COMPARATIVE EVALUATION OF AEROPONIC, HYDROPONIC AND CONVENTIONAL SYSTEMS FOR POTATO MINITUBER PRODUCTION

EVALUAREA COMPARATIVĂ A SISTEMELOR AEROPONICE, HIDROPONICE ȘI CONVENȚIONALE UTILIZATE PENTRU PRODUCEREA MINITUBERCULILOR DE CARTOF

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DOI: https://doi.org/10.35633/inmateh-79-97

Keywords: *Biomass Accumulation, Controlled Environment, Genotype Adaptability, Nutrient Availability, Root-Zone Oxygenation, Soilless Cultivation, Tuberization.*

ABSTRACT

Aeroponic cultivation has emerged as a promising technology for improving potato minitubers production under controlled conditions. This study evaluated the effects of three cultivation systems (aeroponics, hydroponics, and conventional cultivation) and four potato genotypes (Azaria, Brasovia, Cosiana and Cezarina) on plant growth and minitubers production. Plant height, number of minitubers per plant and minitubers weight per plant were assessed. Analysis of variance reveals a statistically significant effect of the cultivation method on plant height at one month ($p < 0.01$) and a highly significant effect on plant height at two months, as well as on the number and weight of minitubers per plant ($p < 0.001$). The variety has a statistically significant effect on plant height at one month ($p < 0.01$) and a highly significant effect on the other parameters analyzed ($p < 0.001$). The interaction between cultivation method and variety is insignificant for plant height at one month ($p > 0.05$), but becomes highly significant for plant height at two months and for production traits ($p < 0.001$), indicating a differentiated response of the varieties to the conditions specific to each cultivation method. Hydroponic cultivation stimulated early plant growth one month after transplanting, whereas aeroponic cultivation resulted in the greatest plant height two months after transplanting. The aeroponic system also produced the highest number of minitubers (37.26 per plant) and the greatest minitubers weight (357.11 g per plant), significantly exceeding both hydroponic and conventional systems. Among the evaluated genotypes, Cosiana, Brasovia and Azaria showed superior minitubers production compared with control cultivar Cezarina. The results demonstrate the high potential of aeroponic cultivation for efficient potato minitubers production and support the implementation of advanced soilless technologies.

REZUMAT

Cultura aeroponică reprezintă o tehnologie promițătoare pentru îmbunătățirea producției de minituberculi de cartof în condiții controlate. Acest studiu a evaluat efectele a trei sisteme de cultură (aeroponică, hidroponică și cultura convențională) și a patru genotipuri de cartof (Azaria, Brasovia, Cosiana și Cezarina) asupra creșterii plantelor și producției de minituberculi. Au fost evaluate înălțimea plantei, numărul de minituberculi per plantă și greutatea minituberculilor per plantă. Analiza varianței evidențiază un efect semnificativ statistic al metodei de cultură asupra înălțimii plantelor la o lună ($p < 0,01$) și un efect foarte semnificativ asupra înălțimii plantelor la două luni, precum și asupra numărului și greutății minituberculilor per plantă ($p < 0,001$). Soiul prezintă un efect semnificativ statistic asupra înălțimii plantelor la o lună ($p < 0,01$) și un efect foarte semnificativ asupra celorlalți parametri analizați ($p < 0,001$). Interacțiunea dintre metoda de cultură și soi este nesemnificativă pentru înălțimea plantelor la o lună ($p > 0,05$), dar devine foarte semnificativă statistică pentru înălțimea plantelor la două luni și pentru caracterele de producție ($p < 0,001$), indicând un răspuns diferențiat al soiurilor la condițiile specifice fiecărei metode de cultură. Cultura hidroponică a stimulat creșterea timpurie a plantei la o lună după transplantare, în timp ce cultura aeroponică a dus la cea mai mare înălțime a plantei la două luni după transplantare. Sistemul aeroponic a produs, de asemenea, cel mai mare număr de minituberculi (37,26 per plantă) și cea mai mare greutate a minituberculilor (357,11 g per plantă), depășind semnificativ atât sistemele hidroponice, cât și cele convenționale. Printre genotipurile evaluate, Cosiana, Brasovia și Azaria au prezentat o producție superioară de minituberculi în comparație cu cultivarul martor, Cezarina. Rezultatele demonstrează potențialul ridicat al culturii aeroponice pentru producția eficientă de minituberculi de cartof și susțin implementarea tehnologiilor avansate de cultivare fără sol în sistemele românești de producție a cartofului de sămânță.

INTRODUCTION

Feeding the expanded global population nutritiously and sustainably will require substantial improvements to the food system. The main challenge will be to produce more food using the same or fewer resources while reducing waste (*Devaux, 2021*). The increasing challenges associated with climate change, water scarcity, soil degradation, and the growing demand for high-quality planting material have stimulated the development of innovative crop production systems (*Tunio et al., 2020*; *Balasundram et al., 2023*; *Deguine, 2023*; *Salma and Kaushal, 2024*). Traditional seed potato production systems are characterized by a low multiplication rate (1:6) and a high risk of disease accumulation (*Sadawarti et al., 2026*). Controlled environment agriculture (CEA), including hydroponic and aeroponic cultivation systems, has gained increasing attention as a promising approach for improving productivity while reducing resource consumption and environmental constraints (*Benke and Tomkins, 2017*; *Eldridge et al., 2020*; *Kozai et al., 2020; Shamshiri et al., 2021; Cheema et al., 2024; Silva Filho et al., 2024; Wang, 2024*). Within this framework, soilless culture systems are increasingly adopted as a major technological component in the modern greenhouse industry (*Savvas and Gruda, 2018*). The technological innovations in solid and non-solid substrate cultivation have significantly improved the controllability of the root environment and the production stability (*Sharma et al., 2024*). Aeroponic cultivation has gained considerable attention in recent years due to its potential to enhance plant growth, nutrient-use efficiency. In aeroponic systems, plant roots are suspended in the air and periodically supplied with a nutrient-rich mist, improving root-zone oxygenation and nutrient availability (*Eldridge et al., 2020*). The aeroponic method is highly efficient (*Sinha, 2025*), requiring less space and less water than even the most optimized hydroponic systems (*Kumari and Kumar, 2019*). Compared with conventional cultivation, aeroponic cultivation considerably reduces water and substrate requirements (*Oljača et al., 2024; Hartinger et al., 2025*). Previous studies have demonstrated that aeroponics can substantially increase the multiplication rate of potato minitubers compared to conventional cultivation methods (*Ritter et al., 2001; Buckseth et al., 2016; Çalışkan et al., 2021*). Recent investigations have also highlighted the advantages of aeroponic systems for producing disease-free plantlets and improving minituber yield under controlled environmental conditions (*Tunio et al., 2020*; *Salma and Kaushal, 2024*). In addition, aeroponic systems allow successive harvesting during the vegetation period, thereby increasing multiplication efficiency (*Brocic et al., 2022*; *Buckseth et al., 2024*; *Oljača et al., 2024*). Multiple harvests not only increase the total number of tubers by 36%, but also improve tuber quality with adjustable tuber size and reduced the number of rotten tubers per plot (*Dianawati, 2025*). Research interest in aeroponic potato cultivation has intensified in recent years due to the possibility of integrating automated monitoring systems, sensors and controlled environmental conditions for optimizing plant growth and productivity. Recent studies have emphasized the importance of genotype, nutrient management and environmental control for maximizing minituber production efficiency under aeroponic conditions (*Cheema et al., 2024*; *Silva Filho et al., 2024*). *Farran and Mingo-Castel (2006)* demonstrated that both planting density and harvesting interval significantly influence minituber yield, with shorter harvesting intervals resulting in higher production efficiency. *Singh et al. (2025)* reported that in the aeroponic system for the production of potato minitubers, crop performance is significantly influenced by the interaction between cultivar, planting date and planting density. Studies conducted in an aeroponic system have demonstrated that this technology allows for the efficient differentiation of potato genotypes according to root system characters, nitrogen use efficiency and production capacity, providing a valuable tool for breeding programs oriented towards the efficient use of resources (*Tiwari et al., 2022*).

Although aeroponic cultivation has the potential to increase potato minituber production, its performance with local genotypes in Eastern Europe remains insufficiently studied. This study compares aeroponic, hydroponic, and conventional cultivation systems using four potato genotypes grown under controlled conditions in Romania. Plant growth, minituber number, and minituber weight were evaluated. It was hypothesized that improved root-zone aeration and nutrient availability in the aeroponic system would enhance productivity compared with the other cultivation systems. The findings contribute to the development of more sustainable potato minituber production systems in Romania.

MATERIALS AND METHODS

Experimental site and plant material

The experiment was conducted in 2025 at the National Institute of Research and Development for Potato and Sugar Beet (NIRDPSB) Brașov, Romania. Four potato (*Solanum tuberosum* L.) genotypes obtained through *in vitro* propagation were evaluated: Azaria, Brasovia, Cosiana, and Cezarina, the latter being used as the control cultivar. Virus-free *in vitro* plantlets, belonging to the four cultivars, were transplanted and cultivated using three cultivation systems: hydroponic, aeroponic, and conventional systems.

Experimental design

The experiment was organized as a bifactorial trial in a completely randomized design with three replicates. Two experimental factors were studied: the cultivation system and the genotype. Factor A comprised three cultivation systems: hydroponics, aeroponics, and conventional cultivation (control), while Factor B consisted of four potato genotypes. Plant growth and minituber production parameters were evaluated throughout the experimental period.

Hydroponic and conventional cultivation systems

For the hydroponic and conventional cultivation systems, transplanting of the *in vitro* plantlets was carried out at the end of May 2025 in a conventional insect-proof greenhouse without temperature control. The nutrient solution pH was maintained at 5.8 ± 0.2, while electrical conductivity (EC) was set at 1.0 mS cm^{-1} during the first week after transplanting and gradually increased to 2.0 mS cm^{-1} over the following two weeks. In the hydroponic system, perlite was used as the growth substrate, and the nutrient solution was supplied daily each morning for 2 h, utilizing the same formulation as the aeroponic system. The conventional cultivation system served as the control and consisted of plants grown in a peat-based substrate under greenhouse conditions. Plants in this system were irrigated daily with water for 2 h to maintain adequate substrate moisture throughout the experimental period. No nutrient solution was supplied to the pots, as was done in the hydroponic and aeroponic systems. Instead, a foliar fertilizer was applied weekly to provide supplemental nutrients and support normal plant development. The conventional system was managed according to a substrate-based cultivation approach and was therefore intentionally maintained without continuous nutrient delivery through the irrigation water, in contrast to the hydroponic and aeroponic systems. This distinction was part of the experimental design and allowed the biological performance of the soilless hydroponic and aeroponic systems to be compared with a conventional substrate-based cultivation system under greenhouse conditions.

Aeroponic cultivation system

For the aeroponic system, transplanting was performed at the beginning of June 2025. Plants were cultivated under controlled environmental conditions using artificial lighting. The aeroponic system was installed in a growth room with temperature and humidity control. The aeroponic system developed at NIRDPSB Brașov was equipped with automated sensors for monitoring and controlling nutrient solution pH, electrical conductivity (EC), and temperature. Recent advances in digital agriculture have further increased the potential of aeroponic production systems. The integration of sensors, automated nutrient management, environmental monitoring, and data-driven decision support systems enables precise control of cultivation conditions and contributes to improved crop performance (*Balasundram et al., 2023; Wang, 2024*). Such technologies are particularly relevant for seed potato production, where uniformity, phytosanitary quality, and multiplication efficiency are critical factors determining the success of the production chain. Figure 1 illustrates images of minituber harvesting obtained via the aeroponic method.

The nutrient solution pH was maintained at 5.8 ± 0.2, while the EC was adjusted to 1.0 mS cm^{-1} during the first week after transplanting and gradually increased to 2.0 mS cm^{-1} over the following two weeks, remaining at this level until the end of the harvesting period. The chemical composition of the nutrient solution corresponded to the following ionic concentrations: macronutrients (in mg L^{-1}) - N: 104, P: 60.3, K: 148, Ca: 16 mg, Mg: 50.4, and S: 48; micronutrients (in mg L^{-1}) - Fe: 0.192, Mn: 0.080, Zn: 0.024, B: 0.016, Cu: 0.016, Mo: 0.006, and Co: 0.003. Plant roots were suspended inside the aeroponic chamber and sprayed with the nutrient solution for 20 seconds at 10-minute intervals, resulting in an automated delivery frequency of approximately 6 cycles per hour.

Air temperature was kept at 20 °C during the day and 18 °C during the night, while the relative humidity ranged between 65% and 70%. The nutrient solution temperature was regulated at 18 °C using a cooling system. The artificial photoperiod was adjusted according to the plant development stage as follows: 16 h of light during the first week after transplanting to reduce transplant stress, 15 h after one month, 14 h after six weeks, and 13 h after two months of cultivation.

The aeroponic cultivation unit used in this study represents a prototype system currently undergoing patent application procedures. Therefore, certain engineering details have been withheld due to ongoing intellectual property protection requirements. However, all cultivation parameters relevant to plant growth and experimental reproducibility are fully detailed herein.

Fig. 1 - Visual aspects of the aeroponic cultivation system and minituber production: (top) root-zone development, stolon architecture, and manual sequential harvesting of potato minitubers inside the aeroponic chambers; (bottom) sorted potato minitubers demonstrating distinct phenotypic characteristics and size uniformity among the evaluated genotypes

Measurements

Plant height was measured one month and two months after transplanting, from the stem base to the top of the canopy. At harvest, the number of minitubers per plant and total minituber weight per plant were recorded for all experimental treatments. For minitubers from aeroponic culture, 8 sequential harvests were performed. For those from classical culture and hydroponic culture, only one harvest was performed. In the aeroponic system, only minitubers larger than 15 mm were included in the statistical analysis. In the hydroponic and conventional systems, no minitubers smaller than 15 mm were obtained. The study primarily focused on the biological performance of the cultivation systems in terms of plant growth and minituber production efficiency.

Statistical analysis

Experimental data were analyzed using two-way analysis of variance (ANOVA) to evaluate the effects of the cultivation system, genotype, and their interaction. Mean comparisons were performed using Duncan's multiple range test at $p < 0.05$. All statistical analyses were carried out using the POLYFACT software package (developed for polyfactorial agricultural experiments). Additionally, regression analysis was performed to evaluate the relationships between plant growth parameters and minituber yield components, with Microsoft Excel (Microsoft Corp., Redmond, WA, USA) utilized for regression modeling, coefficient of determination (R^2) calculation, and graphical representation

RESULTS

The present study demonstrated the clear superiority of aeroponic cultivation over hydroponic and conventional systems for potato minituber production under Romanian conditions. Aeroponics significantly increased plant growth, minituber number, and minituber biomass, indicating that optimized root-zone conditions can substantially improve potato productivity under controlled environments. Overall, the present results support the hypothesis that aeroponic cultivation provides a more favorable environment for potato growth and minituber production than hydroponic or conventional systems. The consistency of the observed responses with previous investigations (*Eldridge et al., 2020; Buckseth et al., 2024; Cheema et al., 2024; Oljača et al., 2024; Silva Filho et al., 2024; Hartinger et al., 2025*) strengthens the evidence supporting the adoption of aeroponic technologies for minituber potato production.

Local and general context

Aeroponic potato cultivation in Romania is currently primarily limited to research applications. Nevertheless, our findings demonstrate its strong potential for optimizing minituber production under controlled conditions. Aeroponics is mainly used in potato cultivation for the production of minitubers as high-quality planting material. This method enables the rapid production of a large number of healthy tubers, originating from pathogen-free plants obtained through in vitro techniques.

Technological advantages and limitations

Despite its obvious advantages, aeroponics also has certain limitations, including high initial costs for infrastructure and equipment, the need for continuous monitoring and advanced technological management, dependence on stable energy sources for optimal system operation, and variability in response depending on cultivar and growing conditions. These aspects may limit large-scale adoption, especially in traditional agricultural systems. In Romania, previous research on the hydroponic method for potato cultivation has shown superior results compared to the conventional method (*Tican, 2018; Tican et al., 2018a*; *Tican et al., 2025*). While studies on aeroponic methods had also been carried out, early systems were inefficient and failed to yield results comparable to international standards (*Tican et al., 2018b*). More recently, *Tican et al. (2026)* presented results regarding minituber production using an aeroponic system across different cultivation periods.

Plant height

The cultivation system exerted a highly significant influence on plant height one month after transfer, indicating that the cultivation system strongly affected the early vegetative growth of potato plants. Furthermore, cultivar also had a very significant effect on plant height, confirming the important role of genotype in growth expression. By two months after transfer, the effect of the cultivation system became even more pronounced (Table 1). Similar observations regarding the influence of soilless systems on plant development were reported by *Ritter et al. (2001)*, who demonstrated that aeroponic and hydroponic systems stimulate vegetative growth compared to conventional cultivation. Consistent with these findings*, Buckseth et al. (2016)* and *Tunio et al. (2020*), emphasized the favorable effect of aeroponics on potato plant growth and physiological activity.

One month after transfer, the hydroponic system significantly stimulated the initial growth of the plants, while two months later, the aeroponic system ensured the most intense stem elongation (Table 2). At the second determination, aeroponics generated the highest mean plant height (89.77 cm), exceeding the conventional system by more than 50 cm. This was due to the superior oxygenation and nutrient availability inherent to the aeroponic system, which enhanced both stem elongation and plant vigor. Consistent results were presented by *Eldridge et al. (2020)*, who mentioned that hydroponic systems provide stable root-zone conditions during early plant development.

Table 1

Analysis of variance

Source of variation	**Sum of squares**	**DF**	**Mean square**	***F***
Analysis of variance for plant height 1 month after transfer				
Cultivation system (*a*)	172.02	2	86.01	20.45 **(6.94; 18.00)
Cultivar (*b*)	283.06	3	94.35	8.30 **(3.16; 5.09)
Cultivation system (*a*) x Cultivar (*b*)	50.27	6	8.38	0.73 ns (2.66; 4.01)
Analysis of variance for plant height 2 months after transfer				
Cultivation system (*a*)	17413.50	2	8706.75	135.86 **(6.94; 18.00)
Cultivar (*b*)	7482.23	3	2494.08	77.02 **(3.16; 5.09)
Cultivation system (*a*) x Cultivar (*b*)	2505.36	6	417.56	12.90 **(2.66; 4.01)

Note: DF, degrees of freedom; ** significant for $p < 0.01$. Values in parentheses represent the critical *F*-values ($F_{0.05}$; $F_{0.01}$)

The differences observed among cultivars demonstrate the strong influence of genotype on vegetative growth and adaptation to intensive cultivation systems. The Cosiana and Brasovia cultivars exhibited the highest values for plant height (Table 3), indicating a superior capacity to exploit favorable growth conditions.

The interaction between cultivation system and genotype significantly influenced plant height, particularly two months after transfer (Tables 4 and 5). At the first evaluation, differences among cultivation systems were less pronounced, although hydroponic cultivation stimulated early vegetative growth in certain cultivars, especially Cosiana and Brasovia. At the second evaluation, aeroponic cultivation markedly enhanced plant growth for all analyzed genotypes, with the highest values recorded for Cosiana and Brasovia.

Table 2

Influence of the cultivation system on plant height (cm) at 1 and 2 months after transfer

Cultivation system (*a*)	**Plant height (cm) at 1 month**		**Diff. (cm)/Signif.**	**Plant height (cm) at 2 months**		**Diff. (cm)/Signif.**
Hydroponic (a_1)	22.90	A	4.48 **	60.06	B	24.06 **
Aeroponic (a_2)	18.12	B	−0.30 ns	89.77	A	53.77 ***
Conventional (a_3) (Ct)	18.42	B	—	36.00	C	—
	LSD ($p < 0.05$) = 2.33; ($p < 0.01$) = 3.85; ($p < 0.001$) = 7.21.			LSD ($p < 0.05$) = 9.09; ($p < 0.01$) = 15.03; ($p < 0.001$) = 28.14.		

Note: Means within the same column followed by the same letter do not differ significantly according to Duncan's multiple range test (p < 0.05).
ns = not significant; ** = significant at p <0.01; *** = highly significant at p < 0.001; Ct = Control system

Table 3

Influence of cultivar on plant height (cm) at 1 month and 2 months after transfer

Cultivar	Plant height (cm) at 1 month		Diff. (cm)/Signif.	Plant height (cm) at 2 months		Diff. (cm)/Signif.
Azaria	18.24	BC	2.11 ns	64.93	B	26.62 ***
Brasovia	23.33	A	7.20 ***	67.25	B	28.94 ***
Cosiana	21.55	AB	5.42 **	77.29	A	38.99 ***
Cezarina (Ct)	16.13	C	–	38.31	C	—

LSD (p 0.05) = 3.34; (p 0.01) = 4.58; (p 0.001) = 6.23. LSD (p 0.05) = 5.63; (p 0.01) = 7.73; (p 0.001) = 10.52.

Note: Means within the same column followed by the same letter do not differ significantly according to Duncan's multiple range test (p < 0.05).

ns = not significant; ** = significant at p <0.01; *** = highly significant at p < 0.001; Ct = Control cultivar.

Table 4

Combined influence of the cultivation system and cultivar on plant height (cm) 1 month after transfer

Cultivation system (*a*)/ Cultivar (*b*)	Hydroponic system (a_1)		Aeroponic system (a_2)		Conventional system (a_3) (Ct)		a_1-a_3 (cm)/ Signif.	a_2-a_3 (cm)/ Signif.
	Plant height (cm)	Diff. (cm)/ Signif.	Plant height (cm)	Diff. (cm)/ Signif.	Plant height (cm)	Diff. (cm)/ Signif.		
Azaria (b_1)	20.54	1.12 ns	16.00	1.36 ns	18.17	3.84 ns	2.37 ns	−2.17 ns
Brasovia (b_2)	25.23	5.81 *	21.27	6.63 *	23.50	9.17 **	1.73 ns	−2.23 ns
Cosiana (b_3)	26.41	6.99 *	20.58	5.95 *	17.67	3.34 ns	8.74 **	2.91 ns
Cezarina (b_4) (Ct)	19.42	—	14.64	—	14.33	—	5.09 ns	0.31 ns

LSD (p < 0.05) = 5.78; (p < 0.01) = 7.93; (p < 0.001) = 10.79. LSD (p < 0.05) = 5.50; (p < 0.01) = 7.76; (p < 0.001) = 11.21.

Note: ns = not significant; * = significant at p <0.05; ** = significant at p <0.01; Ct = Control.

Table 5

Combined influence of cultivation system and cultivar on plant height (cm) 2 months after transfer

Cultivation system (*a*)/ Cultivar (b)	Hydroponic system (a_1)		Aeroponic system (a_2)		Conventional system (a_3) (Ct)		a_1-a_3 (cm)/ Signif.	a_2-a_3 (cm)/ Signif.
	Plant height (cm)	Diff. (cm)/ Signif.	Plant height (cm)	Diff. (cm)/ Signif.	Plant height (cm)	Diff. (cm)/ Signif.		
Azaria (b_1)	60.61	21.86 ***	80.67	21.34 ***	53.50	36.67 ***	7.11 ns	27.17 **
Brasovia (b_2)	62.25	23.50 ***	107.83	48.50 ***	31.67	14.84 **	30.58 ***	76.17 ***
Cosiana (b_3)	78.61	39.86 ***	111.26	51.93 ***	42.00	25.17 ***	36.61 ***	69.26 ***
Cezarina (b_4) (Ct)	38.75	—	59.33	—	16.83	—	21.92 **	42.50 ***

LSD (p < 0.05) = 9.76; (p < 0.01) = 13.38; (p < 0.001) = 18.21. LSD (p < 0.05) = 12.29; (p < 0.01) = 18.47; (p < 0.001) = 29.98.

Note: ns = not significant; ** = significant at p <0.01; *** = highly significant at p < 0.001; Ct = Control.

Minituber number and weight per plant

Analysis of variance revealed highly significant effects of the cultivation system, genotype, and their interaction on minituber number and weight per plant (Table 6). These results indicate that both technological factors and genetic background strongly influence the efficiency of minituber production under controlled cultivation environment. The significant effect of the cultivation system confirms the importance of root environment optimization for improving tuber initiation and biomass accumulation. The significant genotype effect suggests that potato varieties differ in their capacity to adapt to intensive soilless cultivation systems. In addition, the significant interaction between the cultivation system and genotype indicates that the varietal response depends on the cultivation environment, emphasizing the importance of selecting suitable genotypes for aeroponic production systems.

Aeroponic method led to highest number of minitubers/plant (37.26), the difference of 32.59 minitubers, compared to the classical method, being very statistically significant (Table 7). The hydroponic method achieved a mean number of 9.25 minitubers/plant, a value higher than the control, but the difference of 4.58 minitubers compared to the control method was not statistically significant. The results highlight the efficiency of the aeroponic method, by this method the number of minitubers increased by almost 7.97 times compared to the classical method and 4 times compared to the hydroponic method.

Table 6

Analysis of variance

Source of variation	Sum of squares	DF	Mean square	*F*
Analysis of variance for the number of minitubers per plant				
Cultivation system (*a*)	7472.54	2	3736.27	91.84 **(6.94; 18.00)
Cultivar (*b*)	1652.02	3	550.67	65.95 **(3.16; 5.09)
Cultivation system (*a*)*Cultivar (*b*)	2417.32	6	402.89	48.252 **(2.66; 4.01)
Analysis of variance for minituber weight/plant				
Cultivation system (*a*)	568810.50	2	284405.30	191.46 **(6.94; 18.00)
Cultivar (*b*)	247619.30	3	82539.77	56.95 **(3.16; 5.09)
Cultivation system (*a*)* Cultivar (*b*)	190533.80	6	31755.63	21.91 **(2.66; 4.01)

Note: DF, degrees of freedom; ** significant for p <0.01. Values in parentheses represent the critical F-values (F0.05; F0.01)

Table 7

Influence of cultivation system on the number of minitubers and their weight (g)/plant

Cultivation system (*a*)	Minitubers number per plant		Diff./ Signif.	Minituber weight per plant (g)		Diff. (g)/ Signif.
Hydroponic (a_1)	9.25	B	4.58 ns	111.85	B	38.57 ns
Aeroponic (a_2)	37.26	A	32.59 ***	357.11	A	283.83 ***
Conventional (a_3) (Ct)	4.67	B	—	73.28	B	—

LSD (p < 0.05) = 7.24; (p < 0.01) = 11.98; (p < 0.001) = 22.42. LSD (p < 0.05) = 43.74; (p < 0.01) = 72.38; (p < 0.001) = 135.48.

Note: Means within the same column followed by the same letter do not differ significantly according to Duncan's multiple range test (p <0.05). ns = not significant; *** = highly significant at (p < 0.001).

Table 8

Influence of cultivar on the number of minitubers and their weight (g) per plant

Cultivar (*b*)	Minituber number per plant		Diff./ Signif.	Minituber weight per plant (g)		Diff. (g) / Signif.
Azaria (b_1)	20.50	A	15.12***	227.67	A	190.43 ***
Brasovia (b_2)	20.38	A	15.00 ***	223.87	A	186.63 ***
Cosiana (b_3)	21.99	A	16.61 ***	234.20	A	196.96 ***
Cezarina (Ct) (b_4)	5.38	B	—	37.24	B	—

LSD (p <0.05) = 2.86; (p < 0.01) = 3.92; (p < 0.001) = 5.34 LSD (p <0.05) = 37.69 g; (p < 0.01) = 51.68 g; (p < 0.001) = 70.35 g.

Note: Means within the same column followed by the same letter do not differ significantly according to Duncan's multiple range test (p <0.05). *** = highly significant at p < 0.001.

The analysis of cultivar influence (Table 8) highlights significant genetic differences regarding minituber formation and biomass accumulation. The highest values of minitubers number/plant were recorded for Cosiana (21.99 minitubers/plant), Azaria (20.50 minitubers/plant) and Brașovia (20.38 minitubers/plant) varieties with positive, highly statistically significant differences compared to the control variety Cezarina (5.38 minitubers/plant). Regarding the weight of minitubers/plant, the same trend is observed. Cosiana variety achieved the highest value (234.20 g), followed by Azaria (227.67 g/plant) and Brașovia (223.87 g), with very statistically significant differences (196.96 g, 190.43 g and 186.63 g), compared to the control variety Cezarina (37.24 g).

The aeroponic method led to an increase in the number of minitubers for the Azaria, Brasov and Cosiana varieties, obtaining very significant positive differences (41.56; 43.84; 44.28 minituber/plant) compared to the classical method (Table 9).

Table 9

Combined influence of cultivation system and cultivar on the mean number of minitubers per plant

Cultivation system (*a*)/ Cultivar (*b*)	Hydroponic system (a_1)		Aeroponic system (a_2)		Conventional system (a_3) (Ct)		a_1-a_3/ Signif.	a_2-a_3/ Signif.
	Minituber number per plant	Diff./ Signif.	Minituber number per plant	Diff./ Signif.	Minituber number per plant	Diff./ Signif.		
Azaria (b_1)	11.29	6.21 *	45.89	40.00 ***	4.33	−0.84 ns	6.96 ns	41.56 ***
Brasovia (b_2)	7.63	2.55 ns	48.67	42.78 ***	4.83	−0.34 ns	2.80 ns	43.84 ***
Cosiana (b_3)	13.01	7.93 **	48.61	42.72 ***	4.33	−0.84 ns	8.68 *	44.28 ***
Cezarina (b_4) (Ct)	5.08	—	5.89	—	5.17	−	−0.09 ns	0.72 ns

LSD (p <0.05) = 4.95; (p < 0.01) = 6.97; (p < 0.001) = 9.25. LSD (p <0.05) = 8.34; (p < 0.01) = 13.06; (p < 0.001) = 22.58.

Note: ns = not significant; * = significant at p <0.05; ** = significant at p < 0.01; *** = highly significant at p < 0.001.

Table 10

Combined influence of cultivation system and cultivar on mean weight of minitubers per plant

Cultivation system (*a*)/ Cultivar (*b*)	Hydroponic system (a_1)		Aeroponic system (a_2)		Conventional system (a_3) (Ct)		a_1-a_3 (g)/ Signif.	a_2-a_3 (g)/ Signif.
	Minituber weight (g) per plant	Diff. (g)/ Signif.	Minitub. weight (g) per plant	Diff. (g)/ Signif.	Minitub. weight (g) per plant	Diff. (g)/ Signif.		
Azaria (b_1)	180.74	140.99 ***	410.11	362.09 ***	92.17	68.23 *	88.57 *	317.94 ***
Brasovia (b_2)	85.78	46.03 ns	494.17	446.15 ***	91.67	67.73 *	−5.89 ns	402.5 ***
Cosiana (b_3)	141.13	101.38 **	476.14	428.12 ***	85.33	61.39 ns	55.80 ns	390.81 ***
Cezarina (b_4) (Ct)	39.75	—	48.02	—	23.94	—	15.81 ns	24.08 ns

LSD (p <0.05) = 65.27 g; (p < 0.01) = 89.52 g; (p < 0.001) = 121.85 g. LSD (p <0.05) = 70.88 g; (p < 0.01) = 103.46 g; (p < 0.001) = 159.47 g.

Note: ns = not significant; * = significant at p < 0.05; ** = significant at p < 0.01; *** = highly significant at p < 0.001.

The combined effect of the cultivation system and genotype (Table 10) further confirms the superiority of aeroponic systems in enhancing minituber biomass production, recording very significant positive differences compared to the classical method for Azaria, Brasovia, and Cosiana (317.94; 402.5; 390.81 g). All cultivars exhibited maximum minituber weight under aeroponic conditions, with Brasovia, Cosiana, and Azaria showing the most pronounced responses. Hydroponics produced intermediate values, while conventional cultivation resulted in the lowest biomass accumulation, reflecting the physical and physiological constraints of soil-based growth. The superior response recorded for the Cosiana, Brasovia, and Azaria cultivars indicates that genotype plays an essential role in the adaptation to intensive soilless systems. In addition to increasing the number of minitubers, aeroponic cultivation significantly enhanced minituber biomass accumulation. The greater minituber weight recorded under aeroponic conditions may reflect a more efficient allocation of assimilates toward tuber development resulting from optimal root development and continuous nutrient availability.

Regression analysis

Regression analysis revealed a strong positive correlation between plant height and the number of minitubers produced per plant (R = 0.81, p < 0.01), indicating that greater vegetative development was associated with increased minituber production (Figure 2). In the aeroponic system, where water and nutrients are continuously available, vegetative development is often an indicator of the plant's ability to support the tuberization process. The study by *Silva Filho et al.* (2024) confirms a direct correlation between early vegetative growth indicators measured 21 days after transplantation and the final production of minitubers in an aeroponic system, an aspect that is also strongly supported by the findings in this study.

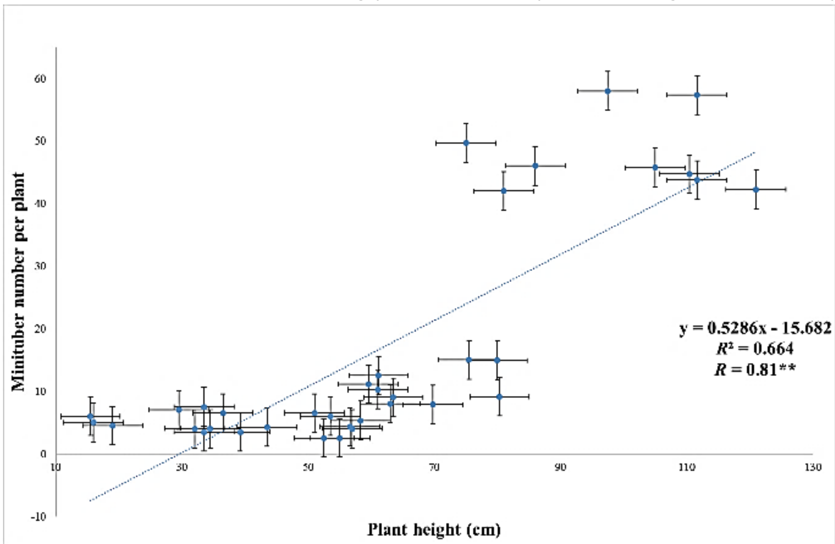

Fig. 2 - Linear regression analysis between plant height (cm) and the number of minitubers per plant across the evaluated potato genotypes and cultivation systems (** indicates significance at p < 0.01).

Limitations and practical implications

Although aeroponics requires a higher initial investment and careful technological management, its capacity to generate high yields of healthy planting material makes this technology promising for the modernization of potato minitubers production in Romania. However, the magnitude of the response differed among genotypes, suggesting that genetic factors strongly influence the ability of plants to exploit the favorable root environment provided by aeroponic systems. An alternative interpretation highlights that part of the observed differences stems not only from the independent cultivation system effects but also from the complex interaction between genotype and specific environmental conditions maintained during cultivation. Therefore, additional studies involving a larger number of genotypes, different nutrient management strategies, and multi-season evaluations would be valuable for confirming the stability of these responses.

Results and Discussions are recommended to be presented as a single section, using subheadings if needed. Be clear and easy to understand but complete and concise in stating and discussing the findings, comparing results with previous works and proposing explanation for the result obtained. All the data of this section must be accompanied by appropriate statistical analyses. Avoid comparisons or contrast which are not relevant to your findings. Avoid any type of speculation unsupported by the data obtained.

CONCLUSIONS

Aeroponic cultivation significantly improved potato plant growth, minituber number and weight compared to hydroponic and conventional cultivation systems. The superiority of the aeroponic system became more evident during advanced vegetation stages.

The aeroponic method leads to obtaining the largest number of minitubers (37.26/plant).

The number of minitubers was ~8 times higher than the classical method and ~4 times higher than the hydroponic method, highlighting the superior efficiency of the aeroponic system;

Among the analyzed genotypes, Cosiana, Brasovia, and Azaria showed superior adaptability to intensive soilless culture systems, recording the highest values for plant development and minituber production. The interaction between the cultivation system and genotype demonstrated that the varietal response plays an important role in the efficiency of minituber production.

The hydroponic method offered intermediate results, but the differences compared to the control were not statistically significant.

The obtained results confirm the potential of aeroponics as an efficient technology for the production of healthy potato planting material in Romania and support its future use in modern minitubers potato production systems.

ACKNOWLEDGEMENT

This research work was carried out with the support of National Institute of Research and Development for Potato and Sugar Beet Brașov and also was financed by Ministry of Research, Innovation and Digitalization, from PN 23 19 01 01 Project "Research on increasing the performance process of the potato minitubers production using an intelligent aeroponic system", period 2023-2026. We mention that for aeroponic system we are in the process of filing patent applications.

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