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Growing conditions and substrates for producing collard green seedlings in a tropical climate

Condições de cultivo e substratos para produção de mudas de couve-manteiga em clima Tropical

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Highlights

35% silver photo-converting mesh favors the production of collard green seedlings.
Environments coated with red photo-converting mesh limit seedling production.
PuroHumus® improves the productive effect of the commercial OrganoAmazon® substrate.
Microclimate management is crucial in collard green seedlings' production.

Abstract

Determining an efficient system for seedling production in greenhouses and on photo-converting mesh, considering the substrates' quality, is essential for obtaining productive and economically viable crops. In this context, the objective of the present study was to evaluate the effects of growing conditions and substrates on the production of collard green seedlings in a tropical climate. Therefore, five growing conditions (i.e., A1: agricultural greenhouse, A2: red 35% Chromatinet®, A3: red 50% Chromatinet®50%, A4: silver 35% Chromatinet®, and A5: silver 50% Chromatinet®) were randomly combined into subdivided plots with four substrate types (S1: OrganoAmazon®, S2: OrganoAmazon® + PuroHumus®, S3: OrganoAmazon® + PuroHumus® + soil + cattle manure, and S4: OrganoAmazon® + PuroHumus® +

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soil + cattle manure + carbonized rice husk). Subsequently, we evaluated their effects on the seedlings' quantitative and qualitative variables. Results showed that the combined use of silver 35% Chromatinet® (A4) and substrate S2 (OrganoAmazon® + PuroHumus®) promoted the best growth conditions for collard green seedlings The greenhouse (A1) when combined with substrate S4 (OrganoAmazon® + PuroHumus® + soil + cattle manure + carbonized rice husk), also favored the production of collard green seedlings. The substrate formulated with OrganoAmazon® + PuroHumus® + soil + manure + carbonized rice husk (S3) is an alternative for producing collard green seedlings. Conversely, the red nets (A2 and A3) and the OrganoAmazon® substrate (S1) used alone did not favor the production of collard green seedlings in a tropical climate.

Key words: *Brassica oleracea* var. acephala. Seedling quality. Photo-converting mesh. Savannah.

Resumo

Determinar um sistema eficiente de produção de mudas, em estufas agrícolas e sobre malhas fotoconversoras, considerando ainda a qualidade de substratos disponíveis, é essencial à obtenção de cultivos produtivos e economicamente viáveis. Nesse contexto, objetivamos avaliar os efeitos de condições de cultivo e de substratos na produção de mudas de couve-manteiga em área de clima Tropical. Para isso, combinamos, em parcelas subdivididas arranjadas inteiramente ao acaso, cinco condições de cultivo (A1: estufa agrícola, A2: Chromatinet®35% vermelha, A3: Chromatinet®50% vermelha, A4: Chromatinet®35% prata e A5: Chromatinet®50% prata) a quatro substratos (S1: OrganoAmazon®, S2: OrganoAmazon® + PuroHumus®, S3: OrganoAmazon® + PuroHumus® + solo + esterco bovino e S4: OrganoAmazon® + PuroHumus® + solo + esterco bovino + casca de arroz carbonizada), e avaliamos os seus efeitos sobre as variáveis quantitativas e qualitativas das mudas. Identificamos que o uso associado entre Chromatinet®35% prata (A4) e o substrato S2 (OrganoAmazon® + PuroHumus®) promoveu as melhores condições para o crescimento das mudas de couve-manteiga nas condições tropicais do estudo. A estufa (A1), quando combinada ao substrato S4 (OrganoAmazon® + PuroHumus® + solo + esterco bovino + casca de arroz carbonizada), também favorece à a produção de mudas de couve. O substrato formulado com OrganoAmazon® + PuroHumus® + solo + esterco + CAC (S3) é uma alternativa para a produção de mudas de couve. As telas de coloração vermelha (A2 e A3) e o substrato OrganoAmazon® (S1) utilizados isoladamente não favoreceram a produção de mudas de couve-manteiga sob as condições de clima Tropical.

Palavras-chave: *Brassica oleracea* var. acephala. Qualidade de mudas. Malhas fotoconversoras. Savana.

Introduction

Collard greens (*Brassica oleracea* var. acephala) are leafy Brassicaceae species widely consumed in Brazil and worldwide. Currently, this species, like other Brassica species, has attracted attention due to its high phytochemical content (carotenoids, phenols, glucosinolates, and vitamins) and its high adaptability to a wide range of soil and climate conditions (Bauer et al., 2022; Díaz-Urbano et al., 2022). In northern Brazil, high rainfall and temperature throughout the year necessitate protected cultivation for collard greens, which thrive in milder temperatures (16 to 22 °C) and can be damaged by excessive rainfall (Novo et al., 2010).

The quality of seedlings is essential in collard green cultivation since plant development hinges on this factor. In this phase, it is imperative to select the correct production environments, considering suitable conditions of temperature, humidity, and solar radiation, as adverse conditions of these factors negatively affect the nutritional quality and vital functions of plants, such as photosynthesis, respiration, evapotranspiration, membrane stability, and their metabolic apparatus (Shimada et al., 2017; Ashenafi et al., 2022; Choi et al., 2022).

Chowdhury et al. (2021) noted that collard greens exposed to adverse environmental conditions, particularly high temperatures (above 23 °C), exhibit a significant reduction in functional compound content (e.g., glucosinolates) and in vegetative growth (biomass, plant height, stem diameter, and root development). This is attributed to deregulations in their physiological processes, compromising total production. Thus, managing the growing conditions for this species is essential for optimal production.

Protected environments used for plant propagation are mainly covered with low-density polyethylene film (agricultural greenhouses). However, the use of photo-converting nets in different colors and shading levels (Aluminet® and Chromatinet®) and monofilament (Sombrite®) is a growing alternative in the production of vegetable seedlings (Monteiro et al., 2022). By modifying the quantity and quality of transmitted solar radiation, these meshes determine the dispersion and reflectance of light, affecting plants' morphological and productive variations (Chagas et al., 2013). According to Meng et al. (2019), collard greens positively respond to changes in efficient light radiation, showing increased leaf expansion, aerial part biomass, and chlorophyll concentrations, which can promote significant production gains.

These characteristics could make these environments an option for the production of collard green seedlings in the savannah region of Roraima, whose high levels of solar radiation and temperature have affected the production of different vegetable species (Monteiro et al., 2016, 2018, 2022). Stamps (2009) reports that divergent effects regarding the use of photo-converting mesh can occur depending on the plant species and even the cultivar used, implying the need for tests on each crop grown in the producing regions.

In addition to environmental factors, substrates are also essential in providing optimal conditions for plant growth. Welter et al. (2011) noted that substrates must be selected based on their physical and chemical properties, compatibility with the plant species, the absence of chemical elements at toxic levels, adequate electrical conductivity, and economic factors, given their high cost in seedling production. As for collard green seedlings, Chiomento et al. (2021) suggest substrates that promote greater water retention and are not exclusively formulated with organic compounds.

In Roraima, two commercial composts are widely used in producing vegetable seedlings: OrganoAmazon® and PuroHumus®. The high costs of commercial composts used in vegetable seedling production necessitate the formulation of alternative substrates with materials that are accessible to each region and that provide desirable physical, chemical, and biological conditions for seedling development, such as rice husks (in natural or carbonized) and manure from different types of animal husbandry.

Therefore, defining a system for producing collard green seedlings that provide the best-growing conditions using the materials available for making substrates in each region is essential for maintaining and improving viable and productive crops. This study aimed to evaluate the influence of growing conditions associated with different substrates on the production of collard green seedlings (*Brassica oleracea* var. acephala) in tropical climate conditions.

Materials and Methods

This study was conducted in the experimental area of the Center of Agrarian Sciences of the Federal University of Roraima, located in the savannah region of Boa Vista, Roraima. Its tropical wet-dry (Aw) climate provides annual rainfall, humidity, and temperature averages of 1,678 mm, 70%, and 27.4 °C, respectively (Araújo et al., 2001). The Georgia collard greens (*Brassica oleracea* var. acephala) have dark green, large, smooth leaves that can be harvested several times during the plant's growth.

The experimental design used was completely randomized (CRD), with treatments arranged in subdivided plots, with five growing conditions (plots) and four substrates (subplots). Each treatment was repeated five times, with ten plants per experimental unit. The growing conditions consisted of an arch-type greenhouse covered with low-density polyethylene (LDPE) [A1] and four nets covered with different Chromatinet® photo-converting meshes: A2 (net with red photo-converting mesh with 35% shading), A3 (net with red photo-converting mesh with 50% shading), A4 (net with silver photo-converting mesh with 35% shading), and A5 (net with silver photo-converting mesh with 50% shading).

The greenhouse (A1) was 6.0 m long, 3.4 m wide and 2.4 m high. It was surrounded by Sombrite® with 50% shading and covered with transparent low-density polyethylene (LDPE) plastic 150 µm thick. The netting had a wooden structure measuring 17 m long, 4 m wide, and 2.5 m high.

The four substrates tested were: S1 [OrganoAmazon® (control substrate)], S2 [OrganoAmazon® + PuroHumus® (1:1 v/v)]; S3 [OrganoAmazon® + PuroHumus® + soil + manure (1:1:1:1 v/v)] and S4 [OrganoAmazon® + PuroHumus® + soil + manure + carbonized rice husk (CRH) (1:1:1:1:1 v/v)]. The substrates were homogenized manually and transferred to containers for subsequent sowing. Table 1 shows the chemical characterization of the substrates.

Table 1
Chemical characterization of the substrates evaluated

Substrate	pH (H_2O)	EC dS cm^{-1}	N	P	K	Ca	Mg	S	B	Cu	Mn	Zn	Fe
			---- cmolc dm^{-3} ----										
S1	7.7	0.029	48.6	0.6	1.0	0.8	0.3	1.0	5.4	0.1	0.5	0.2	0.1
S2	7.1	0.690	81.1	1.0	2.0	1.1	0.7	1.2	7.9	0.1	1.1	0.2	0.3
S3	7.2	0.460	41.6	0.7	1.2	1.1	0.7	1.1	6.3	0.1	0.9	0.3	0.7
S4	7.2	0.490	43.1	0.7	1.5	1.2	0.5	1.2	6.8	0.1	1.0	0.1	0.1

S1 (OrganoAmazon®), S2 (OrganoAmazon® + PuroHumus®), S3 (OrganoAmazon® + PuroHumus® + soil + manure), S4 (OrganoAmazon® + PuroHumus® + soil + manure + CAC). EC (electrical conductivity).

The OrganoAmazon® compost and PuroHumus® organic fertilizer were purchased from local businesses. The soil *"Latossolo Amarelo"* (Oxisol) was collected at 0–20 cm depth, sieved through a 6 mm mesh, and corrected with 0.196 kg m^{-2} of dolomitic limestone 20 days before the experiment was set up. The rice husk underwent complete carbonization. The cattle manure, acquired from extensively reared animals, was sieved and watered daily until cured.

The incidence of light in the environments was defined by the average of the daily records of global solar radiation (GSR), photosynthetically active radiation (PAR), and the PAR/GSR ratio, measured at three set times using portable sensors (LI-COR®). GSR and PAR were obtained using an L1-200 pyranometer and an L1-190 quantum sensor, respectively. Maximum and minimum temperatures were measured daily using thermometers installed inside and outside the environments (Table 2).

Table 2
Mean values of global solar radiation (GSR), photosynthetically active radiation (PAR), PAR/GSR ratio (%), and maximum and minimum temperatures in environments where collard green seedlings are grown

Microclimate assessment	Environments					
	OE	A1	A2	A3	A4	A5
GSR (µmol s^{-1} m^{-2})	2023.9	1134.8	1214.3	896.0	1192.6	978.4
PAR (µmol s^{-1} m^{-2})	852.1	483.1	492.1	381.4	461.9	404.7
PAR/GSR (%)	42.1	42.6	40.5	42.6	38.7	41.4
Max. Temperature (° C)	32.9	37.3	42.3	41.2	38.1	39.2
Min. Temperature (° C)	24.2	22.1	24.3	23.1	22.3	23.6

OE = Outdoor Environment, A1 = Agricultural Greenhouse, A2 = Chromatinet®35% Red, A3 = Chromatinet®50% Red, A4 = Chromatinet®35% Silver, A5 = Chromatinet®50% Silver.

Seeds were sown in 180 cm^3 plastic cups. The cups were perforated at the bottom and filled at the base with gravel type 0 (4.8 – 9.5 mm). The seedlings were irrigated daily in two shifts (morning and afternoon) for 15 minutes using a micro-sprinkler with a flow rate of 8 L h^{-1}. At 20 days after emergence (DAE), the following variables were assessed: number of leaves (NL), plant height (PH), stem diameter (SD), aerial dry mass (ADM), root dry mass (RDM), total dry mass (TDM), and the dimensionless chlorophyll values of the plants. The PH/SD and ADM/RDM ratios and the Dickson quality index (DQI) were evaluated as indices of seedling growth quality. They were determined by: DQI = TDM/(PH/SD + ADM/RDM).

NL was determined by counting the fully expanded leaves. PH was measured using a graduated ruler, from the base of the plant to its apex (cm). SD was determined using a precision digital caliper and expressed in mm. To determine plant mass, the plants were first dried in an oven with forced air circulation at 60 to 70 °C for 72 hours. ADM, RDM, and TDM were determined in grams (g). The chlorophyll assessment was conducted using a ChlorofiLOG® model CFL 1030 electronic chlorophyll meter (Falker index).

The data obtained for each variable, after being checked for normality of distribution using the Shapiro-Wilk test and homogeneity of variance using the Bartlett test, were subjected to analysis of variance. The means of the treatments were grouped and compared using the Scott-Knott test ($p \leq 0.05$). The treatments and variables were also analyzed using multivariate principal component analysis (PCA) to identify the associations of the variables in the principal components that contribute most to the productive variability of collard green seedlings. The growth and chlorophyll analyses were carried out using the Sisvar software (Ferreira, 2019), and the analyses of normality of distribution, homogeneity of variance, and principal components were conducted using the Prism GraphPad 9.5.1 software.

Results and Discussion

The microclimate assessment of the environments (Table 2) showed that the average values for GSR and PAR were different from each other and lower than the values collected from the outside environment. The highest GSR and PAR transmittance values were obtained in the greenhouse (A1) and in the nets with the least shade (red 35% Chromatinet® and silver 35% Chromatinet®35%), and the highest PAR/GSR ratios were obtained in A1 and in red 50% Chromatinet® (A3). PAR is the fraction of GSR that comprises the spectral range of solar radiation with a wavelength of 400 to 700 nm, and it is directly linked to the photochemical events of plants. Therefore, they can be a determining factor in the production of seedlings of different oleraceous species (Caron et al., 2012; Monteiro et al., 2022).

In addition to the greater transmissibility of PAR, the agricultural greenhouse (A1) also reduced average temperature values compared to the netting (Table 2). Red-colored net meshes (A2 and A3) raised ambient temperature significantly, corroborating findings by Silva et al. (2013) in environments utilizing nets of the same color. According to the authors, if the correct temperature management is not applied in these environments, adverse conditions can negatively influence plant production, even in species adapted to tropical conditions, as observed in the production of pine cone seedlings (Sakazaki et al., 2019), tomatoes (Monteiro et al., 2018) and *pimenta-de-cheiro*, a Brazilian chili pepper (Monteiro et al., 2022) in the savannah region of Roraima.

The quantitative growth results (NL, PH, SD, and dry biomass), presented in Tables 3 and 4, show that the vegetative growth of the collard green seedlings depended on the joint action of the factors analyzed since the effect of the interaction between growing conditions (GC) and substrates (S) was significant ($p < 0.05$) in all the variables evaluated.

The analyses of NL, PH, and SD (Table 3) showed that the environments and substrates influenced the outcomes differently for each variable assessed. NL, substrate S2 (OrganoAmazon® + PuroHumus®), in any environment, and S3 (OrganoAmazon® + PuroHumus® + soil + cattle manure), when associated with A1 (greenhouse), A2 (red 35% Chromatinet®) and A4 (silver 35% Chromatinet®), were the most effective in increasing the seedlings' foliage. Regarding the environments, the agricultural greenhouse (A1), combined with the substrates S2 (OrganoAmazon® + PuroHumus®), S3 (OrganoAmazon® + PuroHumus® + soil + cattle manure) and S4 (OrganoAmazon® + PuroHumus® + soil + cattle manure + CRH); and nettings A2 and A4, when combined with the substrates S2 and S3, were the most effective in increasing the seedlings' NL. As for PH, the netting with more shading (red 50% Chromatinet® and silver 50% Chromatinet®), especially when combined with substrates S2 (OrganoAmazon® + PuroHumus®) and S4 (OrganoAmazon® + PuroHumus® + soil + cattle manure + CRH) promoted the greatest seedling growth. Moreover, the effect of S2, especially in environment A4 (silver 35% Chromatinet®), was the most significant in terms of SD compared to the other substrates.

Table 3
Mean number of leaves (NL), plant height (PH), and crown diameter (CD) of collard green seedlings (*Brassica oleracea* var. acephala) grown in different environments and substrates in a tropical climate

Number of leaves					
	S1	S2	S3	S4	*m*
A1	2.92 Ab	3.32 Aa	3.32 Ba	3.52 Aa	3.27
A2	2.72 Ab	3.48 Aa	3.76 Aa	2.36 Bb	3.08
A3	2.72 Ab	3.92 Aa	2.96 Bb	3.16 Ab	3.19
A4	3.30 Ab	3.70 Aa	3.70 Aa	3.15 Ab	3.46
A5	2.90 Ab	3.70 Aa	3.10 Bb	3.10 Ab	3.20
m	2.91	3.62	3.37	3.06	
Plant height (cm)					
	S1	S2	S3	S4	*m*
A1	2.66 Bb	3.84 Ca	3.85 Aa	3.72 Ba	3.52
A2	2.76 Bb	3.26 Da	2.98 Bb	2.46 Db	2.87
A3	3,44 Ab	4.70 Aa	3.78 Ab	4.48 Aa	4.10
A4	3.65 Aa	4.04 Ba	3.75 Aa	2.95 Cb	3.60
A5	3.40 Ac	4.50 Aa	3.90 Ab	3.30 Bc	3.78
m	3.18	4.07	3.65	3.38	
Stem diameter (mm)					
	S1	S2	S3	S4	*m*
A1	0.75 Bb	1.35 Ba	1.34 Aa	1.41 Aa	1.21
A2	1.22 Ab	150 Ba	1.00 Bc	0.85 Bc	1.14
A3	1.10 Ab	1.51 Ba	0.95 Bb	1.32 Aa	1.22
A4	1.21 Ab	1.78 Aa	1.29 Ab	1.18 Ab	1.37
A5	1.17 Aa	1.41 Ba	1,21 Aa	1.19 Aa	1.25
m	1.09	1.51	1.16	1.19	

Values followed by the same letter, lower case in the rows and upper case in the columns, do not differ by the Scott-Knott test ($p < 0.05$). A1 = Agricultural Greenhouse, A2 = Chromatinet®35% Red, A3 = Chromatinet®50% Red, A4 = Chromatinet®35% Silver, A5 = Chromatinet®50% Silver. S1 = Commercial organic compost (CO), S2 = CO + Humus, S3 = Soil + CO + Humus + Manure. S4 = Soil + CAC + CO + Humus + Manure. *m* = mean.

Among the substrates made with alternative materials added to exclusively commercial composts, S3 (OrganoAmazon® + PuroHumus® + soil + manure) provided an increase in NL values in environments A1 (greenhouse), A2 (red 35% Chromatinet®) and A4 (silver 35% Chromatinet®). In addition, PH increased in environments A1, A4, and A5 (silver 50% Chromatinet®), and SD in environments A1 and A4. Similarly, S4 (OrganoAmazon® + PuroHumus® + soil + manure + CRH) efficiently increased NL when associated with A1; PH in environments A1 and A3, and SD in A1.

Substrates S3 and S4 could become viable alternatives to composts produced only with commercial products since they have good physical and chemical content. In addition, using soil and mainly CRH as substrate components could make seedling production viable due to their easy acquisition and low cost.

The treatments inherent to environments A2 (red 35% Chromatinet®) and A3 (red 50% Chromatinet®) and substrate S1 (OrganoAmazon®) were not satisfactory in most of the variables analyzed. These results may be due to the excess solar radiation added to the high temperatures recorded in these environments, as these conditions decrease seedling growth. According to Shimada et al. (2017), plants exposed to high temperatures show severe damage, especially to their photosynthetic complex. According to the authors, increased temperature to levels not tolerated by plants negatively affects photosynthetic rates (gross and net), stomatal conductance, cellular respiration, and transpiration in different species. These problems are caused mainly in photosystem II (FSII) and reduce the functions of the b6/f complex and, consequently, of the photosystem I (FSI), culminating in the non-production of adenosine triphosphate (ATP) and nicotinamide adenine dinucleotide phosphate hydrogen (NADPH) for the subsequent processes of photosynthesis.

In addition to the direct influence on the photosynthetic complex, high temperatures can affect the distribution of ions in different plant organs, directly affecting the ionic homeostasis of plants (Dutra et al., 2011), i.e., the balance and conservation of physiological elements intrinsic to plant physiology can be deregulated by high temperatures. Chowdhury et al. (2021) observed that high temperatures promote a significant reduction in the content of functional compounds of collard greens plants, such as glucosinolates, and a decrease in vegetative growth (biomass, PH, SD, and root development) due to deregulations in their physiological processes, mainly when associated with high relative humidity and higher CO_2 concentrations.

According to the manufacturer, the commercial substrate OrganoAmazon® (S1) is composed of a mixture of cattle, horse, chicken, and sheep manure, sawdust, aged and CRH, peat, sugarcane bagasse, grass clippings, twigs, and foliage. This substrate did not offer good GC, probably due to the low nutritional content provided to the plants compared to the other substrates (Table 1). Although local producers widely use this substrate, we suggest supplementing it with nutrients to produce vegetable seedlings, as its low production efficiency has also been identified in other species (Monteiro et al., 2022).

The treatments showed similar performance regarding the seedlings biomass (Table 4) to those observed in Table 3, especially as for substrates S2 (OrganoAmazon® + PuroHumus®) and S4 (OrganoAmazon® + PuroHumus® + soil + cattle manure + CRH), and environment A1 (greenhouse) and A4 (silver 35% Chromatinet®). Substrate S2, when associated with environment A4 and A5 (silver 50% Chromatinet®), and S4, associated with A1, were the treatments that most promoted an increase in seedling biomass (ADM, RDM, and TDM).

Table 4

Average values of aerial dry mass (ADM) and root dry mass (RDM) of collard green seedlings (*Brassica oleracea* var. acephala) grown in different environments and substrates in a tropical climate

Aerial dry mass (g plant^{-1})					
	S1	S2	S3	S4	*m*
A1	0.04 Bb	0.04 Db	0.04 Bb	0.05 Aa	0.04
A2	0.02 Cc	0.05 Ca	0.03 Bb	0.02 Cc	0.03
A3	0.03 Cc	0.05 Ca	0.03 Bb	0.04 Bb	0.04
A4	0.05 Ab	0.09 Aa	0.05 Ab	0.04 Bc	0.06
A5	0.04 Bb	0.08 Ba	0.02 Cc	0.04 Bb	0.05
m	0.04	0.06	0.04	0.04	
Root dry mass (g plant^{-1})					
	S1	S2	S3	S4	*m*
A1	0.03 Ab	0.04 Ba	0.03 Ab	0.05 Aa	0.04
A2	0.01 Bd	0.05 Ba	0.03 Ac	0.03 Bb	0.03
A3	0.03 Aa	0.03 Ca	0.02 Ba	0.02 Ba	0.02
A4	0.02 Bd	0.06 Aa	0.03 Ac	0.04 Ab	0.04
A5	0.02 Bc	0.04 Ba	0.02 Bc	0.03 Bb	0.03
m	0.02	0.04	0.03	0.04	
Total dry mass (g plant^{-1})					
	S1	S2	S3	S4	*m*
A1	0.07 Ab	0.09 Db	0.08 Ab	0.10 Aa	0.08
A2	0.04 Cc	0.10 Ca	0.07 Bb	0.06 Cb	0.07
A3	0.06 Bb	0.08 Da	0.06 Cb	0.06 Cb	0.06
A4	0.07 Ab	0.15 Aa	0.08 Ab	0.08 Bb	0.10
A5	0.05 Bc	0.12 Ba	0.05 Cc	0.07 Cb	0.07
m	0.06	0.11	0.07	0.07	

Values followed by the same letter, lower case in the rows and upper case in the columns, do not differ by the Scott-Knott test ($p < 0.05$). A1 = Agricultural Greenhouse, A2 = Chromatinet®35% Red, A3 = Chromatinet®50% Red, A4 = Chromatinet®35% Silver, A5 = Chromatinet®50% Silver. S1 = Commercial organic compost (CO), S2 = CO + Humus, S3 = Soil + CO + Humus + Manure. S4 = Soil + CAC + CO + Humus + Manure. *m* = mean.

Comparing only the environment using photo-converting mesh nets and considering the substrate that had the greatest increase in dry mass (S2), the experiment found that the accumulation of photo assimilates in collard green seedlings was directly associated with the color of the mesh and not with the level of shading. The silver-colored nets (A4 and A5) positively and proportionally influenced the accumulation of aerial and root biomass (Table 4), diverging from the results found by Sakazaki et al. (2019) and by Monteiro et al. (2022), who observed greater accumulation of ADM in environments with greater shading, and RDM in environments with less shading, regardless of color. Silva et al. (2013) studied the growth of tomato seedlings on different nets with 50% shading and found no differences in root mass between the environments. However, the effect of coloring was significant in the increase in aerial biomass on gray and aluminized nets.

These results show a balance in the biomass distribution of the collard green seedlings produced in the best treatments, i.e., development was proportional between the aerial and root parts of the seedlings when they were grown in environments A4 (silver 35% Chromatinet®) and A5 (silver 50% Chromatinet®) in substrate S2 (OrganoAmazon® + PuroHumus®), and in environment A1 (greenhouse) in substrate S4 (OrganoAmazon® + PuroHumus® + soil + cattle manure + CRH). The greater accumulation of biomass in the aerial part of seedlings produced in the silver-colored environments (A4 and A5) and in the agricultural greenhouse (A1) was possibly due to the lower maximum temperature values recorded in these environments (Table 2). According to Caron et al. (2012), these conditions favor the quantity and quality of leaves, promoting a greater reserve of photoassimilates and, consequently, a greater biomass accumulation in the seedlings.

In the analysis of growth quality indices (Table 5), only the PH/SD ratio was not influenced by the treatments. According to Rodrigues et al. (2010), this variable indicates the adequate growth of seedlings, in which the increase in PH must be proportionally followed by the thickness of the stem, i.e., lower PH/SD values indicate better conditions for the survival and development of the plants after transplanting. Another important aspect of the PH/SD ratio is determining the occurrence of stunting of seedlings. Stunting may happen due to the low light levels to which seedlings are subjected. However, unlike the findings regarding the *pimenta-de-cheiro* (Brazilian chili pepper) seedlings (Monteiro et al., 2022) and tomato seedlings (Monteiro et al., 2018) under the same conditions as this experiment, PH/SD was not a determining factor in the qualitative selection of collard green seedlings.

Table 5
Average values for plant height/crown diameter (PH/CD) and Dickson quality index (DQI) of collard green seedlings (*Brassica oleracea* var. acephala) grown in different environments and substrates in a tropical climate

PH/CD					
	S1	S2	S3	S4	*m*
A1	36.80	28.53	28.86	26.48	30.17 A
A2	22.,83	21.80	59.02	29.13	33.19 A
A3	31.30	31.64	40.35	34.11	34.35 A
A4	30.15	23.01	29.16	25.,04	26.84 A
A5	29.02	32.17	32.60	27.79	30.39 A
m	30.02 a	27.43 a	38.00 a	28.51 a	
ADM/RDM					
	S1	S2	S3	S4	*m*
A1	1.26 Ca	0.97 Ca	1.26 Aa	1.05 Ba	1.14
A2	2.06 Ba	1.09 Cb	1.39 Ab	0.63 Bc	1.29
A3	1.43 Cb	2.45 Aa	1.82 Ab	1.70 Ab	1.85
A4	2.74 Aa	1.53 Bb	1.47 Ab	0.90 Bc	1.66
A5	2.20 Ba	1.74 Bb	1.41 Ab	1.37 Ab	1.68
m	1.93	1.56	1.47	1.13	
DQI					
	S1	S2	S3	S4	*m*
A1	0.15 Ac	0.22 Cb	0.19 Ac	0.28 Aa	0.21
A2	0.09 Ac	0.20 Ba	0.14 Bb	0.16 Bb	0.17
A3	0.14 Aa	0.15 Da	0.10 Ba	0.12 Ba	0.13
A4	0.13 Ad	0.40 Aa	0.19 Ac	0.23 Ab	0.24
A5	0.10 Ac	0.24 Ca	0.11 Bc	0.16 Bb	0.15
m	0.12	0.26	0.14	0.19	

Values followed by the same letter, lower case in the rows and upper case in the columns, do not differ by the Scott-Knott test ($p < 0.05$). A1 = Agricultural Greenhouse, A2 = Chromatinet®35% Red, A3 = Chromatinet®50% Red, A4 = Chromatinet®35% Silver, A5 = Chromatinet®50% Silver. S1 = Commercial organic compost (CO), S2 = CO + Humus, S3 = Soil + CO + Humus + Manure. S4 = Soil + CAC + CO + Humus + Manure. *m* = mean.

The DQI included morphological variables such as height, diameter, and biomass in a balanced formula. Therefore, it was a good indicator of the quality standard of collard green seedlings since the results (Table 5) align with the quantitative growth analyses (Tables 3 and 4). Analysis of this index suggests that the higher the DQI value, the higher the estimate of seedling quality. As a result, environment A4 (silver 35%

Chromatinet®), combined with substrate S2 (OrganoAmazon® + PuroHumus®), was the treatment that best promoted the development of quality seedlings of collard greens (Table 5), i.e., seedlings submitted to this treatment showed better vigor and uniform development between the aerial part and the root, thus having better conditions for development in the crop. Moreover, the use of substrate S4 (OrganoAmazon® + PuroHumus® + soil + cattle manure + CRH) in environments A1 (greenhouse) and A4 (silver 35% Chromatinet®) proved to be potential combinations for producing collard green seedlings in tropical climate conditions.

Containment of the excessive increase in temperature and good transmissibility, both in terms of quantity and proportion of PAR, were probably determining factors in the better development of the seedlings produced in the greenhouse (A1) and especially in the A4 environment (silver 35% Chromatinet®), since the adverse conditions of these factors negatively affect vital plant functions such as photosynthesis, respiration, evapotranspiration, water relations, and the stability of cell membranes, in addition to influencing the hormonal and metabolic apparatus of plants (Shimada et al., 2017; Ashenafi et al., 2022). This fact partly explains the low production performance of seedlings under the red-colored photo-converting mesh nets (A2 and A3).

The physicochemical characteristics of the substrate made with OrganoAmazon® + PuroHumus® (S2) were effective in the development of the collard green seedlings, mainly due to the nutritional increase provided by PuroHumus®, since OrganoAmazon® did not have good nutritional conditions (Table 1). Therefore, the results of the present study reinforce the efficiency of this combination in the production of seedlings of vegetable and ornamental species since this substrate was the most efficient in the production of seedlings of pepper (Monteiro et al., 2016), tomato (Monteiro et al., 2018), desert rose (Monteiro et al., 2019), Brazilian chili pepper (Monteiro et al., 2022) and now collard greens.

The efficiency of this substrate (OrganoAmazon® + PuroHumus®) for producing collard green seedlings is due to the increase in the content of some nutrients compared to the other substrates (Table 1), especially in the amount of nitrogen (81.1 $\text{cmol}_c\ \text{dm}^{-3}$), phosphorus (1.0 $\text{cmol}_c\ \text{dm}^{-3}$), potassium (2.0 $\text{cmol}_c\ \text{dm}^{-3}$), magnesium (0.7 $\text{cmol}_c\ \text{dm}^{-3}$), boron (7.9 $\text{cmol}_c\ \text{dm}^{-3}$) and manganese (1.1 $\text{cmol}_c\ \text{dm}^{-3}$), which also resulted in the highest electrical conductivity observed (0.69 dS cm^{-1}). Therefore, the study highlighted the nutrients that contributed most to the satisfactory growth of the collard green seedlings.

No significant effect from the treatments was found in the analysis of the chlorophyll content of the plants (Figure 1), indicating that the environments associated with the substrates did not affect the amounts of chlorophyll a and b in the collard green seedlings, even with variations in the levels of radiation and temperature in the seedling production environments.

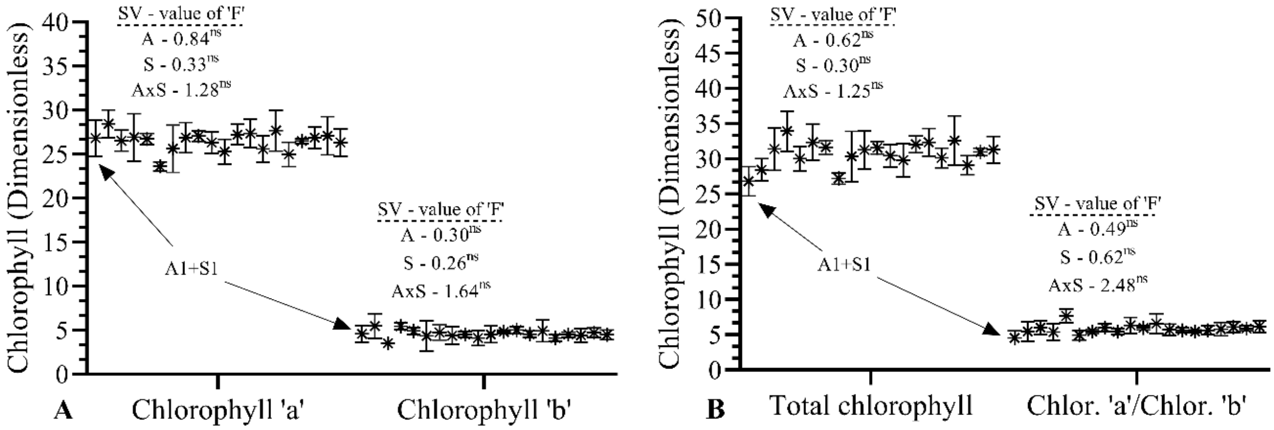

Figure 1. Chlorophyll analysis of collard green seedlings (*Brassica oleracea* var. acephala) subjected to different environments and substrates in a tropical climate.

PCA was used to determine the relationship between the treatments tested and the growth variables, and how they affect the qualitative analysis of seedling development (Figure 2). Together, PC1+PC2 explain 79.2% of the variation in the data. The treatments from the best environments (A1 and A4) and substrates (S2 and S4) grouped positively with the quantitative and qualitative growth variables of the seedlings in the first principal component (PC1). The study also showed the close relationship between the A4+S2, A1+S2, and A1+S4 treatments and the variables TDM, DQI, and RDM (CP2), which were the most effective variables in determining the best treatments for producing cabbage seedlings. The DQI, a qualitative variable that indicates the vigorous growth of the seedlings, was mainly affected by the increase in RDS and TDM of the collard green seedlings.

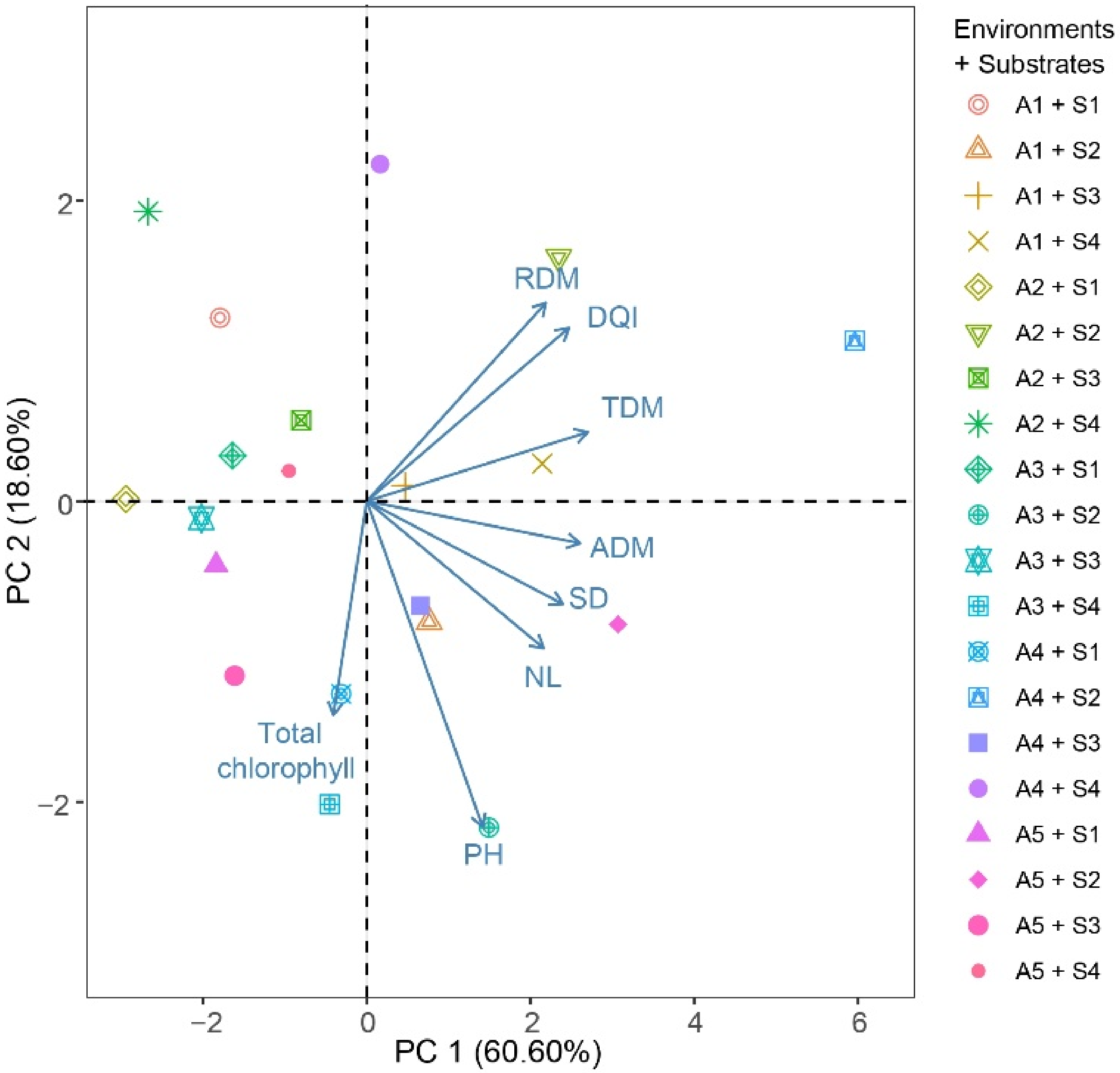

Figure 2. Principal component (PC) analysis for the vegetative variables of collard green seedlings (*Brassica oleracea* var. acephala) subjected to different environments and substrates in a tropical climate.

The literature on the use of red-colored photo-converting mesh nets in the production of seedlings of vegetable species, especially collards, remains scarce. However, some studies indicate their use for vegetable production (Stamps, 2009; Henrique et al., 2011; Sakazaki et al., 2019). Nevertheless, the use of this kind of net in tropical climates should be avoided if the microclimate of the production environment is not controlled. Likewise, we recommend that available commercial substrates be tested before use in the commercial production of collard green seedlings.

Conclusions

The combined use of silver-colored photo-converting mesh nets with 35% shading (silver 35% Chromatinet®) and a substrate formulated with OrganoAmazon® + PuroHumus® (1:1 v/v) favors the production of collard green seedlings in tropical climate conditions. The substrate formulated with OrganoAmazon® + PuroHumus® + soil + manure + CAC (1:1 v/v) is an alternative for producing collard green seedlings. Moreover, an agricultural greenhouse, combined with efficient substrates (S2 and S4), also favored the production of collard green seedlings. The environments with the red Chromatinet® net, regardless of the level of shading, and the commercial OrganoAmazon® substrate used in isolation do not favor the production of collard green seedlings in tropical climate conditions.

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