Effect of amino acid-enriched nutrient solutions on early growth of tomato and scarlet eggplant

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Abstract

Extensive vegetable cultivation requires large areas and labor, increasing production costs. An alternative is hydroponic production, where the plant receives all the nutrients in the necessary concentrations to complete its entire cycle. This study aims to evaluate the initial development of tomato and scarlet eggplant grown in a nutrient solution containing different amino acids. Two simultaneous experiments were conducted in April 2024 at the Andradina Educational Foundation, located in the municipality of Andradina, São Paulo state. The experimental design was completely randomized (CRD). Tomato plants (*Solanum lycopersicum* L.) and scarlet eggplant (*Solanum aethiopicum* gr. Scarlet eggplant) were grown in a nutrient solution containing amino acids: (Control) no amino acids, Tryptophan, Lysine, Cysteine, Phenylalanine and all amino acids, comprising six treatments, with four replicates totaling 24 plots. Each plot consisted of one seedling, and the concentration of each amino acid was 10 mg L^{-1} of nutrient solution. Tomatoes responded better to the presence of amino acids in the nutrient solution. The combination of the amino acids tryptophan, lysine, cysteine, and phenylalanine resulted in enhanced tomato and scarlet eggplant development when grown in nutrient solution. The use of amino acids in nutrient solution may be an alternative to improving the initial development parameters of tomatoes and scarlet eggplant. Lysine and phenylalanine supplementation improved tomato early growth and nitrogen assimilation, while scarlet eggplant responses were moderate. Further studies should evaluate long-term yield and economic feasibility.

Keywords: *Solanum* sp., tryptophan, lysine, cysteine, phenylalanine.

Efeito de soluções nutritivas enriquecidas com aminoácidos no crescimento inicial de tomate e jiló

Resumo

O cultivo extensivo de hortaliças demanda grandes áreas e mão-de-obra, passando a aumentar os custos de produção. Uma alternativa é a produção por sistemas hidropônicos, onde o vegetal irá receber todos os nutrientes nas concentrações necessárias para completar todo o seu ciclo. Esse trabalho tem por objetivo avaliar o desenvolvimento inicial do tomateiro e jiloeiro cultivados em solução nutritiva com diferentes aminoácidos. Foram realizados dois experimentos simultâneos em abril de 2024, na Fundação Educacional de Andradina, localizada no município de Andradina estado de São Paulo. O delineamento experimental foi inteiramente casualizado (DIC), o tomateiro (*Solanurn lycopersicum* L.) e jiloeiro (*Solanum aethiopicum* gr. Gilo) foram cultivados em solução nutritiva com a presença de aminoácidos, sendo eles: ausência de aminoácidos (Controle), triptofano; lisina; cisteína; fenilalamina e com todos os aminoácidos, perfazendo seis tratamentos, com quatro repetições totalizando 24 parcelas, onde cada parcela foi composta por uma plântula, e a concentração de cada aminoácido foi de 10 mg L^{-1} de solução nutritiva. O tomate apresentou maior resposta com a presença de aminoácidos na solução nutritiva. A combinação dos aminoácidos triptofano; lisina; cisteína e fenilalanina proporcionaram maior desenvolvimento do tomate e jiló quando cultivados em solução nutritiva. O uso de aminoácidos em solução nutritiva pode ser uma alternativa para melhorar os parâmetros de desenvolvimento inicial do tomate e jiló. A suplementação com lisina e fenilalanina melhorou o crescimento inicial do tomate e a assimilação de nitrogênio, enquanto as respostas da berinjela vermelha foram moderadas. Estudos futuros devem avaliar o rendimento a longo prazo e a viabilidade econômica.

Palavras-chave: *Solanum* sp., triptofano, lisina, cisteina, fenilalanina.

1. Introduction

A The consumption of vegetables in the human diet is essential to ensure food security, as these plants provide vitamins A, C, and K, as well as minerals such as iron, calcium, potassium, and fiber that aid digestion (Kalia, 2025). Consuming these vegetables enhances the immune system by providing antioxidant compounds that help protect the body against disease and also helps reduce the risk of type 2 diabetes, heart disease, obesity, and certain types of cancer (Olas, 2024; Carlini et al., 2024).

The tomato (*Solanum lycopersicum* L.) is one of the most widely consumed vegetables globally. It is rich in lycopene, an antioxidant that helps prevent cancer, especially prostate cancer, and contributes to skin and vision health through its vitamin A content (Kalia, 2025; Boulaajine; Hajjaj, 2024). In addition to benefiting cardiovascular health by reducing cholesterol and blood pressure thanks to its potassium and vitamin C content, it can be incorporated into weight-loss diets, as it contains only 20 kcal per 100 g of fruit (De Lannoy, 2001; Kaushal; Sadashiva, 2025).

The scarlet eggplant (*Solanum aethiopicum* gr. Gilo) is another vegetable worth highlighting, thanks to its benefits for improving intestinal function, helping to control blood sugar levels and lower cholesterol. It can also be incorporated into weight-loss diets, with approximately 38 kcal per 100 g of fruit. It promotes the production of bile and gastric juices, which facilitates the digestion of fats and ensures better absorption of ingested nutrients (Akin-Osanaiye et al., 2024). In addition to being rich in vitamins C and B complex, it also provides nutrients such as calcium, iron, phosphorus, and potassium, which help regulate blood pressure and balance sodium in the body (Talucder et al., 2024).

Large-scale vegetable cultivation requires large areas of land and labor, which ultimately increases production costs. One option is hydroponic production, in which the plant obtains all the nutrients it needs to complete its cycle from a nutrient solution at appropriate concentrations (Wang et al., 2024). Numerous studies are exploring technologies to improve these systems, ensuring maximum productivity and efficiency. One alternative is the use of amino acids, which can enhance vegetable growth in nutrient solution production systems (Farvardin et al., 2024).

The amino acid tryptophan (Try) is the precursor for the synthesis of the hormone indole-3-acetic acid (IAA). IAA biosynthesis can occur through both tryptophan (Trp)-dependent and -independent pathways. The dependent pathway is through indole-3-pyruvic acid (IPyA) and the indole-3-acetamide (IAM) pathway, which involves a series of steps catalyzed by specific enzymes (Taiz et al., 2017). This hormone acts on root growth, cell elongation (acid growth theory), and tissue differentiation of apical meristems (Atanacio-López et al., 2024).

Lysine (Lys) is an essential amino acid for humans and animals, but in plants it acts as an essential component of proteins, participating in the formation of enzymes and structural proteins that regulate growth (Berkner et al., 2024). It plays a role in secondary metabolism, being a precursor of compounds such as alkaloids and quinolinates, molecules important in defense against pests and pathogens (Boulaajine; Hajjaj, 2024). It may play a role in stress responses through the accumulation of lysine or derivatives in response to saline, thermal, or mechanical stress (Chen et al., 2024).

Another amino acid is cysteine (Cys), which contains the element (S) in its composition. However, it is not essential for plants, but it plays a role in processes such as photosynthesis, respiration, and cell division during development. This amino acid is a component of some structural proteins and enzymes (Kayser; Averesch, 2025), participating in the biosynthesis of glutathione (GSH), which acts as an antioxidant against free radicals, and also in defense compounds such as phytochelatins and thioredoxins (Deng et al., 2024; Song et al., 2024).

Phenylalanine (Phe) is an essential aromatic amino acid in plants, involved in growth, defense, and the production of secondary compounds. It originates from the synthesis of shikimic acid and aids in the formation of lignin in cell walls, enabling strengthening, rigidity, and protection against pests and pathogens. It also plays a role in the production of flavonoids and tannins, which perform antioxidant functions, in the synthesis of dyes such as anthocyanins (Kayser; Averesch, 2025), and in chemical defense through the biosynthesis of phytoalexins and the hormone salicylic acid, which have antimicrobial functions (Zuou et al., 2024). Phenylalanine participates in the formation of aromatic substances and volatile compounds responsible for floral scents, which act as attractants to pollinators (Zhu et al., 2025).

The combined action of these amino acids can enhance plant responses to nutrient-rich growing environments, leading to increased fruit production and dry matter (Furuya; Umemiya 2002; Noroozlo et al., 2019). These developmental responses indicate the optimization of tissue formation and other adaptive structures in plants that may face stresses, whether related to water, salt, light, or the biological impacts of pests and diseases (Song et al., 2024; Chen et al., 2024).

In this scenario, understanding the developmental changes that plants undergo throughout the production cycle is essential to provide relevant data for choosing the most appropriate cultivation system. Despite evidence of amino acid benefits in foliar applications, little is known about their direct influence in hydroponic nutrient solutions. This study hypothesizes that amino acid enrichment enhances early vegetative development in tomato and scarlet eggplant. This work aims to evaluate the initial development of tomato and scarlet eggplant plants grown in nutrient solution with different amino acids.

2. Materials and Methods

2.1 Experimental conditions and experimental design

Two simultaneous experiments were carried out in April 2024, at the Andradina Educational Foundation, located in the municipality of Andradina, state of São Paulo. The experimental design was completely randomized (CRD). Tomato (*Solanum lycopersicum* L.) cultivar Pietra (Sakata®) and scarlet eggplant (*Solanum aethiopicum* gr. Gilo) cultivar Redondo (Feltrin Sementes®) were grown in a nutrient solution with the presence of amino acids, namely: absence of amino acids (Control), tryptophan; lysine; cysteine; phenylalanine and a group with all amino acids, totaling 6 treatments, with four replicates totaling 24 plots, where each plot consisted of one seedling, and the concentration of each amino acid was 10 mg L^{-1} of nutrient solution. The seedlings were obtained from a commercial nursery located in the same municipality, which had an average size of 10.0 cm and 3 ± 1 leaflets per seedling.

The seedlings were grown in nutrient solution with the respective treatments, with the concentrations of each nutrient (Furlani, 1998) where it was applied: 0.75 g L^{-1} of $Ca(NO_3)_2$; 0.53 g L^{-1} of KCl; 0.15 g L^{-1} of P_2O_5 + Ca; 0.4 g L^{-1} of $MgSO_4$; $1.5x10^{-2}$ g L^{-1} of $CuSO_4$; $2.0x10^{-2}$ g L^{-1} of $ZnSO_4$; $1.5x10^{-1}$ g L^{-1} of $MnSO_4$; $1.5x10^{-1}$ of H_3BO_3; $1.5x10^{-2}$ g L^{-1} of Na_2MoO_4; 3.0 g L^{-1} of EDTA+Fe (6%), and maintaining an electrical conductivity adjusted daily to 2,000 ± 100 µS, with a pH of 6.4 ± 0.2. The pH was corrected daily using hydrochloric acid or potassium hydroxide; the solutions were continuously aerated for 24 h during the experiment; the electrical conductivity of the solution was adjusted by adding or removing distilled water.

2.2 Development parameters

Twenty days after the beginning of the experiment, the following variables were determined: aerial part length (APL) obtained from the difference between the final and initial length and expressed in centimeters through the use of a ruler graduated in millimeters; number of fully expanded leaves (NL) obtained by the difference between the final and initial number of leaves; shoot diameter (SD) expressed in centimeters obtained through the use of a caliper graduated in millimeters and at the same time, the total dry masses of the shoot and root (DMAP and DMR) were determined, which was obtained through drying in a circulation and air renewal oven at a constant temperature of 65 °C until they reached constant weight.

2.3 Physiological and biochemical analyses

On the same occasion, the Chlorophyll-a and Chlorophyll-b (Chla and Chlb - µmol m^{-2}) contents were determined through direct reading using the clorofiLOG device, Falker® brand, given the SPAD index values (Parry et al, 2014) and subsequently converted into absolute values of the pigments as described by Chang & Troughton (1972). The nitrogen content (N, g kg^{-1}) in the leaves was also estimated according to Sant'Ana et al., (2010).

2.4 Statistical analysis

For statistical evaluation, the variables were subjected to normality tests using the Shapiro-Wilk test. After meeting the test precepts, analysis of variance was performed using the F test ($p < 0.05$) and their means were compared using the Scott & Knott method at 5% probability (Banzatto; Kronka, 2013). A Pearson correlation was also performed using the RStudio statistical program (R Core Team, 2015).

3. Results

The absence of amino acids in the nutrient solution presented lower average aerial part length (APL) in tomato and scarlet eggplant crops, meaning a difference of approximately 27.79 and 31.27% respectively when compared to the combination with all amino acids that presented the highest, as shown in (Table 1).

Tabela 1. Average values of aerial part length (APL), root length (RL) and stem diameter (SD) of tomato and scarlet eggplant plants grown in nutrient solution with different amino acids.

	APL (cm)		**RL (cm)**		**SD (mm)**	
	Tomato	**Scarlet eggplant**	**Tomato**	**Scarlet eggplant**	**Tomato**	**Scarlet eggplant**
Control	36,37b	15,12b	29,75a	18,12a	3,52b	2,50a
Tryptophan	46,00a	19,00a	33,75a	21,50a	4,17a	2,62a
Lysine	42,50a	20,75a	35,50a	21,00a	3,55b	3,05a
Cysteine	46,50a	18,75a	31,75a	19,75a	3,87b	2,62a
Phenylalanine	44,12a	20,25a	36,25a	24,50a	4,17a	3,12a
All	50,37a	22,00a	37,62a	29,12a	4,25a	3,12a
p-value	0,0013**	0,0054**	0,8315ns	0,0692ns	0,0368*	0,3997ns
GM	44,31	19,31	34,10	22,33	3,92	2,84
CV%	8,35	11,11	26,84	22,32	9,55	19,41

Note: ** = Significant at the 1% probability level ($p < 0.01$); * = significant at the 5% probability level (0.01 = < p < 0.05); Ns = not significant (p > = 0.05). Means followed by the same letter on a straight line do not differ statistically. The *Scott-Knott* method was applied at the 5% probability level. GM: General mean. CV: Coefficient of variation. Source: Authors, 2025.

No statistical difference was observed in root length (RL) after the use of amino acids in a nutrient solution in tomato and scarlet eggplant cultivation. However, a statistical difference was observed in stem diameter only in tomato when grown in a nutrient solution with added amino acids. The combination of all amino acids presented the highest mean, followed by tryptophan and phenylalanine, implying a 15.58% greater difference compared to the absence of amino acids (Control) in the nutrient solution, as shown in (Table 1).

A statistical difference was only observed in the concentration of chlorophylls a and b (Chlorine A and Chlorine B) in tomato when grown in a nutrient solution with amino acids. The application of lysine and the combination of amino acids presented higher means, which reflected a greater difference of approximately 23.80% compared to the non-use of amino acids (Control) in the nutrient solution, as shown in (Table 2).

Table 2. Average values of chlorophylls A and B (Chla and Chlb) and nitrogen (N) of tomato and scarlet eggplant plants grown in nutrient solution with different amino acids.

	Chla (μmol m^{-2})		**Chlb (μmol m^{-2})**		**N (g kg^{-1})**	
	Tomato	**Scarlet eggplant**	**Tomato**	**Scarlet eggplant**	**Tomato**	**Scarlet eggplant**
Control	480.26b	487.75a	160.92b	129.25a	43.4b	37.6c
Tryptophan	517.94b	476.49a	175.98b	154.66a	44.1b	44.0b
Lysine	630.34a	563.41a	201.78a	187.80a	50.9a	48.9a
Cysteine	511.32b	514.99a	170.44b	171.66a	46.2b	46.4a
Phenylalanine	547.62b	503.52a	182.54b	172.84a	48.1a	43.3b

All	622.68a	466.28a	207.56a	157.92a	51.8a	43.8b
p-value	0.0003**	0.0917ns	0.0070**	0.0729ns	0.0298*	0.0001**
GM	551.69	502.08	183.20	162.36	47.4	44.0
CV%	7.73	9.21	9.24	15.79	8.17	5.51

Note: ** = Significant at the 1% probability level ($p < 0.01$); * = significant at the 5% probability level ($0.01 =< p < 0.05$); Ns = not significant ($p >= 0.05$). Means followed by the same letter on a straight line do not differ statistically. The *Scott-Knott* method was applied at the 5% probability level. GM: General mean. CV: Coefficient of variation. Source:Authors, 2025.

Statistical differences were observed in the nitrogen (N) content of tomato and eggplant leaves when grown in a nutrient solution with the presence of amino acids, with the absence of amino acids presenting lower averages, as shown in (Table 2). No statistical difference was observed in the number of leaves (NL) in tomato and eggplant crops after cultivation in a nutrient solution with the presence of amino acids, as shown in (Table 3).

Table 3. Average values of number of leaves (NL), dry mass of aerial part (DMAP) and dry mass of Root (DMR) of tomato and scarlet eggplant plant grown in nutrient solution with different amino acids.

	NL		**DMAP (g)**		**DMR (g)**	
	Tomato	**Scarlet eggplant**	**Tomato**	**Scarlet eggplant**	**Tomato**	**Scarlet eggplant**
Control	8.50a	8.25a	0.281b	0.317a	0.044b	0.061a
Tryptophan	9.00a	8.25a	0.304b	0.505a	0.052b	0.085a
Lysine	7.50a	8.25a	0.502a	0.476a	0.064a	0.075a
Cysteine	8.75a	7.25a	0.298b	0.438a	0.042b	0.072a
Phenylalanine	8.00a	8.25a	0.435a	0.469a	0.067a	0.064a
All	8.00a	7.75a	0.389a	0.380a	0.073a	0.076a
p-value	0.1737ns	0.1376ns	0.0315*	0.0757ns	0.0212*	0.6643ns
GM	8.29	8.00	0.368	0.431	0.057	0.072
CV%	10.15	7.51	26.99	20.84	24.21	29.19

Note: ** = Significant at the 1% probability level ($p < 0.01$); * = significant at the 5% probability level ($0.01 =< p < 0.05$); Ns = not significant ($p >= 0.05$). Means followed by the same letter on a straight line do not differ statistically. The *Scott-Knott* method was applied at the 5% probability level. GM: General mean. CV: Coefficient of variation. Source: Authors, 2025.

Statistical differences were observed in the dry mass of the aerial part (DMAP) and root (DMR) only in the tomato crop when it was cultivated in a nutrient solution with the presence of amino acids, where lysine, phenylalanine and the combination of amino acids presented higher average values, which meant a difference of approximately 44.02% for the dry mass of the aerial part (DMAP) and 39.72% for dry mass of root (DMR) as shown in (Table 3).

4. Discussion

4.1 Development parameters

When the plant is well nourished, it presents a greater development of its organs, and supplementation with amino acids may have enhanced the growth of the aerial part of tomato and scarlet eggplant plants. Garcia et al. (2011) observed different results after the use of amino acids in nutrient solution in tomato cultivation. However, the authors reported that the presence of these compounds in the solution influenced the concentrations of Ca^{2+}, K^{+}, Mg^{2+}, Fe, Cu and Mn, demonstrating the need to better understand the effects of amino acids in solution to ensure maximum productivity when grown in nutrient solution. (Furuya; Umemiya, 2002).

Several hypotheses have been suggested to elucidate the role of amino acids in plant development. Among the possibilities, some indicate alternative routes for the synthesis of indole-3-acetic acid (IAA) in plants, all from amino acids such as tryptophan (Taiz et al., 2017). This demonstrates that the development of internal xylem tissues may have presented greater development, thus reflecting stem diameter. Amino acids can affect physiological functions in plant growth and development directly or indirectly. An example of this is the exogenous application of amino acids, which regulates tomato growth, production, and quality (Sadak et al., 2015).

The most widely used method in large-scale crops is foliar application of amino acids, which has shown positive effects on plant growth, as reported by Mondal et al. (2015). The authors also reported that amino acids can act as coenzymes or precursors in the biosynthesis of glutamine and ornithine, which are precursors of nucleotides and polyamines, molecules important for the development of plant dry matter. Greater amino acid synthesis increases the efficiency of plant metabolism, which influences the photosynthetic rate and carbon accumulation in its dry matter. Understanding the minimum and maximum limits of doses and application methods of amino acids in nutrient solutions can enable a better understanding of these effects on plant dry matter development, thus providing producers with an important decision-making tool for choosing the best application methods and combinations of amino acids, resulting in higher plant yield.

4.2 Physiological parameters

Several studies show that the chlorophyll content of NO^{3-} was highly dependent on the Fe level in both tomato and wheat plants when supplemented with different amino acids, demonstrating that the presence of amino acids directly influences nutrient absorption and plant physiological responses (Mohamed et al., 1987). The use of biostimulants increases photosynthesis and the accumulation of NO^{3-} and total N in lettuce fresh mass, as reported by Navarro-León et al. (2022).

Other studies have reported antagonistic or synergistic effects between the use of amino acids and the absorption of nutrients in solution, which should be well understood and considered by fertilizer producers (Alfosea-Simón et al., 2020; Noroozlo et al., 2019). Nitrogen content in plants is influenced by the presence of exogenously applied amino acids, as reported by Mohamed et al. (1987), and they also showed that plants well-nourished with iron and nitrogen present better photosynthetic responses due to the higher concentration of chlorophylls (Cerdán et al., 2013).

5. Conclusions

Tomatoes responded better to the presence of amino acids in the nutrient solution. The combination of the amino acids tryptophan, lysine, cysteine, and phenylalanine resulted in enhanced tomato and scarlet eggplant development when grown in nutrient solution. The use of amino acids in nutrient solution may be an alternative to improving the initial development parameters of tomatoes and scarlet eggplant. Lysine and phenylalanine supplementation improved tomato early growth and nitrogen assimilation, while scarlet eggplant responses were moderate. Further studies should evaluate long-term yield and economic feasibility.

6. Authors' Contributions

Lucas Aparecido Manzani Lisboa, *Erik Cícero Santos Borge*, *Éder Cícero Santos Borge*, *Brunno de Oliveira Santirso*, *Igor Renato da Costa de Oliveira*, *Fabielli Souza Leite Martins*: conceptualization; writing – original draft; visualization; investigation; data curation. *Lucas Aparecido Manzani Lisboa*, *Erik Cícero Santos Borge*, *Éder Cícero Santos Borge*: writing–original draft. *Lucas Aparecido Manzani Lisboa*: writing –review & editing; supervision.

7. Conflicts of Interest

No conflicts of interest.

Ethics Approval

Not applicable.

10. References

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