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Research Article

Effect of transplanting on vegetative traits in soybean seedlings

Gabriel Naves Caixeta[1], Éder Matsuo[2,*] and Silvana da Costa Ferreira[3]

[1]Institute of Agricultural Sciences, Federal University of Viçosa, Rio Paranaíba Campus, Highway MG 230, Km7, PO Box 22, Rio Paranaiba, MG, Brazil, CEP38810-000.
[2]Institute of Technological and Exact Sciences, Federal University of Viçosa, Rio Paranaíba Campus, Biostatistics Laboratory, Highway MG 230, Km7, PO Box 22, Rio Paranaiba, MG, Brazil, CEP38810-000.
[3]Institute of Biological and Health Sciences, Federal University of Viçosa, Rio Paranaíba Campus, Highway MG 230, Km 7, PO Box 22, Rio Paranaiba, MG, Brazil, CEP38810-000.
*Corresponding author, E-mail: edermatsuo@ufv.br

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Abstract

In recent years, studies have aimed to identify potential additional descriptors for soybean crops. So, the present study evaluates the viability of reducing the number of seeds used in experiments by analyzing the effect of transplanting soybean seedlings on vegetative traits. The experiment was conducted in a greenhouse using seeds from the cultivars BRSGO 7560, BRSMG 752 S, CD 202, BRSGO 8360, BRS 546, and FT-Cristalina. The study followed a 6×4 factorial design in a randomized block arrangement with four replicates. Factor A consisted of six levels (cultivars), and Factor B included four transplanting periods (direct planting in the soil, transplanting at the VE, VC, and V1 stages). To produce seedlings, seeds were sown in a substrate placed in polystyrene trays. Assessments of epicotyl length, internode length on the main stem between the unifoliolate and the 1st trifoliate leaf nodes, petiole length of the 1st trifoliate leaf, rachis length of the 1st trifoliate leaf, and plant height were conducted at V2, V3, and V4 growth stages. For evaluating epicotyl length at V2, V3, and V4 stages and plant height at the V2 stage, it is recommended to transplant seedlings at most at the VC stage. Significant differences were observed among cultivars for all traits evaluated.

Keywords: *Glycine max*; tray; variability; seeds, cultivar protection; juvenile stage; transplant stress.

Introduction

Brazil is a major global producer of soybean (*Glycine max* (L.) Merr), and within the national context, soybean cultivation stands out as significant for the trade balance of the country. The estimated soybean production for the 2023/2024 harvest in Brazil is 147.38 million tons, driven by various factors, including increased productivity (Companhia Nacional de Abastecimento [CONAB], 2024; Noronha et al. 2024). Part of this remarkable success is attributed to genetic improvement programs developed by numerous research institutions and Brazilian universities (Oda et al., 2015).

The Cultivar Protection Law (Law No. 9,456), regulated by Decree No. 2,366 of November 5, 1997, ensures the rights of breeders of new plant cultivars (Campos, Machado, Viana, & Azevedo, 2009). For a cultivar to receive protection, it must meet three basic requirements: it must be distinct, homogeneous, and stable (Viana, 2013). In Brazil, these trials are the responsibility of the breeder, and a distinct cultivar is one that clearly differs from any other whose existence is recognized at the time of the protection request. The criteria for distinction are established by the competent authority (Viana, 2013) and are outlined in the guidelines for conducting DHE (Distinctness, Homogeneity, and Stability) tests for soybean cultivars (Ministério da Agricultura Pecuária e Abastecimento [MAPA], 2009).

Various studies have identified phenotypic traits in the juvenile stage of soybean plants as potential additional descriptors for the crop (Camargos, Campos, Alves, Ferreira, & Matsuo, 2019; Gontijo et al., 2023; Nogueira et al., 2008). During experimental setups, to ensure the desired number of normal seedlings per pot, a higher number of seeds are sown per pot. This practice results in the use of a greater number of seeds overall, and depending on seed quality, more seeds germinate than needed, with most seedlings per pot subsequently discarded.

The production of vegetable seedlings is primarily based on optimizing environmental and seedling management conditions, selecting and discarding atypical or low-vigor seedlings to achieve uniformity in the field and minimizing seed consumption per unit area. Specifically, under protected cultivation, vegetable seedling production has seen significant growth due to advantages over traditional systems, typically conducted in open seedbeds. Benefits include earlier development, reduced phytopathogenic contamination risk, a higher ratio of planted seeds to obtained seedlings, better use of seedling production areas, easier cultural practices (thinning, irrigation, fertilization, pest control), less transplant stress, and shorter crop cycles in the field, allowing for more cultivation cycles in the same location (Bezerra, 2003). Consequently, seedling production and subsequent transplantation are routine practices in tomato (Rodrigues, Leal, Costa, Paula, & Gomes, 2010), bell pepper (Santos, Sediyama, Salgado, Vidigal, & Reigado, 2010), zucchini (Salata, Higuti, Godoy, Magro, & Cardoso, 2011), and lettuce (Andriolo, Espindola, & Stefanello, 2003) cultivation.

In soybean cultivation, in cases where pigeons heavily attacked prior direct sowing, seedlings were grown in expanded polystyrene trays and transplanted 10 days after sowing (Charlo, Castoldi, Vargas, Braz, & Mendonça, 2008; Castoldi et al., 2009). For greater plant uniformity, sowing in trays followed by transplanting into pots was adopted (Moraes, Agostinetto, Galon, & Rigoli, 2009), as well as sowing in sand beds and transplanting at the VC developmental stage to standardize seedlings (height and vigor) (Matsuo, Sediyama, Oliveira, Cruz, & Oliveira, 2012). When seed quantity was limited, pre-inoculated seeds were sown in 400 mL disposable plastic cups and transplanted into experimental plots 15 days after sowing (Monteiro, Alves, Matos, Silva, Silva, 2016). These practices demonstrate that seedling production and subsequent transplanting in soybean cultivation have been used for experimental setups, both in the field and in greenhouses. Thus, it is feasible to study the transplantation of soybean seedlings for experimental purposes under greenhouse conditions with plants grown in pots. This method, involving sowing seeds in trays with substrate (for seedlings) and subsequent transplanting into pots, can serve as an alternative to reduce seed use in experiments. Therefore, the objective was to evaluate the effect of seedling transplantation on vegetative traits in soybean seedlings.

Materials and Methods

The experiment was conducted in a greenhouse located at the Federal University of Viçosa, Rio Paranaíba *Campus*, in the municipality of Rio Paranaíba, MG, Brazil. The geographical coordinates are Latitude 19°11'37", Longitude 46°14'50", Altitude 1,067 m. Crop management practices, fertilization, cultural treatments, irrigation, and pest control were performed according to technical recommendations for soybean cultivation (Sediyama, 2009). Maximum and minimum temperatures were recorded daily, with an average minimum temperature of 18.2°C and an average maximum temperature of 46.4°C.

The pots were filled with 3 dm³ of soil and subsequently distributed on benches. Seeds of the following cultivars were used: BRSGO 7560, BRSMG 752 S, CD 202, BRSGO 8360, BRS 546, and FT-Cristalina. The experiment followed a 6×4 factorial scheme in a randomized block design with four replications. Factor A consisted of six levels (cultivars), and factor B comprised four transplanting stages (direct planting in soil, transplanting at stages VE, VC, and V1), as per Fehr & Caviness (1977). The experimental unit was the average of two plants cultivated in a single pot.

In the direct planting treatment (without transplanting), eight seeds were sown per pot, and at the VC development stage, the seedlings were standardized to two plants per pot. To assess the effects of transplanting, seeds were sown in substrate-filled expanded polystyrene trays with 128 cells per tray on the same day as those planted directly in the soil. During the period between sowing and transplanting, the trays were kept on wooden racks inside the greenhouse. Water was supplied to the seedlings through frequent irrigation to maintain a high substrate moisture level, and no nutrients were applied. Transplanting was performed as the plants reached the desired developmental stages.

Seedlings were evaluated using a millimeter ruler (in centimeters) for the following traits: epicotyl length on the main stem (EL), internode length on the main stem between the unifoliolate leaf insertion node and the first trifoliolate leaf (INL), petiole length of the first trifoliolate leaf (PL), rachis length of the first trifoliolate leaf (RL), and plant height (PH) at developmental stages V2, V3, and V4 (Fehr & Caviness, 1977).

For statistical analysis, analysis of variance was performed according to the model below:

$$y_{ijk} = m + b_k + A_i + B_j + (AB)_{ij} + e_{ijk}$$

Where:
y_{ijk} is the general average of the experiment,
b_k is the effect of the k-th block,
A_i is the effect of the i-th factor A (cultivar),
B_j is the effect of the j-th factor B (transplanting stage),
$(AB)_{ij}$ is the interaction effect of A*B, and
e_{ijk} is the error

Averages were compared using Tukey's test at a 5% probability level when necessary, following a preliminary analysis of assumptions (Banzatto & Kronka, 2008). Data analysis was performed in the Biostatistics Laboratory at the Institute of

Exact and Technological Sciences of the Federal University of Viçosa, Rio Paranaíba Campus, using R software (R Core Team, 2024).

Results and Discussion

A significant effect ($p < 0.05$) was observed for double interactions regarding the studied variables, except for internode length and petiole length of the first trifoliolate leaf evaluated at stage V2, and rachis length of the first trifoliolate leaf evaluated at stages V2, V3, and V4. For variables with non-significant double interactions ($p > 0.05$), the isolated effects of cultivar and transplanting were significant ($p < 0.05$) (Table 1). The coefficients of variation were 12.68%, 12.61%, and 12.79% for EL_V2, EL_V3, and EL_V4, respectively; 13.80%, 11.50%, and 11.83% for INL_V2, INL_V3, and INL_V4, respectively; 20.97%, 11.91%, and 9.95% for PL_V2, PL_V3, and PL_V4, respectively; 17.61%, 16.19%, and 14.67% for RL_V2, RL_V3, and RL_V4, respectively; and 11.01%, 9.48%, and 8.87% for PH_V2, PH_V3, and PH_V4, respectively.

Table 1. Summary of the analysis of variance, using a factorial scheme in a randomized block design, for the traits epicotyl length, internode length on the main stem between the unifoliolate leaf node and the 1st trifoliolate leaf, petiole length of the 1st trifoliolate leaf, rachis length of the 1st trifoliolate leaf, and plant height at developmental stages V2, V3, and V4, in an experiment conducted in a greenhouse, Rio Paranaíba – MG[1]

Sources of variation	Df	Mean Squares					
		Epicotyl length			Internode length		
		V2[1]	V3	V4	V2	V3	V4
Blocks	3	1.574	1.518	1.296	0.646	0.826	0.701
Cultivars (C)	5	33.848**[2]	33.989**	33.486**	9.179**	8.747**	8.375**
Transplanting (T)	3	50.568**	50.563**	48.296**	0.587**	0.203[ns]	0.125[ns]
C x T	15	0.881*	0.859*	0.934*	0.098[ns]	0.558**	0.517**
Residue	69	0.430	0.431	0.460	0.101	0.111	0.126
Average (cm)		5.17	5.21	5.31	2.31	2.90	3.00
CV (%)		12.68	12.61	12.79	13.80	11.50	11.83
Sources of variation	Df	Petiole length			Rachis length		
		V2	V3	V4	V2	V3	V4
Blocks	3	1.315	0.156	1.247	0.009	0.004	0.011
Cultivars (C)	5	5.807**	27.809**	28.339**	0.437**	0.785**	0.832**
Transplanting (T)	3	4.582**	8.436**	47.189**	0.499**	0.960**	1.010**
C x T	15	0.350[ns]	2.261**	4.837**	0.034[ns]	0.041[ns]	0.032[ns]
Residue	69	0.677	1.074	1.172	0.020	0.025	0.024
Average (cm)		3.92	8.70	10.88	0.80	0.97	1.05
CV (%)		20.97	11.91	9.95	17.61	16.19	14.67
Sources of variation	Df	Plant height					
		V2	V3	V4			
Blocks	3	5.594	9.310	14.027			
Cultivars (C)	5	90.449**	208.645**	263.120**			
Transplanting (T)	3	62.192**	42.002**	28.416**			
C x T	15	1.693**	5.554**	9.448**			
Residue	69	0.880	1.375	2.096			
Average (cm)		8.52	12.37	16.33			
CV (%)		11.01	9.48	8.87			

[1]Developmental stages (Fehr & Caviness, 1977); [2]**, *, ns: Significant at 1%, 5%, and non-significant levels by the F-test.

The interaction effect of Cultivar × Transplanting was analyzed, and the results for epicotyl length at stages V2, V3, and V4 are shown in Table 2. When fixing the transplanting effect revealed significant differences among cultivars. In general, the

BRSGO 7560 cultivar showed the highest average at all transplanting levels and in all evaluations (developmental stages V2, V3, and V4), while FT-Cristalina had the lowest average, and CD 202 behaved as an intermediate. This indicates significant differences among cultivars across different transplanting levels.

Table 2. Averages, in centimeters, of epicotyl length evaluated at developmental stages V2, V3, and V4 as a function of six soybean cultivars and four transplanting levels, in a greenhouse, Rio Paranaíba – MG.

Developmental stages V2								
Cultivars	Transplanting							
	Direct planting in soil		VE		VC		V1	
BRSGO 7560	6.78	Ba[1]	6.05	Ba	5.96	Ba	10.46	Aa
BRSMG 752 S	5.96	Ba	5.55	Bab	5.44	Bab	8.80	Ab
CD 202	4.50	Bb	3.71	Bc	4.05	Bcd	7.29	Ac
BRSGO 8360	4.21	Bbc	3.11	Bcd	3.38	Bcd	5.59	Ad
BRS 546	4.55	Bb	4.43	Bbc	4.30	Bbc	6.23	Acd
FT-Cristalina	3.13	Bc	2.33	Bd	2.83	Bd	5.47	Ad
CV (%)	12.68							
Developmental stages V3								
Cultivars	Transplanting							
	Direct planting in soil		VE		VC		V1	
BRSGO 7560	6.83	Ba	6.10	Ba	6.06	Ba	10.50	Aa
BRSMG 752 S	5.98	Ba	5.55	Bab	5.48	Bab	8.85	Ab
CD 202	4.58	Bb	3.75	Bc	4.05	Bcd	7.35	Ac
BRSGO 8360	4.23	Bbc	3.28	Bcd	3.39	Bcd	5.61	Ad
BRS 546	4.61	Bb	4.43	Bbc	4.33	Bbc	6.26	Acd
FT-Cristalina	3.16	Bc	2.34	Bd	2.88	Bd	5.50	Ad
CV (%)	12.61							
Developmental stages V4								
Cultivars	Transplanting							
	Direct planting in soil		VE		VC		V1	
BRSGO 7560	6.86	Ba	6.19	Ba	6.06	Ba	10.53	Aa
BRSMG 752 S	6.03	Bab	5.78	Bab	5.54	Bab	8.91	Ab
CD 202	4.65	Bbcd	3.94	Bc	4.15	Bbcd	7.45	Ac
BRSGO 8360	4.25	Bcd	3.33	Bcd	3.44	Bcd	5.63	Ad
BRS 546	4.71	Bbc	4.60	Bbc	4.70	Babc	6.35	Acd
FT-Cristalina	3.28	Bd	2.50	Bd	2.95	Bd	5.53	Ad
CV (%)	12.79							

[1]Within each evaluation period (developmental stages V2, V3, and V4), means followed by the same uppercase letters horizontally and lowercase letters vertically do not differ statistically by Tukey's test (α = 5%).

When analyzing the transplanting effect within each cultivar, it was found that transplanting at stages VE and VC did not differ significantly from direct planting in soil, while these three levels differed statistically from transplanting at stage V1. This suggests that if transplanting soybean seedlings is necessary, it should ideally occur no later than the VC stage, especially when evaluating epicotyl length at developmental stages V2, V3, or V4.

Internode length showed differences among cultivars for all evaluation stages (at V2, considering transplanting levels averaged, and at V3 and V4, within each transplanting level) (Table 3). The FT-Cristalina cultivar had the lowest average in all evaluation stages and transplanting levels, either independently or with other shorter cultivars. Regarding the transplanting effect, internode length was similar for plants directly sown in soil and those transplanted at VE and VC for all cultivars at stages V3 and V4, except for CD 202 at stages V3. Thus, transplanting at VE and VC did not affect internode length compared to direct planting. For CD 202, transplanting at VE is recommended for evaluation at V3.

Table 3. Average, in centimeters, of internode length on the main stem between the unifoliolate leaf node and the 1st trifoliolate leaf evaluated at developmental stages V2, V3, and V4 as a function of six soybean cultivars and four transplanting levels, in a greenhouse, Rio Paranaíba – MG.

Developmental stages V2										
Cultivars	Cultivars									
	Plantio no solo		VE		VC		V1		Averages	
BRSGO 7560	2.93		2.70		2.88		2.88		2.84	b[1]
BRSMG 752 S	3.83		3.34		3.14		3.48		3.44	a
CD 202	2.58		2.45		2.08		2.36		2.37	c
BRSGO 8360	2.03		1.59		1.60		1.88		1.77	d
BRS 546	2.08		2.15		1.85		2.24		2.08	cd
FT-Cristalina	1.39		1.04		1.30		1.61		1.33	e
Averages	2.47	A	2.21	BC	2.14	C	2.41	AB		
CV (%)	13,80									
Developmental stages V3										
Cultivars	Transplanting									
	Direct planting in soil		VE		VC		V1			
BRSGO 7560	3.73	ABa[1]	3.35	ABab	3.80	Aa	3.11	Bab		
BRSMG 752 S	4.10	Aa	3.97	Aa	3.72	Aa	3.71	Aa		
CD 202	3.43	Aab	3.38	Aab	2.60	Bb	2.70	Bb		
BRSGO 8360	2.38	Ac	2.03	Ac	2.37	Abc	2.53	Ab		
BRS 546	2.93	Abc	3.06	Ab	2.58	Ab	2.61	Ab		
FT-Cristalina	1.64	Bd	1.33	Bd	1.83	Bc	2.65	Ab		
CV (%)	11.50									
Developmental stages V4										
Cultivars	Transplanting									
	Direct planting in soil		VE		VC		V1			
BRSGO 7560	3.75	Aa	3.43	Aab	3.82	Aa	3.26	Aab		
BRSMG 752 S	4.15	Aa	4.11	Aa	3.83	Aa	3.65	Aa		
CD 202	3.50	Aab	3.45	Aab	2.96	ABb	2.77	Bb		
BRSGO 8360	2.51	Ac	2.10	Ac	2.47	Abc	2.62	Ab		
BRS 546	2.99	Abc	3.17	Ab	2.76	Ab	2.72	Ab		
FT-Cristalina	1.74	Bd	1.42	Bc	1.97	Bc	2.76	Ab		
CV (%)	11.83									

[1]Within each evaluation period (developmental stages V2, V3, and V4), means followed by the same uppercase letters horizontally and lowercase letters vertically do not differ statistically by Tukey's test (α = 5%).

The petiole length of the first trifoliolate leaf showed statistically significant differences among cultivars for evaluations at V2, V3, and V4 after interaction analysis across different transplanting levels (Table 4). Generally, BRSGO 7560 and BRSMG 752 S had the highest averages for petiole length, while FT-Cristalina showed the lowest (either independently or with other shorter cultivars). For transplanting effects, at V2, seedlings directly sown in soil had higher averages compared to other levels. At V3 and V4, petiole length for directly shown seedlings was statistically similar to those transplanted at VE, or at VE and VC, or at VE, VC, and V1, depending on the cultivar.

For rachis length of the first trifoliolate leaf, cultivars showed differentiated behavior at stages V2, V3, and V4, indicating a significant cultivar effect (Table 5). Regarding transplanting effects, at stages V2 and V3, plants directly sown in soil had the lowest rachis length compared to those transplanted at VE and VC. At stages V4, seedlings transplanted at VE had the longest rachis, followed by VC-transplanted seedlings, while direct planting and V1-transplanted seedlings showed the shortest lengths.

Table 4. Averages, in centimeters, of the petiole length of the 1st trifoliolate leaf evaluated at developmental stages V2, V3, and V4 as a function of six soybean cultivars and four transplanting levels, in a greenhouse, Rio Paranaíba – MG.

Developmental stages V2										
	Transplanting									
Cultivars	Direct planting in soil		VE		VC		V1		Averages	
BRSGO 7560	5.16		4.69		4.59		4.63		4.77	a[1]
BRSMG 752 S	5.20		3.80		3.68		4.20		4.22	ab
CD 202	3.90		3.53		3.21		3.24		3.47	bc
BRSGO 8360	5.16		4.40		3.61		3.56		4.18	ab
BRS 546	4.45		3.83		3.13		3.95		3.84	bc
FT-Cristalina	3.41		2.84		2.99		3.03		3.07	c
Averages	4.55	A	3,85	B	3,53	B	3,77	B		
CV (%)	20.97									

Developmental stages V3								
	Transplanting							
Cultivars	Direct planting in soil		VE		VC		V1	
BRSGO 7560	11.19	Aa[1]	10.11	Aab	11.25	Aa	9.64	Aa
BRSMG 752 S	9.59	ABab	10.85	Aa	9.23	ABab	8.31	Bab
CD 202	8.65	Abc	7.04	ABc	7.59	ABb	6.06	Bc
BRSGO 8360	10.25	Aab	8.31	Bbc	8.96	ABb	7.33	Bbc
BRS 546	8.50	Abc	9.33	Aab	9.58	Aab	8.86	Aab
FT-Cristalina	6.81	Ac	6.64	Ac	7.85	Ab	6.99	Abc
CV (%)	11.91							

Developmental stages V4								
	Transplanting							
Cultivars	Direct planting in soil		VE		VC		V1	
BRSGO 7560	12.95	Ba	13.49	ABa	15.01	Aa	10.75	Ca
BRSMG 752 S	11.34	Bab	13.70	Aa	9.23	Cc	8.90	Cabc
CD 202	10.05	Abc	11.58	Aab	9.91	Ac	7.60	Bc
BRSGO 8360	11.60	Aab	11.54	Aab	12.24	Ab	8.69	Babc
BRS 546	9.99	Bbc	13.03	Aa	12.58	Ab	10.03	Bab
FT-Cristalina	8.44	Bc	9.61	ABb	11.06	Abc	7.90	Bbc
CV (%)	9.95							

[1]Within each evaluation period (developmental stages V2, V3, and V4), means followed by the same uppercase letters horizontally and lowercase letters vertically do not differ statistically by Tukey's test ($\alpha = 5\%$).

Additional studies are suggested for internode length and rachis length to better understand their behavior concerning genetic and environmental variations and their interaction with transplanting stages.

Plant height analysis (Table 6) showed that seedlings sown directly in soil or transplanted at VE and VC had statistically similar heights at stages V2, V3, and V4, except for BRSMG 752 S at V3 and BRSGO 7560 at stages V4. Cultivars showed different behaviors for plant height at stages V2, V3, and V4. At stages V2, BRSGO 7560 and BRSMG 752 S had the highest means, while BRSGO 8360 and FT-Cristalina had the lowest averages across all transplanting levels.

Table 5. Averages, in centimeters, of the rachis length of the 1st trifoliolate leaf evaluated at developmental stages V2, V3, and V4 as a function of six soybean cultivars and four transplanting levels, in a greenhouse, Rio Paranaíba – MG.

Cultivars	Stages V2		Stages V3		Stages V4	
BRSGO 7560	0.93	a[1]	1.08	a	1.11	a
BRSMG 752 S	0.95	a	1.13	a	1.19	a
CD 202	0.90	a	1.17	a	1.27	a
BRSGO 8360	0.54	b	0.58	c	0.64	c
BRS 546	0.85	a	1.04	a	1.16	a
FT-Cristalina	0.66	b	0.85	b	0.95	b
Transplanting	**Stages V2**		**Stages V3**		**Stages V4**	
Direct planting in soil	0.72	b	0.83	b	0.92	c
VE	0.96	a	1.19	a	1.29	a
VC	0.88	a	1.10	a	1.16	b
V1	0.65	b	0.78	b	0.84	c

[1]For Cultivars and Transplanting, separately, and within each developmental stages V2, V3, and V4, means followed by the same lowercase letters vertically do not differ statistically by Tukey's test ($\alpha = 5\%$).

Table 6. Averages, in centimeters, of plant height evaluated at developmental stages V2, V3, and V4 as a function of six soybean cultivars and four transplanting levels, in a greenhouse, Rio Paranaíba – MG.

Developmental stages V2								
Cultivars	Transplanting							
	Direct planting in soil		VE		VC		V1	
BRSGO 7560	10.75	Ba[1]	9.69	Ba	9.85	Ba	14.33	Aa
BRSMG 752 S	11.19	Ba	10.43	Ba	10.18	Ba	14.56	Aa
CD 202	8.59	Bb	7.30	Bb	7.23	Bb	10.73	Ab
BRSGO 8360	7.04	ABbc	5.64	Bbc	5.73	Bbc	8.04	Ac
BRS 546	7.45	ABb	7.25	ABb	6.74	Bbc	8.50	Ac
FT-Cristalina	5.49	Bc	4.11	Bc	4.91	Bc	8.84	Abc
CV (%)	11.01							
Developmental stages V3								
Cultivars	Transplanting							
	Direct planting in soil		VE		VC		V1	
BRSGO 7560	15.53	Bab	13.98	Bb	14.63	Ba	17.83	Aa
BRSMG 752 S	16.63	BCa	17.98	ABa	15.44	Ca	19.74	Aa
CD 202	13.89	Ab	11.91	Abc	11.79	Ab	12.33	Ac
BRSGO 8360	10.46	Ac	8.43	Ad	8.60	Acd	9.98	Ac
BRS 546	10.03	Bc	10.63	Bcd	10.85	Bbc	14.79	Ab
FT-Cristalina	7.40	Bd	5.91	Be	7.34	Bd	10.91	Ac
CV (%)	9.48							
Developmental stages V4								
Cultivars	Transplanting							
	Direct planting in soil		VE		VC		V1	
BRSGO 7560	20.93	Aa	18.13	Bb	20.56	ABa	21.21	Ab
BRSMG 752 S	20.71	Ba	21.91	Ba	21.71	Ba	24.71	Aa
CD 202	16.13	Ab	15.65	Abc	14.71	Ab	14.70	Ac
BRSGO 8360	13.80	Abc	11.25	Ad	12.84	Abc	11.96	Ac
BRS 546	13.55	Bbc	13.46	Bcd	14.09	Bbc	20.05	Ab
FT-Cristalina	12.41	ABc	11.60	Bd	11.34	Bc	14.53	Ac
CV (%)	8.87							

[1]Within each evaluation period (developmental stages V2, V3, and V4), means followed by the same uppercase letters horizontally and lowercase letters vertically do not differ statistically by Tukey's test ($\alpha = 5\%$).

Between sowing and transplanting, visual differences in seedling growth and development were observed. Seedlings transplanted at VE and VC did not exhibit vegetative overlap, while those transplanted at V1 grew in a restricted area due to limited tray cell space, causing seedling clustering and overlap of unifoliolate and developing trifoliolate leaves, likely resulting in pre-transplant etiolation.

Plants compete for sunlight, and shaded leaves receive low light levels, leading to reduced photosynthetic rates (Taiz & Zeiger, 2012). Plants under a canopy receive mostly far-red light, causing elongated stems (Salisbury & Ross, 2012). Increased sowing density enhances intraspecific competition for water, nutrients, and light, leading to plant etiolation (Mauad, Silva, Almeida-Neto, & Abreu, 2010). Soybean growth is influenced by shading levels, with increased shading promoting growth (Tibolla et al., 2019), and shading levels from 0% to 70% caused increased epicotyl length and plant height in early growth stages (Gontijo et al., 2023).

Differences in soybean cultivar traits such as epicotyl length, internode length between unifoliolate and trifoliolate leaf nodes, petiole length of the first trifoliolate leaf, rachis length, and plant height align with literature findings (Camargos et al., 2019; Gontijo et al., 2021; Nogueira et al., 2008). Moreover, genetic influence on these traits has been reported, showing minimal environmental effects through genotypic determination coefficients and/or CVg/CVe ratios (Chaves et al., 2017; Hanyu, Ferreira, Cecon, & Matsuo, 2020; Nogueira et al., 2008; Silva et al., 2016).

Conclusions

For the evaluation of epicotyl length at developmental stages V2, V3, and V4, as well as plant height at developmental stage V2, it is suggested to transplant seedlings that are, at most, at the VC developmental stage.

Significant differences among cultivars were identified for all evaluated traits.

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