5% = 5.23; *p* 1% = 7.29; *p* 0.1% = 10.30. LSD year: *p* 5% = 5.17; *p* 1% = 7.26.

Table 12. Year × cultivation method × cultivar interaction - plant height (cm) two months after transfer

Cultivar	2026 (a1)					2025 (a2)					a1-a2/Sig.	
	Aero.(b1)	Diff./Sig	Conv.(b2)	Diff./Sig	b1-b2/Sig	Aero.(b1)	Diff./Sig	Conv.(b2)	Diff./Sig	b1-b2/Sig	b1	b2
Azaria (c1)	82.56	17.06 ***	51.42	37.42 ***	31.14 ***	80.67	21.33 ***	53.50	36.67 ***	27.17 ***	1.89	-2.08 ns
Brașovia (c2)	114.67	49.17 ***	29.17	15.17 **	85.50 ***	107.83	48.50 ***	31.67	14.83 **	76.17 ***	6.83 ns	-2.50 ns
Cosiana (c3)	108.56	43.06 ***	34.92	20.92 ***	73.64 ***	111.22	51.89 ***	42.00	25.17 ***	69.22 ***	-2.67 ns	-7.08 ns
Cezarina (c4)	65.50	-	14.00	-	51.50 ***	59.33	-	16.83	-	42.50 ***	6.17 ns	-2.83 ns

LSD cultivar: *p* 5% = 8.78; *p* 1% = 11.93; *p* 0.1% = 15.98. LSD method: *p* 5% = 11.11; *p* 1% = 16.63; *p* 0.1% = 26.84. LSD year: *p* 5% = 9.90; *p* 1% = 14.82; *p* 0.1% = 24.66.

The aeroponic advantage was highly significant for every cultivar in both years, with the largest differences recorded for Brașovia (85.50 cm in 2026, 76.17 cm in 2025) and Cosiana (73.64 cm and 69.22 cm, respectively). The between-year differences within each method were not significant for any cultivar (Table 12).

Table 13. Year × cultivation method interaction - number of minitubers per plant

Method	2026 (a1)	Diff./Sig.	2025 (a2)	Diff./Sig.	a1-a2/Sig.
Aeroponic (b1)	40.59	33.84 ***	37.26	32.60 ***	3.33 ns
Conventional (b2, control)	6.75	-	4.67	-	2.08 ns
	LSD: *p* 5% = 5.98; *p* 1% = 9.90; *p* 0.1% = 18.54.			LSD: *p* 5% = 6.11; *p* 1% = 11.83; *p* 0.1% = 30.15.	

The number of minitubers per plant was highly significantly higher under aeroponic than under conventional cultivation in both years (+33.84 and +32.60 minitubers/plant, respectively), while the difference between years within the same method was not significant (Table 13).

*Table 14***.** Year × cultivar interaction - number of minitubers per plant

Cultivar	2026 (a1)	Diff./Sig.	2025 (a2)	Diff./Sig.	a1-a2/Sig.
Azaria (c1)	21.93	10.10 ***	25.11	19.59 ***	-3.18 ns
Brașovia (c2)	14.58	2.75 ns	26.75	21.22 ***	-12.17 oo
Cosiana (c3)	46.33	34.50 ***	26.47	20.95 ***	19.86 **
Cezarina (c4) (control)	11.83	-	5.53	-	6.31 *

LSD (c): *p* 5% = 3.27; *p* 1% = 4.45; *p* 0.1% = 5.96.
LSD (a): *p* 5% = 5.06; *p* 1% = 9.56; *p* 0.1% = 24.81.

In 2026, Cosiana produced the highest number of minitubers per plant (46.33), highly significantly above Cezarina (11.83); in 2025 the highest values were recorded for Brașovia (26.75) and Cosiana (26.47). Between years, Cosiana increased significantly (+19.86), Brașovia decreased highly significantly (-12.17), while the change for Azaria was not significant (Table 14).

Table 15. Cultivation method × cultivar interaction - number of minitubers per plant

Cultivar	Aeroponic (b1)	Diff./Sig.	Conventional (b2)	Diff./Sig.	b1-b2/Sig.
Azaria (c1)	42.58	35.72 ***	4.46	-6.04 ooo	38.13 ***
Brașovia (c2)	37.50	30.64 ***	3.83	-6.67 ooo	33.67 ***
Cosiana (c3)	68.76	61.90 ***	4.04	-6.46 ooo	64.72 ***
Cezarina (c4) (control)	6.86	-	10.50	-	-3.64 ns

LSD (c): *p* 5% = 3.27; *p* 1% = 4.45; *p* 0.1% = 5.96.
LSD (b): *p* 5% = 5.04; *p* 1% = 7.78; *p* 0.1% = 13.18.

Under aeroponic cultivation, Cosiana produced the most minitubers per plant (68.76), followed by Azaria (42.58) and Brașovia (37.50), all highly significantly above the control; under conventional cultivation the same three cultivars fell below the control. The aeroponic-versus-conventional difference was highly significant for Azaria, Brașovia and Cosiana (+38.13, +33.67 and +64.72 minitubers/plant, respectively) but not for Cezarina (Table 15).

Table 16. Year × cultivation method × cultivar interaction - number of minitubers per plant

Cultivar	2026 (a1)					2025 (a2)					a1-a2/Sig.	
	Aero.(b1)	Diff./Sig	Conv.(b2)	Diff./Sig	b1-b2/Sig	Aero.(b1)	Diff./Sig	Conv.(b2)	Diff./Sig	b1-b2/Sig	b1	b2
Azaria (c1)	39.28	31.44 ***	4.58	-11.25 ooo	34.69 ***	45.89	40.00 ***	4.33	-0.83 ns	41.56 ***	-6.61 ns	0.25 ns
Brașovia (c2)	26.33	18.50 ***	2.83	-13.00 ooo	23.50 ***	48.67	42.78 ***	4.83	-0.33 ns	43.83 ***	-22.33 oo	-2.00 ns
Cosiana (c3)	88.92	81.08 ***	3.75	-12.08 ooo	85.17 ***	48.61	42.72 ***	4.33	-0.83 ns	44.28 ***	40.31 ***	-0.58 ns
Cezarina (c4)	7.83	-	15.83	-	-8.00 o	5.89	-	5.17	-	0.72 ns	1.95 ns	10.67 *

LSD cultivar: *p* 5% = 4.63; *p* 1% = 6.29; *p* 0.1% = 8.42. LSD method: *p* 5% = 7.13; *p* 1% = 11.00; *p* 0.1% = 18.64. LSD year: *p* 5% = 7.12; *p* 1% = 12.12; *p* 0.1% = 26.11.

In 2026, Cosiana reached the highest number of minitubers per plant under aeroponic cultivation (88.92), highly significantly above the control cultivar; between years, Cosiana increased highly significantly under aeroponic cultivation (+40.31), whereas Brașovia decreased highly significantly (-22.33). Under conventional cultivation the between-year difference was significant only for Cezarina (+10.67) (Table 16).

Table 17. Year × cultivation method interaction - minituber weight (g) per plant

Method	2026 (a1)	Diff./Sig.	2025 (a2)	Diff./Sig.	a1-a2/Sig.
Aeroponic (b1)	324.30	275.62 ***	357.11	283.83 ***	-32.81 ns
Conventional (b2, control)	48.69	-	73.28	-	-24.59 ns

LSD (b): *p* 5% = 49.69; *p* 1% = 77.26; *p* 0.1% = 144.61. LSD (a): *p* 5% = 50.51; *p* 1% = 99.60; *p* 0.1% = 260.47.

Minituber weight per plant was highly significantly higher under aeroponic than under conventional cultivation in both years (+275.62 g in 2026, +283.83 g in 2025), while the differences between years were not significant under either method (Table 17).

Table 18. Year × cultivar interaction - minituber weight (g) per plant

Cultivar	2026 (a1)	Diff./Sig.	2025 (a2)	Diff./Sig.	a1-a2/Sig.
Azaria (c1)	201.00	159.95 ***	251.14	215.16 ***	-50.14 o
Brașovia (c2)	133.51	92.45 ***	292.92	256.93 ***	-159.41 oo
Cosiana (c3)	370.42	329.36 ***	280.74	244.75 ***	89.68 **
Cezarina (c4) (control)	41.06	-	35.98	-	5.07 ns

LSD (c): *p* 5% = 35.85; *p* 1% = 48.73; *p* 0.1% = 65.26. LSD (a): *p* 5% = 47.29; *p* 1% = 84.06; *p* 0.1% = 201.24.

In 2026, Cosiana recorded the highest minituber weight per plant (370.42 g); in 2025 the highest values were obtained by Brașovia (292.92 g), Cosiana (280.74 g) and Azaria (251.14 g), all highly significantly above the control cultivar. Between years, Cosiana increased significantly (+89.68 g), while Azaria and Brașovia decreased (-50.14 g and -159.41 g, respectively) (Table 18).

Table 19. Cultivation method × cultivar interaction - minituber weight (g) per plant

Cultivar	Aeroponic (b1)	Diff./Sig.	Conventional (b2)	Diff./Sig.	b1-b2/Sig.
Azaria (c1)	361.22	315.57 ***	90.92	59.53 **	270.31 ***
Brașovia (c2)	366.05	320.40 ***	60.38	28.99 ns	305.68 ***
Cosiana (c3)	589.90	544.25 ***	61.25	29.86 ns	528.65 ***
Cezarina (c4) (control)	45.65	-	31.39	-	14.26 ns

LSD (c): *p* 5% = 35.85; *p* 1% = 48.73; *p* 0.1% = 65.26. LSD (b): *p* 5% = 44.82; *p* 1% = 66.96; *p* 0.1% = 107.68.

Under aeroponic cultivation, Cosiana attained the highest minituber weight per plant (589.90 g), followed by Brașovia (366.05 g) and Azaria (361.22 g); under conventional cultivation Azaria recorded the highest value (90.92 g). The aeroponic-versus-conventional difference was highly significant for Azaria, Brașovia and Cosiana but not for Cezarina (Table 19).

Table 20. Year × cultivation method × cultivar interaction - minituber weight (g) per plant

	2026 (a1)					2025 (a2)					a1-a2/Sig.	
Cultivar	Aero.(b1)	Diff./Sig	Conv.(b2)	Diff./Sig	b1-b2/Sig	Aero.(b1)	Diff./Sig	Conv.(b2)	Diff./Sig	b1-b2/Sig	b1	b2
Azaria (c1)	312.33	269.06 ***	89.67	50.83 *	222.67 ***	410.11	362.09 ***	92.17	68.22 *	317.94 ***	-97.78 o	-2.50 ns
Brașovia (c2)	237.93	194.66 ***	29.08	-9.75 ns	208.85 ***	494.17	446.14 ***	91.67	67.72 *	402.50 ***	-256.23 ooo	-62.58 ns
Cosiana (c3)	703.67	660.39 ***	37.17	-1.66 ns	666.50 ***	476.14	428.12 ***	85.33	61.39 *	390.81 ***	227.53 ***	-48.17 ns
Cezarina (c4)	43.28	-	38.83	-	4.44 ns	48.02	-	23.94	-	24.08 ns	-4.75ns	14.89 ns

LSD cultivar: *p* 5% = 50.70; *p* 1% = 68.91; *p* 0.1% = 92.29. LSD method: *p* 5% = 63.39; *p* 1% = 94.70; *p* 0.1% = 152.29. LSD year: *p* 5% = 65.01; *p* 1% = 106.21; *p* 0.1% = 215.57.

In 2026, Cosiana produced the highest minituber weight per plant under aeroponic cultivation (703.67 g); under conventional cultivation, Azaria recorded the highest value. Between years, minituber weight under aeroponic cultivation increased significantly only for Cosiana (227.53 g); under

conventional cultivation, no between-year difference was significant (Table 20).

The significant year × cultivar and year × method × cultivar interactions for number and weight (Tables 14, 16, 18, 20) show that the stability of cultivar performance differed. In 2025 the three superior cultivars were similar under aeroponics (45.8-48.67 minitubers per plant), whereas in 2026 they diverged: Cosiana rose to 88.92 and Brașovia fell to 26.33 (Table 16). Cosiana therefore combined the highest yield with a significant year-to-year gain, while Brașovia was the least stable. The higher plant height recorded one month after transfer in 2026, especially for Azaria and Brașovia under the aeroponic system, points to a superior capacity of these genotypes to exploit the aeroponic conditions in that particular cycle; because cultivation technology and parameters were identical in both years, the differences observed between years most likely reflect the biological response of the cultivars to aeroponic cultivation combined with natural variability between experimental cycles rather than a genuine year effect. Similarly, the variation in minituber number and weight observed for certain cultivar × method combinations between years - such as the marked increase for Cosiana and decrease for Brașovia under aeroponic cultivation - suggests a differential genotypic sensitivity to subtle, difficult-to-control factors specific to each cultivation cycle. The origin and physiological condition of the plant material can influence minituber production under aeroponics. Buckseth et al. (2024) showed that different plant sources led to variation in production potential in an aeroponic system, and Brocic et al. (2022) reported that, besides cultivar, the type of planting material affected minituber formation. Production under aeroponics may also vary with the timing of the cultivation cycle, as indicated by our earlier results on minituber production in different cultivation periods (Tican et al., 2026a). These factors may have contributed to the between-year differences observed here for certain cultivar × method combinations, even though the aeroponic technology and cultivation parameters were the same in both years.

The particular behavior of the control cultivar Cezarina

In the case of the control cultivar Cezarina, conventional cultivation in 2026 produced a higher number of minitubers, yet their total weight remained low, indicating the formation of smaller and lighter individual minitubers. This response suggests a limited capacity of Cezarina to accumulate and redistribute assimilates toward storage organs under conventional cultivation conditions, so that the higher number of minitubers formed was not reflected in a corresponding increase in total biomass.

Correlations among plant growth and minituber production traits

Pearson correlation analysis revealed positive, statistically highly significant relationships ($p \leq 0.01$) among all the traits analyzed. The strongest association was recorded between the number of minitubers per plant and minituber weight per plant ($r = 0.972$). Minituber weight per plant was also strongly correlated with plant height two months after transfer ($r = 0.814$), whereas plant height one month after transfer showed only moderate correlations with the other traits ($r = 0.374$-0.565). All correlations are positive, suggesting that good vegetative development is associated with a high capacity for minituberization.

Table 21. Pearson correlation coefficients among the traits analyzed

Trait	Height 1 month	Height 2 months	Minitubers/ plant	Minitubers weight/plant	r
Height 1 month	1	0.565**	0.374**	0.391**	1
Height 2 months	0.565**	1	0.755**	**0.814****	0.75
Minitubers/plant	0.374**	0.755**	1	**0.972****	0.5
Minitubers weight/plant	0.391**	**0.814****	**0.972****	1	0.25

***. indicates a statistically significant correlation at the 0.01 level (two-tailed).*

Relationships among vegetative development and tuberization traits

The very strong correlation between the number of minitubers per plant and minituber weight per plant (r = 0.972) confirms the close association between tuberization intensity and total biomass accumulation, indicating a very strong positive association between minituber number and total production weight. The strong correlation between plant height two months after transfer and minituber weight (r = 0.814) suggests that greater vegetative vigor at this later developmental stage is associated with higher tuberization potential, whereas the comparatively weaker correlations involving plant height at one month indicate that early vegetative growth is a less reliable predictor of final tuberization performance. Taken together, these relationships support the conclusion that both cultivation method and cultivar genotype act primarily by enhancing vegetative development, which in turn translates into greater minituber production.

Despite this, the consistent advantage of aeroponics over two years supports its use for rapid multiplication of in vitro material, with Cosiana being the most promising of the tested cultivars. Aeroponic potato production in Romania is still at research stage, and these results provide a basis for larger trials.

CONCLUSIONS

The aeroponic system was the main driver of performance. Plant height at two months was 91.29 cm versus 34.19 cm under conventional cultivation. Minituber number was 38.93 versus 5.71 per plant (about 6.8-fold higher) and minituber weight 340.71 g versus 60.98 g per plant (all differences highly significant, $p \leq 0.001$). The absence of mechanical impedance allows unrestricted root and stolon development. Continuous water and nutrient availability supports leaf area and photosynthesis, and therefore the assimilate flux toward storage organs. The advantage increased over time, from +4.35 cm at one month to +57.10 cm at two months, consistent with progressive biomass accumulation.

Cosiana showed the highest tuberization capacity, with 36.40 minitubers and 325.58 g per plant averaged over both systems. Brașovia showed the greatest vegetative vigor, reaching 26.13 cm at one month and 111.25 cm at two months under aeroponics. Azaria also performed well. These differences may reflect a higher genetic potential for stolon initiation and assimilate partitioning toward tubers (sink strength), fully expressed when root-zone conditions are non-limiting.

The Cosiana cultivar in aeroponic conditions performed best, with 68.76 minitubers and 589.90 g per plant.

Year did not significantly affect plant height at two months or minituber number and weight. A significant effect appeared only at one month (21.88 vs. 18.27 cm), driven by the aeroponic response (+8.25 cm). Cosiana made the best use of the 2026 year, with +19.86 minitubers and +89.68 g per plant relative to 2025.

Minituber number and weight were very strongly correlated (r = 0.972**), and vegetative vigor at two months was associated with production (r = 0.814** with weight; r = 0.755** with number). This indicates that photosynthetically active vegetative development precedes and supports tuberization.

Aeroponic cultivation, particularly with cv. Cosiana, is the most promising option for rapid multiplication of *in vitro* material. The advantage of aeroponic cultivation was maintained across the two experimental years, although cultivar-specific responses varied between years and provide a basis for larger-scale trials.

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