

Effect of microtunnels on the acclimatization and development of potato varieties in Huánuco

Efecto de microtúneles para la aclimatación y desarrollo de variedades de papa en Huánuco

Bertha Lucila Campos Ríos^{1,a} , Alberth Jeremías Soto Amante^{1,b} ,
Gabriela Saravia Castillo^{2,c} , María de Lourdes Tapia y Figueroa^{3,c} 

Institutional affiliation

¹ Universidad de Huánuco, Huánuco, Perú.

² Independiente, Lima, Perú.

³ Universidad Nacional Agraria La Molina, Lima, Perú.

Academic degree

^a Livestock Engineer

^b Environmental Engineer

^c Agricultural engineer

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ABSTRACT

Objective. To evaluate the effect of two types of microtunnels (plastic and tocuyo fabric) on the early growth of three potato varieties, identifying their interaction during the 28 days after installation (DAI). **Methods.** A completely randomized factorial experiment with nine treatments (3 varieties × 3 microtunnels) was conducted. Survival rate, plant height, number of leaves, number of nodes, aerial fresh weight, and root length were evaluated at 7, 14, 21, and 28 DAI. Data were processed using analysis of variance (ANOVA) and Tukey's mean comparison test ($p < 0.05$). **Results.** The results showed that although the plastic microtunnel increased initial growth, the tocuyo microtunnel provided more stable and sustained growth. The best overall performance corresponded to the canchán variety, which exhibited higher survival and greater root development under tocuyo conditions. Likewise, the Qompis variety stood out in fresh weight at 14, 21, and 28 DAI. Therefore, the tocuyo microtunnel offers balanced conditions to sustain the early growth of potato plants, whereas plastic accelerates emergence but does not maintain vigor in later stages, being the canchán variety which showed the best overall response under tocuyo cover conditions.

Keywords: *Solanum tuberosum*; microtunnel; agricultural plastic; canchán; qompis; tomasa.

RESUMEN

Objetivo. Evaluar el efecto de dos tipos de microtúneles (de plástico y de tocuyo) sobre el crecimiento temprano de tres variedades de papa, identificando la interacción durante los 28 días posteriores a la instalación (DDI). **Métodos.** Se realizó un experimento factorial completamente al azar con nueve tratamientos (3 variedades × 3 microtúneles). Se evaluaron la sobrevivencia, la altura de planta, el número de hojas, el número de nudos, el peso fresco aéreo y la longitud de la raíz, registrados a los 7, 14, 21 y 28 DDI. Los datos fueron procesados mediante análisis de varianza (ANOVA) y medias de Tukey ($p < 0.05$). **Resultados.** Mostraron que, si bien el microtúnel de plástico incrementó el crecimiento inicial, fue el microtúnel de tocuyo el que generó un crecimiento estable y sostenido. El mejor desempeño integral correspondió a la variedad canchán, que presentó mayor supervivencia y mayor desarrollo radicular bajo tocuyo. Asimismo, la variedad qompis destacó en peso fresco a los 14, 21 y 28 DDI. Por lo tanto, el microtúnel de tocuyo ofrece condiciones equilibradas para sostener el crecimiento temprano de la papa, mientras que el plástico acelera la emergencia, pero no mantiene el vigor en etapas posteriores, siendo la variedad canchán la que muestra la mejor respuesta general bajo las condiciones de la cobertura de tocuyo.

Palabras clave: *Solanum tuberosum*; microtúnel; plástico agrícola; canchán; qompis; tomasa.

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Introduction

Potato (*Solanum tuberosum* L.) continues to be one of the key crops of the global agri-food system due to its high productivity, adaptability to different agroecological conditions, and ability to generate consistent yields even under diverse agricultural practices (Devaux et al., 2021; Mølmann & Johansen, 2025). Likewise, it contributes to income and food security (Ortiz & Mares, 2017; Pérez et al., 2024), as it is considered a source of carbohydrates and nutrients for humans (Zierer et al., 2021). On the other hand, despite climatic challenges, potato maintains high productive potential under proper management, which positions it as a strategic crop for sustainable agricultural development (Adekanmbi et al., 2024; Islam et al., 2024).

Early establishment of the potato crop is a critical phase that determines seedling survival, root system formation, and final crop yield. In regions where low nighttime temperatures, high thermal variability, or water deficit at the surface predominate, crop uniformity and productivity are affected (Scavo et al., 2023). In this scenario, the use of structures such as microtunnels is a relevant strategy for modifying conditions, which favors establishment (Sahu & Dubey, 2023; Šrečkov et al., 2025).

Microtunnels can influence temperature, relative humidity, and radiation, generating conditions that can accelerate emergence and initial growth; however, their effectiveness will depend on the characteristics of the material. Recent studies have shown that plastic coverings can increase temperature and water use efficiency, improving early plant vigor (Xiu et al., 2023; Liu et al., 2024). However, excessive heat retention and limited ventilation can induce microclimatic stress, reduce root development, and compromise the physiological stability of the crop (López-Martínez et al., 2021). In contrast, materials such as agricultural fabrics facilitate ventilation and reduce thermal amplitude.

At the genetic level, the response of potato to microclimate modifications depends largely on the genotype. Research related to genotype × environment interaction has revealed significant differences in phenotypic plasticity, tolerance to thermal variation, efficiency in root development, and yield stability among varieties (Zinta et al., 2022; Tatarowska et al., 2024). This variability implies that the effectiveness of a microtunnel cannot be generalized, but rather must be evaluated in its specific interaction with each cultivated variety. Consequently, evaluating the combined response of different materials and varieties is essential for generating sustainable recommendations.

In this context, the present research was conducted to compare the effects of two microtunnel materials—plastic and tocuyo—on the early development of plants of three potato varieties, evaluating morphological variables associated with establishment. The objective of the study was to determine the interaction between the covering material and the variety and to identify the most efficient combination for potato cultivation.

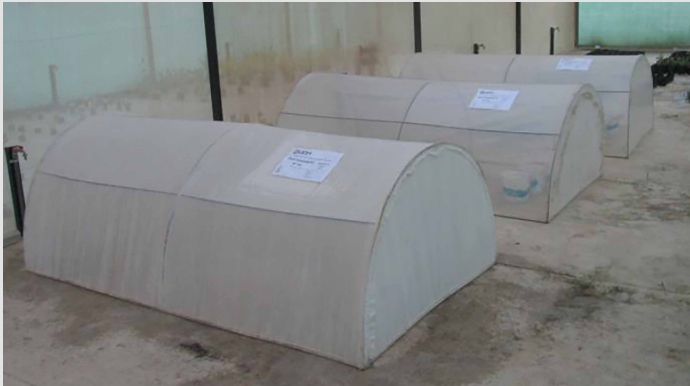
Methods

Type and area of study

The study had a quantitative and experimental approach, with a completely randomized factorial design (3×3), corresponding to three microtunnel materials: Tocuyo fabric, 10-14 plastic (open for 10 hours, closed for 14 hours), and 24-hour plastic (closed for 24 hours), and three potato varieties: canchán, qompis, and tomasa.

La investigación se llevó a cabo en el invernadero de la Universidad de Huánuco, ubicado en la ciudad de Huánuco, Perú. Ello se desarrolló entre noviembre de 2024 y febrero de 2025.

The experimental area consisted of three microtunnel modules, each measuring 3 m², covered with the corresponding material (Figure 1).

Figure 1*Microtunnels for the installation of plants at the acclimatization stage*

Population and sample

The experimental population consisted of in vitro micropropagated potato plants, previously rooted under laboratory conditions.

For each combination of variety × microtunnel material, 40 plants were established, and all individuals were evaluated. In total, the experiment included 360 plants (3 varieties × 3 materials × 40 plants).

Variables and data collection instruments

Five quantitative growth variables representative of the acclimatization stage were evaluated:

1. **Plant height (cm):** measured from the collar to the main apex of the plant.
2. **Number of leaves (units):** count of fully expanded leaves.
3. **Number of nodes (units):** total number of visible nodes on the plant.
4. **Fresh plant weight (g):** weight of the aboveground part of the plant, determined using an analytical balance, using a sample of 10 plants per evaluation.
5. **Root length (cm):** measured from the collar to the distal end of the main root.
6. **Plant survival (%):** calculated as the percentage of live plants relative to the initial total number, using the following formula:

$$\text{Survival} = (\text{lives plants} / \text{total plants}) \times 100$$

Measurements were taken at 7, 14, 21, and 28 DDI.

Data collection techniques and procedures

The micropropagated seedlings were transplanted into trays with a substrate composed of prepared soil, moss, soil, humus, and supplemental fertilizer. Once transplantation was completed, they were placed in the microtunnel corresponding to each treatment.

The variables were evaluated every 7 days, as indicated in the previous section. Likewise, survival was recorded at each evaluation date, considering plants with leaf turgor and active growth as live plants.

Data analysis

The experiment was conducted under a completely randomized factorial design (3 × 3), with three microtunnel materials and three potato varieties, considering material type and variety as factors.

An ANOVA was performed to determine the main effects and the material × variety interaction in the evaluations conducted at 7 and 14 DDI. Likewise, Tukey's multiple comparison test ($\alpha = 0.05$) was performed to separate the means.

In the evaluations at 21 and 28 DDI, because seedling survival was limited to a single type of material, a one-way ANOVA (variety) was applied.

Data processing and statistical analysis were carried out using RStudio software (version 3.6.3).

Results

Plant survival

Seedling survival showed marked variations according to the material used in the microtunnel and the variety (Table 1). Treatments under the tocuyo microtunnel showed consistent and favorable performance, with initial survival values above 92 % in the three varieties, reaching 100 % survival at 21 DDI. In contrast, treatments with 10-14 plastic showed a lower and unstable survival pattern. Although the varieties started between 57.5 % and 72.5 %, a pronounced decrease was observed at 14 DDI, mainly in the canchán and tomasa varieties. This decline suggests that the microenvironment generated by this material presents more drastic fluctuations in temperature and humidity, which compromise the initial vigor and development of young tissues.

For their part, plastic microtunnels with 24-hour coverage (24 plastic) presented the lowest survival among the materials evaluated. This suggests that the longer coverage time generates conditions that severely compromise seedling establishment. Although tomasa showed relatively greater resistance to these conditions, none of the treatments with plastic approached the performance observed with tocuyo.

Likewise, it was observed that canchán is the variety most susceptible to suboptimal microenvironments, whereas tomasa showed greater tolerance. These responses indicate the existence of a combined effect between the covering material and the variety.

Table 1
Percentage of plant survival of three potato varieties under three types of microtunnel during the first four weeks after installation (7, 14, 21, and 28 DDI)

Material: variety	7 DDI	14 DDI	21 DDI	28 DDI
Tocuyo: canchán	95.00 %	96.43 %	100.00 %	100.00 %
Tocuyo: qompis	92.50 %	96.29 %	100.00 %	100.00 %
Tocuyo: tomasa	97.50 %	96.55 %	100.00 %	100.00 %
Plastic 10-14: canchán	57.50 %	23.08 %		
Plastic 10-14: qompis	72.50 %	52.63 %		
Plastic 10-14: tomasa	72.50 %	42.11 %		
Plastic 24: canchán	20.00 %			
Plastic 24: qompis	22.50 %			
Plastic 24: tomasa	40.00 %			

Plant height

At 7 DDI, plant height showed highly significant differences among the three factors: microtunnel material ($p < 0.01$), variety ($p < 0.01$) and the material × variety interaction ($p < 0.001$). At 14 DDI, the significant effect of

the material and interaction was maintained ($p < 0.001$), although the effect of the variety did not show statistically significant differences (Table 2).

This behavior suggests that growth was conditioned both by the physical conditions of the microenvironment generated by the covering material and by the response of each variety.

According to Tukey's test (Table 4), at 7 DDI, the greatest heights were observed in the combinations of the tomasa variety with 24 plastic and 10–14 plastic, with values of 5.61 cm and 5.38 cm, respectively, followed by tocuyo–canchán (5.33 cm) and tocuyo–qompis (5.21 cm), the latter two being the most developed at 14 DDI, with 8.90 cm and 9.00 cm, respectively.

Of the three materials evaluated, only the first one (tocuyo) presented results up to 28 DDI. Plant height showed highly significant differences both at 21 DDI ($p < 0.001$) and at 28 DDI ($p < 0.001$). These values indicate that elongation differed consistently among the varieties, maintaining a stable trend (Table 3).

In this case, according to Tukey's test (Table 5), the qompis variety was significantly different from canchán and tomasa, presenting the greatest development at 21 DDI and 28 DDI, with 15.27 cm and 23.82 cm, respectively.

Number of Leaves

At 7 DDI, the number of leaves did not show significant differences among the materials, but did show differences among the varieties ($p < 0.01$) and in the material $\times$ variety interaction ($p < 0.001$). This suggests that initial leaf emergence was mainly conditioned by the potato variety and its response to environmental conditions. At 14 DDI, the effect of the material showed a slight influence, while the variety was highly significant ($p < 0.001$), in contrast to the interaction, which was not statistically significant (Table 2). This could indicate

Table 2

ANOVA of the effects of microtunnel material, potato variety, and their interaction on vegetative development parameters at 7 and 14 DDI in microtunnels

Description	Plant height								Number of leaves							
	7 DDI				14 DDI				7 DDI				14 DDI			
	Df	F value	Pr(>F)	NS	Df	F value	Pr(>F)	NS	Df	F value	Pr(>F)	NS	Df	F value	Pr(>F)	NS
Material	2	6.342	0.00276	**	1	19.585	4.71E-05	***	2	2.106	0.12838		1	3.515	0.066240	.
Variety	2	6.109	0.00338	**	2	2.783	0.070737	.	2	5.599	0.00528	**	2	9.443	0.000304	***
Material: Variety	4	5.146	0.00096	***	2	10.833	0.000111	***	4	5.487	0.00058	***	2	0.196	0.822728	
Error	81				54				81				54			
Description	Number of nodes								Fresh weight							
	7 DDI				14 DDI				7 DDI				14 DDI			
	Df	F value	Pr(>F)	NS	Df	F value	Pr(>F)	NS	Df	F value	Pr(>F)	NS	Df	F value	Pr(>F)	NS
Material	2	0.123	0.8847		1	151.17	< 2E-16	***	2	1.296	0.2791		1	18.976	5.96 E-05	***
Variedad	2	12.708	1.58E-05	***	2	54.00	1.31 E-13	***	2	6.976	0.0016	**	2	4.009	0.0238	*
Material: Variedad	4	3.491	0.0111	*	2	17.91	1.08 E-06	***	4	2.969	0.0243	*	2	2.994	0.0585	.
Error	81				54				81				54			
Description	Root length															
	7 DDI				14 DDI											
	Df	F value	Pr(>F)	NS	Df	F value	Pr(>F)	NS								
Material	2	2.166	0.12128		1	22.20	1.7 E-05	***								
Variety	2	2.023	0.13892		2	91.92	< 2E-16	***								
Material: Variety	4	3.986	0.00529	**	2	61.98	1.04E-14	***								
Error	81				54											

Note. Df = degrees of freedom; NS = significance level.

that variations inherent to the variety predominated over the covering material. The mean results (Table 4) indicated that the tomasa variety generated greater leaf formation under the 24 plastic (9.90) and 10–14 plastic (7.20) microtunnels, which were statistically equal to each other. However, this trend changed at 14 DDI, when the best development was observed in the tocuayo material for the tomasa (15.10) and qompis (12.10) varieties.

In the final stage of development, the number of leaves showed significant differences among the varieties in both evaluations ($p < 0.001$; Table 3). This was reflected in the comparison of means (Table 5), where the tomasa variety showed the greatest leaf formation at 21 DDI, with 21.80 leaves per plant, and was significantly different from the other varieties. Although at 28 DDI tomasa maintained the highest value (23.75), this was statistically equal to that of the qompis variety (18.67).

Number of Nodes

Regarding the number of nodes, at 7 DDI, highly significant differences among varieties were identified ($p < 0.001$), while the material $\times$ variety interaction was lower ($p < 0.05$). In contrast, at 14 DDI, the three factors (material, variety, and interaction) showed highly significant effects ($p < 0.001$). Thus, stem development was regulated both by the characteristics of the variety and by the type of covering material (Table 2). In this regard, the tomasa variety showed greater node formation at 7 DDI (11.00) under the 24 plastic microtunnel and at 14 DDI under the tocuayo material, which generated the highest number of shoots (13.20), being statistically different from the other treatments in both cases (Table 4).

On the other hand, at 21 DDI, the number of nodes differed significantly among varieties ($p < 0.001$), whereas no differences were observed at 28 DDI. This is reflected in the results of Tukey’s test (Table 5), where, at 21 DDI, the tomasa variety stood out with 15.20 nodes per plant, being statistically different. At 28 DDI, although the three varieties were numerically different, they were statistically equal.

Fresh weight

The fresh weight variable showed significant differences for the variety factor ($p < 0.01$) and, to a lesser extent, for the material $\times$ variety interaction ($p < 0.05$). However, at 14 DDI, the results showed that the effect of the material ($p < 0.001$) had a greater influence, while the variety ($p < 0.05$) had a lesser influence. On the other hand,

Table 3
ANOVA of the effects of the microtunnel material (tocuyo) on the vegetative development of potato varieties at 21 and 28 DDI in microtunnels

Description	Df	Plant height						Number of Leaves					
		21 DDI			28 DDI			21 DDI			28 DDI		
		F value	Pr(>F)	NS	F value	Pr(>F)	NS	F value	Pr(>F)	NS	F value	Pr(>F)	NS
Variety	2	12.59	0.000137	***	114.1	6.77E-14	***	21.96	2.17E-06	***	16.11	2.48E-05	***
Error	27												

Descripción	Df	Número de nudos						Fresh weight					
		21 DDI			28 DDI			21 DDI			28 DDI		
		F value	Pr(>F)	NS	F value	Pr(>F)	NS	F value	Pr(>F)	NS	F value	Pr(>F)	NS
Variety	2	29	1.89E-07	***	3.105	0.0611	.	5.777	0.00816	**	10.76	0.000366	***
Error	27												

Description	Df	Root length					
		21 DDI			28 DDI		
		F value	Pr(>F)	NS	F value	Pr(>F)	NS
Variety	2	74.75	9.83E-12	***	98.96	3.72E-13	***
Error	27						

Note. Df = degrees of freedom; NS = significance level.

Table 4

Comparison of means using Tukey's test ($p \leq 0.05$) for the material $\times$ variety interaction in vegetative development parameters at 7 and 14 DDI in microtunnels

Material: variety	Plant height (cm)				Number of leaves				Number of nodes				Fresh weight (g)				Root length (cm)			
	7 DDI		14 DDI		7 DDI		14 DDI		7 DDI		14 DDI		7 DDI		14 DDI		7 DDI		14 DDI	
Tocuyo: canchán	5.33	a	8.90	a	4.90	b	7.30	b	5.60	b	5.20	b	0.11	b	0.19	b	6.31	a	8.00	a
Tocuyo: qompis	5.21	a	9.00	a	4.80	b	12.10	ab	2.90	b	5.20	b	0.17	b	0.31	a	6.05	a	8.50	a
Tocuyo: tomasa	4.63	ab	6.30	b	3.50	b	15.10	a	5.10	b	13.20	a	0.13	b	0.28	a	3.03	ab	1.87	d
Plastic 10-14: canchán	4.27	abc	6.64	b	5.10	b	6.00	b	4.20	b	1.00	c	0.13	b	0.17	b	6.04	a	6.11	b
Plastic 10-14: qompis	4.32	abc	5.43	b	5.90	b	9.00	b	2.50	b	1.90	c	0.12	b	0.17	b	4.29	ab	4.28	c
Plastic 10-14: tomasa	5.38	a	7.02	b	7.20	ab	12.13	ab	6.80	b	3.63	b	0.24	ab	0.19	b	5.54	a	4.42	c
Plastic 24: canchán	3.24	bc			2.88	b			2.38	b			0.14	b			4.21	ab		
Plastic 24: qompis	2.69	c			3.56	b			1.56	b			0.10	b			1.84	b		
Plastic 24: tomasa	5.61	a			9.90	a			11.00	a			0.33	a			5.68	a		

Note. Means with the same letter within a column do not differ significantly according to Tukey's test ($p \leq 0.05$).

the material $\times$ variety interaction indicates minimal influence ($0.05 < p < 0.10$; Table 2). Therefore, vegetative growth and fresh matter accumulation were influenced both by the properties of the microtunnel material and by the physiological capacity of each variety. Nevertheless, the treatments with the best results at 14 DDI were the tocuyo microtunnels, with the qompis (0.31 g) and tomasa (0.28 g) varieties, which were statistically different from the other interactions (Table 4).

Regarding the treatments with tocuyo, fresh weight showed significant differences among varieties at both evaluation times ($p < 0.01$ and $p < 0.001$ for 21 DDI and 28 DDI, respectively; Table 3). The persistence of significance over time suggests sustained differentiation in growth and resource assimilation. In this case, the variety that presented the highest fresh weight at both times was qompis, with 0.50 g and 0.83 g at 21 DDI and 28 DDI, respectively (Table 5).

Root length

Root length showed significant differences only in the material $\times$ variety interaction ($p < 0.05$) at 7 DDI, suggesting that initial root development depended on the combination of both factors. On the other hand, at 14 DDI, the three factors showed highly significant effects ($p < 0.001$), indicating that both the microenvironment and the variety determined root development (Table 2). The canchán variety under the tocuyo microtunnel showed better root development at 7 DDI (6.31 cm) and 14 DDI (8.00 cm), followed by the qompis variety under the same material, with values of 6.05 cm and 8.50 cm at 7 DDI and 14 DDI, respectively (Table 4).

Since the treatments with tocuyo microtunnels were the ones that survived until 28 DDI, highly significant differences among the varieties were observed ($p < 0.001$; Table 3). Again, the qompis and canchán varieties achieved the greatest development, with values of 11.70 cm and 10.77 cm, respectively, at 28 DDI, and were significantly different from tomasa (Table 5).

Table 5

Comparison of means using Tukey's test ($p \leq 0.05$) of the effects of the microtunnel material (tocuyo) on the vegetative development of potato varieties at 21 and 28 DDI in microtunnels

Variety	Plant height (cm)				Number of leaves				Number of nodes				Fresh weight (g)				Longitud de raíz (cm)			
	21 DDI		28 DDI		21 DDI		28 DDI		21 DDI		28 DDI		21 DDI		28 DDI		21 DDI		28 DDI	
canchán	13.36	a	15.01	b	9.7	c	11.43	b	7.10	b	9.29	a	0.29	b	0.40	b	9.21	a	10.77	a
qompis	15.27	a	23.82	a	15.5	b	18.67	a	8.60	b	13.17	a	0.50	a	0.83	a	9.51	a	11.70	a
tomasa	10.06	b	13.90	b	21.8	a	23.75	a	15.20	a	12.25	a	0.42	ab	0.55	b	1.15	b	0.89	b

Note. Means with the same letter within a column do not differ significantly according to Tukey's test ($p \leq 0.05$).

Discussion

The results of the present study show that microtunnel coverage modulated the establishment and vegetative development of potato plants, which depend on both the material and the variety. This interaction is particularly relevant during the early stages of acclimatization. Previous studies on the use of microtunnels indicate that the climatic conditions within the structure alter the transpiration demand of plants, which affects their establishment rate (Torres & Arancibia, 2023). The nearly complete survival under tocuayo indicates that this material created a more stable environment, moderating the temperature and humidity within the structure. In contrast, the plastic material negatively affected plant establishment. Although there is evidence that the use of this material can generate benefits, it could not be considered a universal solution, since factors such as the climate of the area, species, among others, are involved (Zhang et al., 2020; Zhou et al., 2023).

In particular, the 24 plastic treatment in the tomasa variety promoted the greatest aboveground vigor at 7 DDI, whereas, from 14 DDI onward, the treatments with tocuayo microtunnels (specifically with the qompis and tomasa varieties) stood out in most of the aboveground variables. These findings coincide with those observed in research conducted under conditions in Ecuador, where the Superchola and Chaucha varieties showed an increase in aboveground biomass and, consequently, an optimization of the photosynthetic rate (Bermeo et al., 2023). Likewise, root length was consistently greater in tocuayo-canchán and tocuayo-qompis during the study period. These patterns are interpreted as part of the microclimatic dynamics generated by the different materials and of the differential varietal response to this microenvironment.

In other crops, such as strawberry and pepper, higher yields than those obtained under open-field conditions were found (Zermeño-González et al., 2019; Abad-Abad et al., 2020), which optimizes aboveground vigor. Bermeo et al. (2023) reported an increase in yield in potato cultivation, with 12.6 t/ha, and reached between 83 and 86 leaves per plant. On the other hand, Torres & Arancibia (2023) improved vegetative growth, increasing water and nutrient use efficiency. Likewise, in crops such as melon, harvest increased during the first 15–18 days, accumulating between 65 and 80% (Gaytán-Mascorro et al., 2020).

Closed plastic microtunnels induce, in the short term, a warm and humid microclimate, conditions that favor physiological processes such as cell expansion and emergence (López-Martínez et al., 2021; Xu et al., 2023). In studies comparing low tunnels and plastic covers, increases in canopy and substrate temperature have been recorded, which can accelerate initial growth; however, if these increases are permanent, they can cause thermal stress (Adamović et al., 2021; López-Martínez et al., 2021; Liu et al., 2024). Likewise, microtunnels with nonwoven polypropylene fabric drastically reduced pathogen incidence through better ventilation (Molina, 2005), which is similar to the transpiration-related effect of tocuayo. This supports the observations of the present study, in which the initial advantage of plastic microtunnels was not maintained and, in the medium term, the treatments with tocuayo microtunnels stood out in the different variables evaluated, such as plant height, number of leaves, number of nodes, and fresh weight.

Limited ventilation and heat accumulation in continuously closed microtunnels can raise daytime temperature above the physiological optimum, reducing the photosynthetic rate or imposing thermal stress on tissues, especially when aboveground biomass begins to increase (Yordanova et al., 2021; Kader et al., 2024). On the other hand, these plastic microtunnels can alter water dynamics, as well as soil oxygenation, effects that also ultimately condition root development and, therefore, the transfer of water and nutrients to the aboveground part (Kovácsné Madar & Takácsné Hájos, 2022; Shi et al., 2022; Meng et al., 2022), which could be the possible cause of the negative results of the plastic microtunnels.

In contrast, tocuayo, a material with greater permeability and better air exchange, provides a more stable internal microclimate, which positively influences soil moisture conditions. This corresponds to the consistently greater root lengths observed in the canchán and qompis varieties. Thus, root architecture is sensitive to thermal and water variations, which explains why ventilated coverage favors an early and robust root system, associated with greater resilience and potential yield (Joshi et al., 2016; Zinta et al., 2022; Gaisser et al., 2024).

The varietal heterogeneity observed, with the tomasa variety standing out early under the plastic microtunnel and the canchán and qompis varieties standing out under the tocuyo microtunnel at later stages, confirms the existence of a microtunnel–variety interaction. This pattern is consistent with studies on genotype × environment interaction, which indicate divergent varietal responses to environmental differences (Nasir & Toth, 2021; Kwambai et al., 2024; Zhou et al., 2025).

Conclusions

The evaluated coverings generated microenvironments that directly influenced plant survival and early establishment, confirming that the modifications induced by the microtunnel are decisive at this stage of development. In particular, the tocuyo microtunnel showed greater permeability, which promoted a more stable environment, reflected in better survival and plant development; furthermore, it evidenced the interaction between the environment generated by the covering and the genotype. In contrast, the plastic covering produced greater variability in the internal environment, which increased plant stress and decreased the survival rate. In this context, the canchán variety under the tocuyo microtunnel showed the most favorable performance, suggesting greater adaptive capacity and a more efficient physiological response to the microclimate generated.

These findings highlight the importance of appropriately selecting both the type of covering and the cultivated variety, due to their combined effect on the success of crop establishment. In Peruvian agriculture, prioritizing the use of tocuyo microtunnels in varieties such as canchán not only favors progressive ventilation and greater aboveground vigor, but also represents a more sustainable alternative to plastic materials, optimizing acclimatization in high-altitude areas. In this regard, it is recommended to expand the evaluation scale of this type of microtunnel, incorporating a greater number of plants and extending its application to diverse geographical conditions, in order to validate its efficiency and promote its adoption in production systems.

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Author contributions

BLCR: project leader, responsible for supervision and monitoring.
AJSA: responsible for project implementation and data collection.
GSC: responsible for article drafting, statistical advice, and data analysis and interpretation.
MLTF: research advisor.

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Conflicts of interest

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Correspondence:

Bertha Lucila Campos Ríos
E-mail: bertha.campos@udh.edu.pe