SILVA, M.; MOTA, B.; FERREIRA, R.; SILVA, M.; SOUZA, N.; CRAVEIRO, C. Yield of amazonian spinach as affected by seedling quality. **Revista de Agricultura Neotropical**, Cassilândia-MS, v. 13, n. 1, e9971, 2026. ISSN 2358-6303. DOI: https://doi.org/10.32404/rean.v13i1.9971.

Yield of amazonian spinach as affected by seedling quality

Márcio Silva[1], Bárbara Mota[1], Regina Ferreira[1], Márcia Silva[1], Nárcya Souza[2], Camila Craveiro[1]

[1]Universidade Federal do Acre, Rio Branco, Acre, Brasil. Email: marciochaves10silva@gmail.com, barbaramot@gmail.com, reginalff@yahoo.com.br, marcia081chaves@hotmail.com, camila.freire@sou.ufac.br

[2]Universidade de São Paulo, ESALQ, Piracicaba, São Paulo, Brasil. Email: narcya.souza@gmail.com

Received: 30/09/2025; Accepted: 06/01/2026.

ABSTRACT

Amazonian spinach is classified as a non-conventional vegetable species with high agricultural potential and may serve as an alternative to conventional leafy crops. This study aimed to evaluate the yield of Amazonian spinach plants grown from seedlings produced using cuttings of different sizes. The experiment was conducted at the experimental unit of the Federal University of Acre from May to July 2023. A completely randomized design was adopted, with three treatments and ten replications. The treatments consisted of seedlings produced from cuttings with different numbers of nodes: T1 = 1 node; T2 = 2 nodes; and T3 = 3 nodes. After 50 days of cultivation, the following variables were evaluated: height, stem diameter, total number of shoots, total number of leaves, leaf width, leaf length, shoot fresh mass, root fresh mass, shoot dry mass, root dry mass, and yield. Seedling quality significantly affected plant productivity. Plants derived from seedlings produced from 3-node cuttings exhibited the highest yields. Although plants originating from 1- and 2-node cuttings completed their development, they showed lower productivity. The use of 3-node cuttings is therefore recommended to enhance the yield of Amazonian spinach.

Keywords: *Alternanthera sessilis* (L.) R.Br. ex DC., Unconventional vegetable, Cutting, Productivity.

Produtividade de espinafre da Amazônia em função da qualidade das mudas

RESUMO

O espinafre da Amazônia é classificado como uma hortaliça não convencional de elevado potencial agrícola, podendo constituir uma alternativa às hortaliças folhosas convencionais. Este estudo teve como objetivo avaliar a produtividade de plantas de espinafre amazônico cultivadas a partir de mudas produzidas por estacas de diferentes tamanhos. O experimento foi conduzido na unidade experimental da Universidade Federal do Acre, no período de maio a julho de 2023. Adotou-se o delineamento inteiramente casualizado, com três tratamentos e dez repetições. Os tratamentos consistiram em mudas produzidas a partir de estacas com diferentes números de nós: T1 = 1 nó; T2 = 2 nós; e T3 = 3 nós. Após 50 dias de cultivo, foram avaliadas as seguintes variáveis: altura das plantas, diâmetro do caule, número total de brotações, número total de folhas, largura foliar, comprimento foliar, massa fresca da parte aérea, massa fresca das raízes, massa seca da parte aérea, massa seca das raízes e produtividade. A qualidade das mudas influenciou significativamente a produtividade das plantas. Plantas oriundas de mudas produzidas a partir de estacas com 3 nós apresentaram as maiores produtividades. Embora as plantas provenientes de estacas com 1 e 2 nós tenham completado seu desenvolvimento, apresentaram menor produtividade. Assim, recomenda-se, portanto, o uso de estacas com 3 nós para aumentar a produtividade do espinafre amazônico.

Palavras-chave: *Alternanthera sessilis* (L.) R.Br. ex DC., Hortaliça não convencional, Estaquia, Produtividade.

1. Introduction

Vegetables have been cultivated since the beginning of agricultural activity and have played a significant role in food supply, nutrition, and economic development. They are generally characterized as herbaceous plants with short cultivation cycles, intensive management requirements, and edible parts that can be consumed directly, often without prior processing. Vegetables are essential to human nutrition and health, as they provide essential nutrients, vitamins, fiber, and bioactive compounds, and contribute to hydration, digestive health, and disease prevention (Schreinemachers et al., 2018; White and Gleason, 2022).

Despite their recognized importance for food and nutritional security, vegetable production is currently driven predominantly by market demands, with emphasis on high-yielding species and intensive production systems, often neglecting biodiversity and nutritional considerations. Furthermore, the intensification of climate change has led to increased agricultural losses, reduced species diversity, and heightened food insecurity (Gabam and Borges, 2020; White and Gleason, 2022). In this context, non-conventional food plants represent a viable alternative, as they are generally well adapted to local environmental conditions, exhibit high species diversity, and contribute to improved nutritional quality (Gabam and Borges, 2020; Padilha et al., 2023).

Among these species, Amazonian spinach (*Alternanthera sessilis* (L.) R.Br. ex DC.) stands out as a perennial herb with erect and decumbent growth habits, reaching up to 30 cm in height. It has green, slightly wrinkled leaves and is commonly propagated by stem cuttings. Belonging to the Amaranthaceae family and native to the Amazon region, it is classified as a leafy vegetable and is popularly known as monkey's ear, samba lettuce, poor man's spinach, and Amazon spinach. The species typically grows spontaneously in humid and shaded environments and remains underutilized, being cultivated only in small quantities by traditional populations (Kinupp and Lorenzi, 2014).

Amazonian spinach has considerable food and pharmacological potential, primarily due to its high protein content, which can reach 25% per 100 g of dry matter. Additionally, it contains significant levels of minerals, vitamins, fiber, antioxidants, and other bioactive compounds (Nikam and Namdas, 2022). Its leaves and young shoots are consumed raw or cooked and are frequently incorporated into traditional culinary preparations (Kinupp and Lorenzi, 2014; Hwong et al., 2022).

Although the species presents substantial potential as an alternative to conventional vegetables, particularly due to its environmental adaptability and nutritional and pharmacological composition, agronomic information to support crop establishment remains limited. The scarcity of scientific data regarding seedling production and crop management hinders the expansion and consolidation of its cultivation (Kinupp and Lorenzi, 2014; Silva et al., 2023).

Seedling quality is directly associated with successful vegetable production, underscoring the importance of producing high-quality planting material to achieve greater yields (Souza et al., 2020). High-quality seedlings are characterized by favorable genetic attributes, adequate propagation material, and appropriate management practices, all of which influence plant development and final productivity. These factors reinforce the importance of proper agronomic practices from the earliest stages of cultivation (Gallegos-Cedillo et al., 2021). In the case of Amazonian spinach, Silva et al. (2023) reported that cuttings of different sizes result in seedlings of varying quality; however, the effect of these differences on final crop yield remains unknown.

Studies evaluating the yield and productivity of conventional vegetables using seedlings of varying quality indices have demonstrated significant differences in production for species such as lettuce (*Lactuca sativa* L.) (Simões et al., 2015; Antunes et al., 2018), chicory (*Eryngium foetidum* L.) (Souza et al., 2020), and tomato (*Solanum lycopersicum* L.), among others. However, similar studies involving non-conventional species remain scarce.

Although non-conventional food plants represent promising alternatives for strengthening food and nutritional security and reducing dependence on conventional crops, agronomic information for most of these species, including Amazonian spinach, is still limited. From this perspective, this study aimed to evaluate the yield of Amazonian spinach cultivated from seedlings produced using cuttings of different sizes.

2. Material and Methods

The experiment was conducted in a greenhouse located in the experimental garden of the Federal University of Acre, Rio Branco, Acre, Brazil (9°57′36″ S; 67°52′14″ W; 163 m altitude), from April to June 2023. During the experimental period, the mean temperature was 24.7 °C, relative humidity averaged 80.2%, and accumulated precipitation was 267.2 mm.

A completely randomized design was adopted, with three treatments and ten replications, totaling 30 experimental units. The treatments consisted of cultivating Amazonian spinach from seedlings produced using cuttings of different sizes: T1 = seedlings produced from 1-node cuttings (2 buds; ± 4 cm in length); T2 = seedlings produced from 2-node cuttings (4 buds; ± 6 cm in length); and T3 = seedlings produced from 3-node cuttings (6 buds; ± 10 cm in length), following the methodology described by Silva et al. (2023).

Sixty seedlings were produced using herbaceous material collected from adult mother plants grown in seedbeds. The plant material was sectioned according to the treatment specifications and placed in 200 cm³ polystyrene containers filled with commercial Mecplant® substrate. Irrigation was performed daily using a manual watering can.

Seedlings were maintained in the greenhouse for 30 days until they exhibited fully developed leaves and visible root systems. After this period, they were transplanted into 5-L pots filled with the same commercial Mecplant® substrate. One seedling was transplanted per pot according to the experimental design. Plants were maintained under greenhouse conditions and irrigated daily with a manual watering can.

The commercial substrate used for seedling production and pot cultivation presented the following chemical attributes: pH = 5.6; P = 2.09 mg L^{-1}; K = 112.0 mg L^{-1}; Ca = 122.0 mg L^{-1}; Mg = 44.8 mg L^{-1}; S = 134.0 mg L^{-1}; B = 0.08 mg L^{-1}; Cu = 0 mg L^{-1}; Fe = 0 mg L^{-1}; Mn = 0.60 mg L^{-1}; Na = 37.0 mg L^{-1}. Physical characteristics were: bulk density (D.a) = 269.0 kg m^{-3}; water retention capacity (C.R.A) = 249.36%; and electrical conductivity (C.E) = 0.639 mS cm^{-1}. Only the initial substrate was used throughout the experiment, and no supplementary fertilization was applied.

At the time of transplanting, 10 seedlings per treatment were evaluated to determine seedling quality, as described by Silva et al. (2023). The following variables were measured: height (H), stem diameter (SD), shoot dry mass (SDM), root dry mass (RDM), and total dry mass (TDM). The Dickson quality index (DQI) was subsequently calculated.

Seedling height (H) was measured using a graduated ruler (cm), and stem diameter (SD) was measured with an analog caliper (mm). For determination of SDM and RDM, plant material was dried in a forced-air circulation oven at 65 °C until constant mass and weighed on a precision balance (0.01 g accuracy).

The Dickson quality index (DQI) was calculated according to Dickson et al. (1960), using Equation 1:

$$DQI = \frac{TDM}{\left(\frac{H}{SD}\right) + \left(\frac{SDM}{RDM}\right)} \quad (1)$$

Where: IQD - Dickson quality index; H - height (cm); SD - stem diameter (mm); TDM - Total dry mass (g); SDM - Shoot dry mass (g) and RDM - Root dry mass (g).

Harvest was performed at 50 days after transplanting. The following variables were evaluated: height (H), stem diameter (SD), total number of shoots (TNS), total number of leaves (TNL), leaf width (LW), leaf length (LL), shoot fresh mass (SFM), root fresh mass (RFM), shoot dry mass (SDM), root dry mass (RDM), total fresh mass (TFM), total dry mass (TDM), and yield (Y).

Ten plants per treatment were evaluated. Stem height and diameter were measured while plants were still in the pots, followed by counting the total number of leaves and shoots. The shoot was separated from the root system using pruning shears. Roots were carefully washed to remove adhered substrate, and excess surface moisture was removed with paper towels.

Plant height, leaf width, leaf length, and root length were measured with a graduated ruler (cm). Stem diameter was measured with a digital caliper (mm). The number of leaves and shoots was determined by direct counting. Fresh and dry masses of shoots and roots were measured using a precision digital scale (0.01 g accuracy). Dry mass was obtained after drying the material in a forced-air circulation oven at 65 °C until constant mass.

Yield (packs $plant^{-1}$) was calculated based on a standard commercial weight of 300 g per pack, using shoot fresh mass (SFM), according to Equation 2:

$$Y = \frac{SFM\ (g)}{300\ g\ (commercial\ pack)} \quad (2)$$

Where: Y = yield (packs $plant^{-1}$); SFM = shoot fresh mass (g); and 300 g = standard weight of a commercial pack.

The adoption of 300 g as a commercial standard is based on the average market weight commonly used for vegetable bunches. This standardization reflects commercial practice, ensures comparability with production systems using similar criteria, and provides a realistic estimate of commercial productivity.

Data were subjected to outlier detection using the Grubbs test, normality assessment using the Shapiro–Wilk test, and homogeneity of variances using the Cochran test. Subsequently, analysis of variance (ANOVA) was performed using the F test. When statistical significance was detected, means were compared using the Tukey test at 5% probability. To evaluate the influence of seedling quality on plant development and yield, multivariate analysis was performed using principal component analysis and multiple correlation analysis. Statistical analyses were conducted using the open-source software R.

3. Results and Discussion

Cutting size significantly influenced ($p < 0.05$) the formation of Amazonian spinach seedlings for height (H), shoot dry mass (SDM), root dry mass (RDM), total dry mass (TDM), and Dickson quality index (DQI), whereas no significant effect was observed for stem diameter (SD). Seedlings produced from cuttings with 3 nodes (6 buds; ± 10 cm in length) exhibited superior development and quality, with greater height, shoot and root dry mass, and higher DQI values (Table 1).

The superior quality observed in seedlings produced from 3-node cuttings confirms that larger cuttings promote enhanced seedling development, as reported by Silva et al. (2023). Larger cuttings likely contain greater amounts of stored reserves, favoring rooting and leaf emission during seedling establishment (Melo et al., 2019; Tofanelli and Mógor, 2021).

Root and shoot formation in cuttings depends on the interaction of environmental conditions, substrate characteristics, and intrinsic genetic factors. Moreover, not all species are equally amenable to vegetative propagation. The performance of cuttings during seedling formation is closely associated with endogenous auxin levels and carbohydrate reserves, which play fundamental roles in rooting and shoot development. These processes are directly related to the quantity of reserve substances present in the cutting, which support sprouting and initial seedling growth (Melo et al., 2019; Sá et al., 2022).

Table 1. Height (H), stem diameter (SD), shoot dry mass (SDM), root dry mass (RDM), total dry mass (TDM), and Dickson Quality Index (DQI) of Amazonian spinach seedlings produced from cuttings. Rio Branco, AC, 2023

Cutting	H	SD	SDM	RDM	TDM	DQI
	-------- mm --------		----------------- g -----------------			-- index --
1 node	41.8 c	4.33 a	0.12 b	0.05 b	0.17 b	0.05 b
2 nodes	61.0 b	4.43 a	0.14 b	0.06 b	0.20 b	0.05 b
3 nodes	87.2 a	4.40 a	0.25 a	0.12 a	0.37 a	0.09 a
MSD	7.78	0.56	0.09	0.05	0.16	0.03
CV (%)	16.03	7.18	14.36	19.48	15.75	11.83

*Means followed by the same lowercase letter in the column do not differ ($p < 0.05$) by the Tukey test. MSD - Minimum Significant Difference. CV - Coefficient of variation.

Cuttings with 1 and 2 nodes (2 buds; ± 4 cm and 4 buds; ± 6 cm in length, respectively) resulted in lower seedling quality. However, complete development was observed, and no significant differences were detected between these treatments for most variables, except for height, which may have been influenced by the initial cutting size (Table 1). Although smaller cuttings produced seedlings of comparatively lower quality, their use may be advantageous for species multiplication or maintenance of mother plant stocks, as smaller cuttings increase the number of propagules obtained per plant (Tofanelli and Mógor, 2021; Silva et al., 2023).

Despite this potential advantage, the use of high-quality seedlings is essential to maximize plant development. The Dickson quality index integrates biomass accumulation and morphometric parameters, providing a robust indicator of seedling vigor.

The superior performance of seedlings derived from larger cuttings is likely associated with higher reserve accumulation, which enhances root and shoot formation and supports early plant establishment (Sá et al., 2022; Silva et al., 2023). For cultivated Amazonian spinach plants, seedling quality significantly affected ($p < 0.05$) height (H), total number of shoots (TNS), total number of leaves (TNL), shoot fresh mass (SFM), root fresh mass (RFM), shoot dry mass (SDM), root dry mass (RDM), total fresh mass (TFM), total dry mass (TDM), and yield (Y). No significant differences ($p < 0.05$) were observed for stem diameter (SD), leaf width (LW), or leaf length (LL) (Table 2). Plants established from seedlings with higher DQI values (produced from 3-node cuttings) exhibited superior vegetative development, with higher mean values for H, TNS, and TNL. However, no significant differences were observed between plants derived from 1- and 2-node cuttings.

Table 2. Height (H), stem diameter (SD), total number of shoots (TNS), total number of leaves (TNL), leaf length (LL), and leaf width (LW) in Amazonian spinach plants grown from seedlings produced with different node numbers. Rio Branco, AC, 2023

Seedlings	H	SD	TNS	TNL	LW	LL
	-- cm --	-- mm --	------- uni -------		------- cm -------	
1 node	18.87 b	5.10 a	5.00 b	255.14 c	5.56 a	5.00 a
2 nodes	19.27 b	4.98 a	4.86 b	296.14 b	6.10 a	5.31 a
3 nodes	21.23 a	5.02 a	6.29 a	335.71 a	5.90 a	5.28 a
MSD	1.23	0.37	0.93	22.01	0.77	0.43
CV (%)	19.79	4.86	5.38	5.46	9.65	6.04

*Means followed by the same lowercase letter in the column do not differ ($p < 0.05$) by the Tukey test. MSD - Minimum Significant Difference. CV - Coefficient of variation.

The highest mean values for H, TNS, and TNL were observed in plants derived from seedlings produced from 3-node cuttings, exceeding the other treatments by approximately 11%, 28%, and 22%, respectively (Table 2). The superior performance in height, number of shoots, and number of leaves is likely associated with seedling quality, as these variables exhibited responses consistent with the differences observed during the seedling stage. These parameters are critical for evaluating vegetative growth and overall plant establishment in leafy vegetables.

Height, total number of shoots, and total number of leaves are key morphological indicators of plant development and are widely used as non-destructive measures of vegetative performance. These variables are strongly associated with biomass accumulation. Increased plant height and shoot number generally result in a greater number of leaves, which in turn enhances photosynthetic capacity and biomass production. An increase in leaf number is typically associated with greater light interception, higher photosynthetic activity, and increased productivity and vigor (Taiz et al., 2017; Yin et al., 2019; Gallegos-Cedillo et al., 2021).

No significant differences were observed among treatments for SD, LW, or LL (Table 2). Stem diameter, standardized during seedling production, remained uniform after transplanting and subsequent development, indicating that initial differences in seedling quality did not affect this structural trait. Similarly, leaf dimensions (LW and LL) were not influenced by seedling quality, suggesting that under uniform cultivation conditions, plants expressed comparable leaf expansion and biomass allocation patterns.

Stem diameter is an important indicator of plant structural robustness, as it supports the aerial portion of the plant, which represents the majority of total biomass. Leaf dimensions (LW and LL) are also critical productivity parameters, as leaf area directly influences light interception and photoassimilate production. In leafy vegetables, leaves constitute the principal commercial component and represent the largest proportion of shoot fresh mass, serving as a direct indicator of productivity (Taiz et al., 2017; Gallegos-Cedillo et al., 2021).

Greater biomass accumulation was observed in plants established from higher-quality seedlings (3-node cuttings), with clear differentiation among the three treatments for SFM, RFM, SDM, RDM, TFM, and TDM, which increased progressively with seedling quality (Table 3). Silva et al. (2023) reported differences in the quality of Amazonian spinach seedlings produced from cuttings of varying sizes and suggested that these differences could influence subsequent plant development and yield.

Table 3. Shoot fresh mass (SFM), root fresh mass (RFM), shoot dry mass (SDM), root dry mass (RDM), total fresh mass (TFM), total dry mass (TDM), and yield (Y) in Amazonian spinach plants grown from seedlings produced with different node numbers. Rio Branco, AC, 2023.

Seedlings	SFM	RFM	SDM	RDM	TFM	TDM	Y
	grams^{-1}						packs
1 node	84.12 c	13.57 b	9.55 c	2.81 c	97.69 c	12.36 c	0.28 c
2 nodes	98.45 b	16.57 a	11.72 b	3.34 b	115.02 b	15.07 b	0.33 b
3 nodes	113.80 a	18.42 a	13.71 a	3.79 a	132.22 a	17.50 a	0.37 a
MSD	8.29	2.11	1.37	0.35	10.05	1.59	0.03
CV (%)	6.08	19.54	8.61	7.77	6.35	7.80	6.31

*Means followed by the same lowercase letter in the column do not differ ($p < 0.05$) by the Tukey test. MSD - Minimum Significant Difference. CV - Coefficient of variation.

Although no significant differences were observed among treatments for mass variables during the seedling stage, marked differences became evident after cultivation. Total fresh and dry mass were approximately 35% and 41% higher, respectively, in plants derived from 3-node cuttings compared with those from 1-node cuttings (Table 3).

Fresh and dry mass are fundamental parameters in vegetable evaluation. Fresh mass is directly associated with commercial productivity, as vegetables are typically marketed based on fresh weight. In contrast, dry mass reflects biomass accumulation and physiological performance, providing a more accurate indicator of plant growth efficiency and photosynthetic activity under specific environmental conditions (Taiz et al., 2017; Gallegos-Cedillo et al., 2021).

The greater biomass accumulation observed in plants established from higher-quality seedlings is likely associated with their superior initial vigor at transplanting. Seedling quality is recognized as a fundamental factor for achieving higher yield and productivity in vegetable crops, directly influencing plant performance (Antunes et al., 2018). High-quality seedlings contribute to improved establishment, greater uniformity, enhanced resistance to pests and diseases, more efficient resource use, better product quality, and potentially reduced production costs (Yin et al., 2019).

Regarding yield, the highest mean values were recorded in plants derived from seedlings produced from 3-node cuttings, followed by those from 2- and 1-node cuttings, respectively. When yield was correlated with seedling quality, higher-quality seedlings resulted in superior final yield. Notably, although seedlings produced from 1- and 2-node cuttings did not differ significantly in quality at the seedling stage (Table 3), differences in yield were observed after cultivation, indicating that subtle variations in initial propagule size may influence subsequent plant performance.

Plants derived from 3-node cuttings exhibited yields 32% higher (0.37 packs $plant^{-1}$) than those derived from 1-node cuttings (0.28 packs $plant^{-1}$) and 12% higher than those from 2-node cuttings (0.33 packs $plant^{-1}$) (Table 3). This superior yield is associated with the initial vigor of the seedlings, as more vigorous plants exhibit greater capacity for resource acquisition and utilization, leading to enhanced photosynthetic activity and biomass allocation (Yin et al., 2019).

Studies examining the relationship between seedling quality and final yield in vegetables have reported species-specific responses, reinforcing the importance of initial seedling vigor for optimal plant development. Simões et al. (2015) and Souza et al. (2020), working with lettuce and chicory, respectively, demonstrated that higher-quality seedlings resulted in greater final productivity, which was attributed to improved early development and biomass accumulation. However, variations between seedling quality indices and final productivity may occur depending on species and cultivation conditions.

From a practical standpoint, the results indicate that the use of cuttings with a higher number of nodes represents a feasible and low-cost strategy to improve both seedling quality and yield of Amazonian spinach. Because vegetative propagation requires minimal inputs and no specialized equipment, this approach is particularly suitable for family farming and agroecological production systems. Adoption of this technique may facilitate the expansion of this non-conventional food plant (PANC) among small-scale producers, contributing to crop diversification, food and nutritional security, and the valorization of underutilized leafy vegetables within sustainable production systems.

Correlation analysis revealed significant associations ($p < 0.05$) among most evaluated variables, with predominantly positive and weak correlations, as well as the occurrence of some negative correlations (Figure 1). Among biometric growth variables, strong positive correlations were observed between SFM, RFM, SDM, RDM, TNL, and Y.

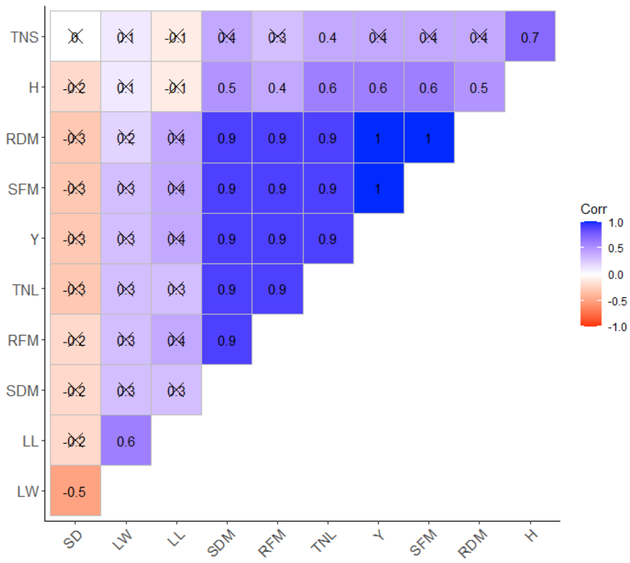

Figure 1. Correlation analysis among the response variables evaluated in Amazonian spinach plants grown from seedlings produced with different node numbers. Rio Branco, AC, 2023. Positive and negative correlations are represented in blue and red, respectively; color intensity and circle size are proportional to the correlation coefficients. Height (H), stem diameter (SD), total number of shoots (TNS), total number of leaves (TNL), leaf length (LL), leaf width (LW), shoot fresh mass (SFM), root fresh mass (RFM), shoot dry mass (SDM), root dry mass (RDM), and yield (Y).

The variables LW, LL, H and TNS exhibited non-significant correlations ($p < 0.05$) with most other variables, although the associations were generally positive and weak. Significant positive correlations were observed between LW and LL, and between TNS and H. Height also showed significant positive correlations with SDM, SFM, RDM, TNL, and Y. In contrast, SD exhibited non-significant correlations (p <

0.05) with nearly all evaluated variables and was predominantly negatively associated, except for a significant negative correlation with LW (Figure 1). The strong positive correlations among SFM, SDM, RFM, RDM, TNL, and Y are directly related to plant growth and productivity. Yield (Y) is calculated primarily based on shoot fresh mass; therefore, variations in SFM are inherently reflected in yield values. Shoot and root biomass accumulation are physiologically interconnected, as the development of the aerial part stimulates root growth, and expanding plants require increased uptake of water and mineral nutrients.

The total number of leaves (TNL) is also strongly associated with plant development, since leaves are the primary organs responsible for photosynthesis. Increased leaf number enhances photosynthetic capacity, thereby promoting greater biomass production and yield (Taiz et al., 2017).

The non-significant correlations observed for LL, LW, SD, and TNS with most variables are attributable to the uniform development of these traits among treatments.

The absence of correlation involving SD suggests that the standardization of cutting diameter during seedling production influenced subsequent plant formation, maintaining similar stem thickness across treatments.

Likewise, LL and LW developed similarly regardless of cutting size, showing significant positive correlation only with each other. This pattern reflects an intrinsic morphological characteristic of the species, in which leaf length and width exhibit proportional growth, as previously observed in seedlings by Silva et al. (2023).

Principal component analysis (PCA) organized the variables into distinct groupings in the biplot (Figure 2). The first two principal components accounted for 75.8% of the total variation in yield-related data, with Dimension 1 (Dim1) explaining 59.7% and Dimension 2 (Dim2) explaining 16.1% of the variance in the correlation matrix. PCA therefore enabled the identification of variability patterns and associations among variables and treatments, elucidating the response of Amazonian spinach plants to differences in seedling quality.

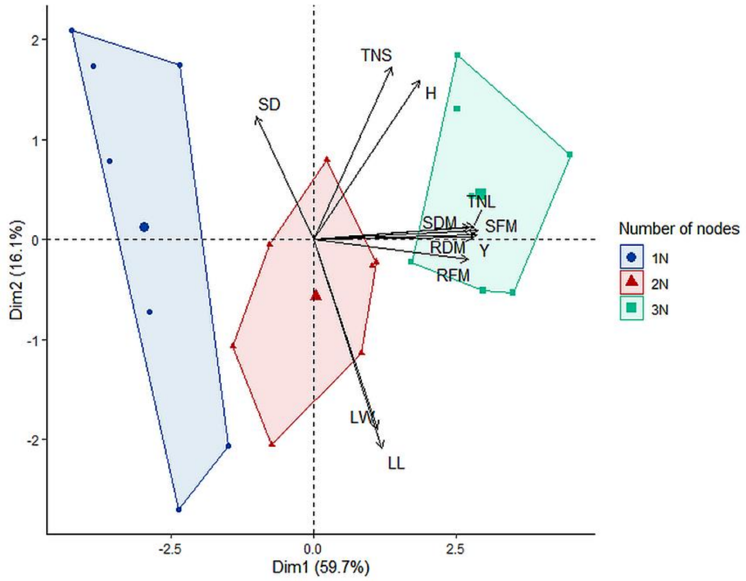

Figure 2. Principal component analysis of variables associated with the development of Amazonian spinach plants grown from seedlings produced from cuttings with different node numbers. Rio Branco, AC, 2023. Height (H), stem diameter (SD), total number of shoots (TNS), total number of leaves (TNL), leaf length (LL), leaf width (LW), shoot fresh mass (SFM), root fresh mass (RFM), shoot dry mass (SDM), root dry mass (RDM), and yield (Y).

Clear differentiation among treatments was evidenced by the formation of distinct polygons in the biplot. The variables H, TNS, LW, LL, TNL, SFM, RFM, SDM, RDM, and Y contributed predominantly to Dim1. Among these, TNL, SFM, RFM, SDM, RDM, and Y showed strong association with plants derived from 3-node cuttings, whereas H, TNS, LL, and LW were more closely associated with the treatment using 2-node cuttings (Figure 2).

The variables associated with 3-node seedlings exhibited strong interrelationships, as indicated by the formation of acute angles between vectors, corroborating the correlation results.

In Dim2, contribution to total variation was limited. Only SD exhibited notable contribution in this dimension, showing greater association with plants derived from 1-node cuttings and weaker association with those from 2-node cuttings (Figure 2).

In the PCA, SD was positioned antagonistically relative to most other variables, particularly LL and LW, consistent with the correlation analysis. The low contribution of SD and its lack of strong association with specific treatments suggest that the initial standardization of cutting diameter was maintained throughout plant development. Plants established from higher-quality seedlings exhibited superior vegetative development, as highlighted by PCA, which demonstrated clear differentiation among treatments. This separation reflects the influence of seedling quality on growth and final yield of Amazonian spinach. Seedling vigor is a decisive factor in vegetable production, as it directly affects growth dynamics and biomass allocation among plant organs (Antunes et al., 2018; Yin et al., 2019; Gallegos-Cedillo et al., 2021).

It is important to emphasize that the present study was conducted under protected conditions using containers, which may influence plant growth, root expansion, and biomass allocation compared with open-field cultivation. Therefore, caution is advised when extrapolating these findings to field conditions. Further studies under varying soil types, management practices, and environmental conditions are necessary to validate these results and to support recommendations for large-scale production.

4. Conclusions

The number of nodes per cutting significantly influences the growth, quality, and productivity of Amazonian spinach seedlings. Cuttings with a greater number of nodes result in enhanced biomass accumulation, higher Dickson quality index values, and increased commercial yield, confirming the importance of cutting size in vegetative propagation.

The use of three-node cuttings is therefore recommended for seedling production, as it represents a simple, low-cost, and efficient strategy to improve productivity. This practice is particularly suitable for family farming and agroecological systems and may contribute to the expansion and consolidation of Amazonian spinach cultivation.

Authors' Contribution

All authors contributed to this manuscript. Márcio Chaves da Silva: Conceptualization, research, experimentation, methodology, statistical analysis, investigation, data curation, writing, revision, editing, and supervision. Bárbara Barbosa Mota: Conceptualization, experimentation, methodology, statistical analysis, and writing. Regina Lúcia Felix Ferreira: Writing, revision, and editing. Márcia Chaves Silva: Experimentation, methodology, and writing. Nárcya Trindade de Souza: Conceptualization, methodology, and writing. Camila Freire Craveiro: Writing and editing.

Acknowledgments

The authors thank the Federal University of Acre (UFAC) and the Horticulture Laboratory of the Graduate Program in Plant Production for the institutional support and infrastructure provided for the development of this study.

Bibliographic References

Antunes, L.F.D.S., Scoriza, R.N., França, E.M., Silva, D.G.D., Correia, M.E.F., Leal, M.A.D.A., Rouws, J.R.C., 2018. Desempenho agronômico da alface crespa a partir de mudas produzidas com gongocomposto. Revista Brasileira de Agropecuária Sustentável, 8(3), 57-65. https://doi.org/10.21206/rbas.v8i3.3009

Dickson, A., Leaf, A.L., Hosner, J.F., 1960. Quality appraisal of white spruce and white pine seedling stock in nurseries. The Forestry Chronicle, 36(1), 10-13. https://doi.org/10.5558/tfc36010-1

Gabam, S.V.F., Borges, O.M.A., 2020. Knowledge, Nutritional Value and Uses of Some Non Conventional Plant Foods. Novel Techniques in Nutrition and Food Science, 5(3), 462-464. https://doi.org/10.31031/NTNF.2020.05.000613

Gallegos-Cedillo, V.M., Diánez, F., Nájera, C., Santos, M., 2021. Plant agronomic features can predict quality and field performance: a bibliometric analysis. Agronomy, 11(11), 1-31. https://doi.org/10.3390/agronomy11112305

Hwong, C.S., Leong, K.H., Aziz, A.A., Junit, S.M., Noor, S.M., Kong, K.W., 2022. Alternanthera sessilis: Uncovering the nutritional and medicinal values of an edible weed. Journal of Ethnopharmacology, 298(1), 115608. https://doi.org/10.1016/j.jep.2022.115608

Kinupp, V.F., Lorenzi, H., 2014. Plantas Alimentícias Não Convencionais (PANC) no Brasil: guia de identificação, aspectos nutricionais e receitas ilustradas, primeira ed. Nova Odessa, Plantarum.

Melo, M.N.V., Silva, V.H.D., Perdoná, M.J., 2019. Ambientes para produção de mudas de nogueira-macadâmia por estaquia. Revista Científica ANAP Brasil, 12(27), 88-97. https://doi.org/10.17271/19843240122720192242

Nikam, S.R., Namdas, D.D., 2022. Preliminary Phytochemical Analysis of Alternanthera sessilis Leaves (Linn). R. Br. ex DC. Ymer, 21(1), 220-225. https://doi.org/10.37896/YM ER21.01/20

Padilha, A.F., Pietrobelli, S.R., Pereira, G.F., Finatto, T., Madeira, N.R., Vargas, T.D.O., 2023. Análise bibliométrica da produção científica sobre plantas alimentícias não convencionais. Interações, 24(2), 427-443. http://dx.doi.org/10.20435/inter.v24i2.3830

Sá, F.P., Gomes, E.N., Maggioni, R.A., Wendling, I., Helm, C.V., Sant'anna-Santos, B.F., Zuffellato-Ribas, K.C., 2022. Biochemical and anatomical features of adventitious rhizogenesis in apical and basal mini-cuttings of Ilex paraguariensis. New Forests, 53(3), 411-430. https://doi.org/10.1007/s11056-021-09855-0

Schreinemachers, P., Simmons, E.B., Wopereis, M.C.S., 2018. Tapping the economic and nutritional power of vegetables.

Global food security, 16(1), 36-45. https://doi.org/10.1016/j.gfs. 2017.09.005

Silva, M.C., Oliveira, R.V., Mota, B.B., Silva, M.C., Ferreira, R.L.F, 2023. Qualidade de mudas de espinafre da Amazônia (*Alternanthera sessilis* L.) propagadas por estacas. Scientia Naturalis, 5(1), 238-251. https://doi.org/10.29327/269504.5.1-16

Simões, A.C., Alves, G.K., Ferreira, R.L., Araújo Neto, S.E., 2015. Qualidade da muda e produtividade de alface orgânica com condicionadores de substrato. Horticultura brasileira, 33(4), 521-526. https://doi.org/10.1590/S0102-053620150000400019

Souza, L.G.D.S., Ferreira, R.L.F., Araújo Neto, S.E.D., Silva, N.M., Uchôa, T.L., Almeida, W.A., 2020. Chicory yield influenced by seedling quality and growing environment. Horticultura Brasileira, 38(2), 224-229. https://doi.org/10.1590/S0102-053620200216

Taiz, L., Zeiger, E., Moller, I.M., Murphy, A., 2017. Fisiologia e Desenvolvimento Vegetal, sexta ed. Sinauer Associates, Sunderland.

Tofanelli, M.B.D., Mógor, Á.F., 2021. Plantio horizontal de miniestacas de ora-pro-nóbis: Um novo método. Research, Society and Development, 10(4), e17510414054-e17510414054. https://doi.org/10.33448/rsd-v10i4.14054

White, R.R., Gleason, C.B., 2022. Global human-edible nutrient supplies, their sources, and correlations with agricultural environmental impact. Scientifc Reports, 12(1), 16781). https://doi.org/10.1038/s41598-022-21135-1

Yin, Q., Tian, T., Han, X., Xu, J., Chai, Y., Mo, J., Yue, M., 2019. The relationships between biomass allocation and plant functional trait. Ecological Indicators, 102(1), 302-308. https://doi.org/10.1016/j.ecolind.2019.02.047