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CROP PRODUCTION

# Postharvest indices of radish and coriander in intercropped systems under green manure and population densities

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**ABSTRACT.** The objective of this work was to estimate the postharvest quality indices of radish and coriander products in an intercropping system based on different equitable amounts of hairy woodrose (*Merremia aegyptia* L.) and roostertree (*Calotropis procera* (Ait.) R. Br) biomass in two cropping seasons in a semi-arid environment. The experiment was set up in completely randomized blocks with treatments arranged in a 4 × 4 factorial scheme, with 4 replications. The first factor consisted of equitable amounts of biomass mixtures of hairy woodrose and roostertree at doses of 20, 35, 50, and 65 t $ha^{-1}$ on a dry basis, and the second factor of coriander population densities of 400, 600, 800, and 1,000 thousand plants $ha^{-1}$, intercropped with 500 thousand plants $ha^{-1}$ of radish. The characteristics evaluated in both crops were pH, soluble solids (SS), titratable acidity (TA), SS/TA ratio, total soluble sugars (TSS) and vitamin C content (vitamin C), and the chlorophyll *a* and *b*, total chlorophyll, and carotenoid contents were also evaluated in coriander. Fertilization with green manures *M. aegyptia* and *C. procera* increased the radish postharvest indices, SS, TA, and TSS, reaching maximum values in the biomass amounts of 39.35, 20, and 40.65 t $ha^{-1}$, respectively, and improved the quality of radish roots grown in intercropping with coriander. This practice with these green fertilizers promoted improvements in the quality of coriander pigments after intercropping with radish, which was expressed as increases in chlorophyll *a* and *b*, total chlorophyll, and carotenoid contents in the biomass amounts of 43, 53, 43, and 65 t $ha^{-1}$, respectively.

**Keywords:** *Raphanus sativus*; *Coriandrum sativum*; product quality; organic fertilization; planting densities.

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## Introduction

The intercropping of tuberous vegetables with leafy crops has increased in semi-arid environments, as they are considered companion plants, as they mutually help each other utilize environmental resources (Guerra et al., 2022a; Rabelo et al., 2019; Grangeiro et al., 2008). Among these types of crops is the intercropping of radish (*Raphanus sativus* L.) and coriander (*Coriandrum sativum* L.), in which radish is a tuberous vegetable with great consumption demand, mainly due to its nutritional quality (Araújo et al., 2020), as a source of vitamins A, complex B, and C, iron, folic acid, nicotinic acid, potassium, dietary fiber, thiamine, and riboflavin, and low caloric content (Filgueira, 2013; Oliveira et al., 2010). It is also rich in natural bioactive compounds, anthocyanins and secondary metabolites, which have anticancer and antioxidant properties (Manivannan et al., 2019), indicating greater quality. Coriander is a leafy vegetable rich in vitamins A, complex B and C and a source of calcium and iron. Its consumption is associated with its use as a medicinal plant and mainly in cooking as a condiment, especially in the north and northeast regions of Brazil (Alves et al., 2020; Filgueira, 2013).

Radish and coriander are vegetables with short cycles and nutrient demands, and the quality of their products can be compromised by factors such as the cultivation system, fertilization management (involving types and quantities of fertilizers used) and plant population density of component crops of the system (Sousa et al., 2022; Araújo et al., 2020). Nutritional disorders trigger changes in the plant's metabolism, modifying physiology, morphology and, mainly, biochemical relationships, resulting in the suppression of plant growth and the formation of isoporized roots (tasteless and spongy roots) and cracked roots in radish, and affecting its postharvest quality (Silva et al., 2017a; Taiz et al., 2017).

The appearance, texture, flavor and food safety of the vegetables are physicochemical and aesthetic attributes used in quality assessment, which determine the degree of acceptance of vegetables by the final consumer (Chitarra & Chitarra, 2005). These attributes are related to titratable acidity, hydrogen ionic potential, vitamin C content and soluble solids, which are correlated with the sugar content (Valero & Serrano, 2010).

The nutrient availability from green manure together with adequate management of population density of one of the crops in the intercropping system can become an alternative for vegetable production with good postharvest product quality. The practice of green manuring promotes the optimization of cultivation system conditions, ensuring satisfactory levels of nutrients and conditions favorable to plant growth and root development (Silva et al., 2017a) and thus contributing to the production of more healthy foods without added pesticides (Silva et al., 2021). In the Caatinga biome, spontaneous species, such as hairy woodrose (*M. aegyptia*) and roostertree (*C. procera*), are used as green manure and have improved the postharvest quality of tuberous and leafy vegetables in intercropping systems (Lino et al., 2023; Guerra et al., 2022b).

Evaluating the postharvest indices of beet roots intercropped with lettuce under green manure in different equitable amounts of *M. aegyptia* and *C. procera* biomass (20, 35, 50 and 65 t $ha^{-1}$ on a dry basis) with different lettuce population densities (150, 200, 250 and 300 thousand plants $ha^{-1}$) in two cropping seasons in a semi-arid environment, Guerra et al. (2022b) observed that the lettuce crop presented the best postharvest indices when subjected to fertilization with a quantity of *M. aegyptia* and *C. procera* biomass of 20 t $ha^{-1}$ in lettuce population densities between 203 and 300 thousand plants $ha^{-1}$. Beet cultivation achieved the best indices when fertilized with green manure quantities between 20 and 55 t $ha^{-1}$ and with lettuce population densities of 150 – 300 thousand plants $ha^{-1}$. Lino et al. (2023) evaluated the postharvest indices of arugula leaves and beetroot roots in an intercropping system under a biomass mixture of different green manures in diverse population densities of arugula in two cropping seasons in a semi-arid environment and observed that arugula presented the best postharvest indices when fertilized at green manure biomass doses of 20, 20, and 65 t $ha^{-1}$ in the population density of 1,000,000 plants $ha^{-1}$. The beet crop showed the best post-harvest indices for TA, pH, and TSS using green manures biomass doses of 65, 41, and 40 t $ha^{-1}$, respectively, in the arugula planting density of 1,000,000 plants $ha^{-1}$.

In this context, the objective of this work was to determine the postharvest indices of radish roots intercropped with coriander using green manure with different equitable amounts of *Merremia aegyptia* and *Calotropis procera* biomass and different coriander population densities in a semi-arid environment.

## Material and methods

### Characterization of the experimental areas and experimental design

The experiments were conducted under field conditions during the cropping seasons from October to December 2021 and September to November 2022 at the 'Rafael Fernandes' Experimental Farm belonging to the *Universidade Federal Rural do Semi-Árido* (UFERSA), which located in the Lagoinha District, 20 km from the municipality of Mossoró, Rio Grande do Norte State, Brazil, with geographic coordinates 5°03'37" south latitude, 37°23'50" west longitude and approximate 80 m altitude.

The region's climate, according to Köppen's classification is 'BShw', that is, dry and very hot, with two distinct seasons—a dry season from June to January and a rainy season from February to May (Beck et al., 2018). The average meteorological data recorded for the period of crop development and growth are presented in Table 1 and Figure 1 (Labimc, 2022).

The soils in the experimental areas are classified as dystrophic red-yellow Argisol with a sandy loam texture (Santos et al., 2018). To evaluate soil fertility, simple soil samples were collected in the 0–20 cm layer, transformed into a composite sample for analysis of the chemical characteristics at the Water, Soil and Plant Tissue Analysis Laboratory of the Federal Institute of Education, Science and Technology of Ceará – Limoeiro do Norte Campus. The chemical attributes are presented in Table 2.

**Table 1.** Average meteorological data for minimum, means and maximum temperatures, relative humidity, solar radiation and wind speed during the development and growth period of radish intercropped with coriander in the 2021 and 2022 cropping seasons.

| Cropping seasons | Temperature (°C) | | | Relative humidity (%) | Solar radiation (MJ $m^{-2}$) | Wind speed (m $s^{-1}$) |
|---|---|---|---|---|---|---|
| | Minimum | Mean | Maximum | | | |
| 2021 | 23.32 | 29.90 | 36.48 | 67.60 | 274.80 | 2.80 |
| 2022 | 22.53 | 29.38 | 36.23 | 62.87 | 256.41 | 1.71 |

Source: Labimc (2022).

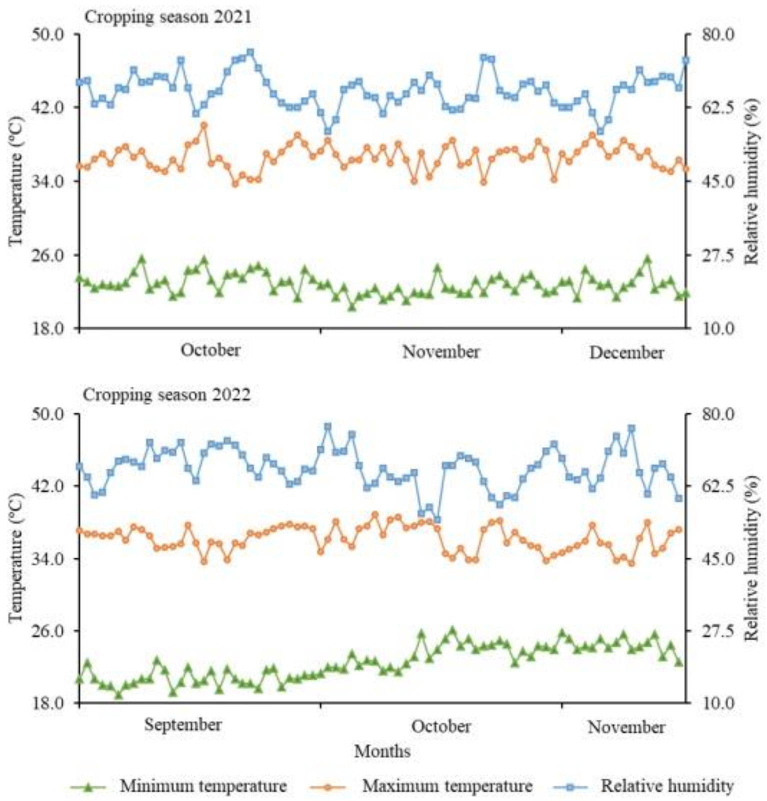


**Figure 1.** Daily averages of temperature and air relative humidity during the radish and coriander cropping seasons of 2021 and 2022.

**Table 2**. Chemical analyses of the soils in the areas where the experiments were implemented before incorporation of green manure in the cropping seasons of 2021 and 2022.

| Soils | C | OM | pH | EC | P | K | Ca | Mg | Na | Cu | Fe | Mn | Zn | B |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | ------ g kg$^{-1}$ ----- | | ($H_2O$) | dS m$^{-1}$ | mg dm$^{-3}$ | | --------------------mmol$_c$ dm$^{-3}$ ---------------------- | | | | | | | |
| 1 | 7.92 | 12.97 | 6.60 | 0.56 | 32.00 | 2.59 | 23.70 | 6.50 | 2.30 | 0.30 | 4.80 | 6.10 | 2.70 | 0.50 |
| 2 | 7.20 | 12.41 | 7.10 | 0.19 | 7.00 | 1.16 | 20.10 | 6.10 | 0.43 | 0.20 | 6.80 | 12.70 | 1.70 | 0.48 |

C: carbon; OM: organic matter; pH ($H_2O$): hydrogen ionic potential; EC: electrical conductivity; P: phosphorus; K: potassium; Ca: calcium; Mg: magnesium; Na: sodium; Cu: copper; Fe: iron; Mn: manganese; Zn: zinc; B: boron.

Both experiments were set up in a randomized complete block design with treatments arranged in a 4 × 4 factorial scheme, with 4 replications. The first factor consisted of equitable amounts of the mixtures of hairy woodrose (*M. aegyptia*) and roostertree (*C. procera*) biomass at doses of 20, 35, 50, and 65 t ha$^{-1}$ on a dry basis, and the second factor was the coriander population density with amounts of 400, 600, 800, and 1,000 thousand plants ha$^{-1}$, corresponding to 40, 60, 80, and 100% of the recommended density in a single crop (RDSC), intercropped with 500 thousand radish plants ha$^{-1}$, corresponding to 100% of the recommended density in single crop.

Radish–coriander intercropping was established in alternating strips in the proportion of 50% of the area cultivated with radish and 50% of the area cultivated with coriander. In each experimental plot, the alternating strips were made up of four rows flanked by two rows of coriander on one side and two rows of radish on the other side, which were used as borders. The total area of each plot was 2.88 m$^2$ (2.40 m × 1.20 m), with a useful area of 1.60 m$^2$ (1.60 × 1.00 m). The harvest area consisted of the two strips of central plants, excluding the first and last plants in each row of the strips, which were used as borders. In this cultivation system, the same population densities for radish in monocropping were used, with the following densities: 400, 600, 800, and 1,000 thousand plants ha$^{-1}$ (Figure 2).

The spacing between crop rows in the strips was 0.20 m, and within the coriander rows the spacing between holes with two plants varied according to the population densities studied, namely 0.100, 0.075, 0.060, and 0.050 m, providing 64, 96, 128, and 160 plants per harvest area, respectively, corresponding to population densities of 400, 600, 800, and 1,000 thousand plants ha$^{-1}$. The spacing between the radish holes was 0.05 m, with 1 plant per hole.

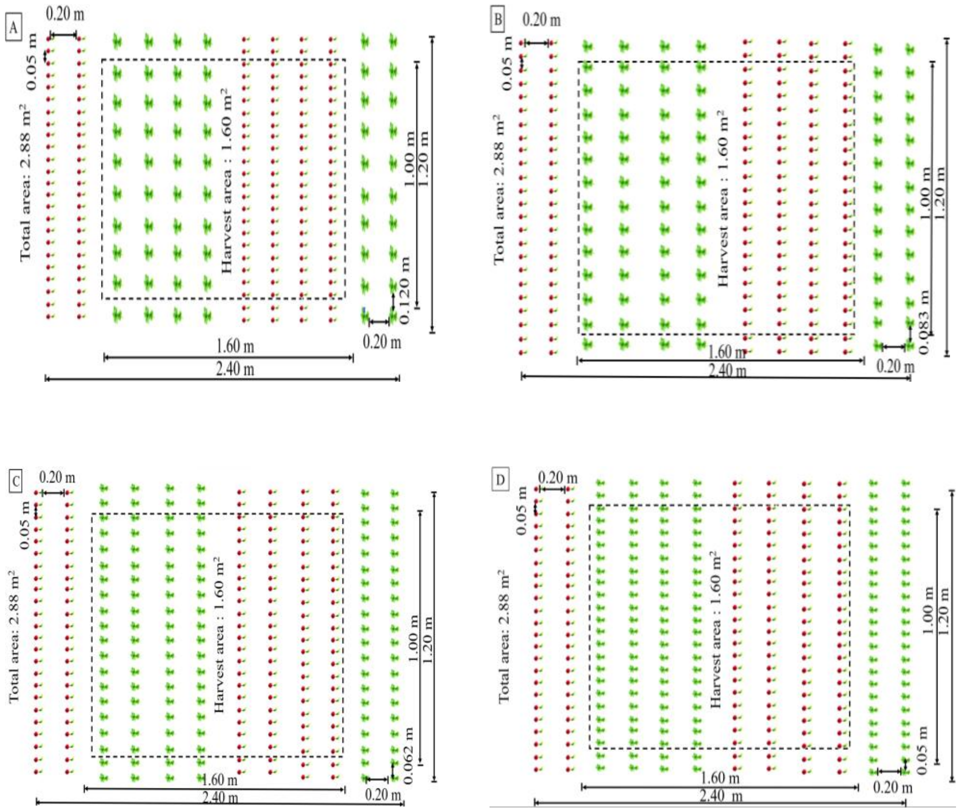


**Figure 2.** Representation of the intercropped experimental plots of radish and coriander fertilized with equitable amounts of *M. aegyptia* and *C. procera* biomass at population densities of 400 (A), 600 (B), 800 (C), and 1,000 (D) thousand plants $ha^{-1}$ of coriander intercropped with 500 thousand plants $ha^{-1}$ of radish.

## Installation and conduction of the experiments

Soil preparation consisted of mechanical cleaning of the experimental areas with the aid of a tractor with an attached plow and mechanized lifting of the beds with a rotary digger. Subsequently, pre-planting solarization was carried out with transparent plastic, such as Vulca Brilho Bril Flex (30 microns), for 30 days to combat phytopathogenic microorganisms present in the soil that could affect crop productivity (Silva et al., 2017b). After the solarization period, the material used as green fertilizer was incorporated on October 13, 2021, and October 5, 2022, using hoes. From incorporation to crop harvesting, microsprinkler irrigation was carried out daily in two shifts (morning and afternoon). The amount of water supplied was determined by the values of the radish cultivation coefficient (initial Kc = 0.45; average Kc = 0.95; and final Kc = 0.65), obtained by Alves et al. (2018) in the Arapiraca region, with irrigation depths, when necessary, of approximately 8 mm $day^{-1}$. The green manures used to fertilize coriander and radish in intercropping were made from spontaneous Caatinga species, hairy woodrose (*Merremia aegyptia*) and roostertree (*Calotropis procera*), collected in different areas of the municipality of Mossoró, Rio Grande do Norte State, Brazil. These materials were collected before the beginning of flowering, and after collection, the plants were crushed in a forager to obtain particles measuring 2 – 3 cm, which were dehydrated at room temperature until reaching 10% humidity and subsequently subjected to laboratory analysis. The chemical compositions obtained in the 2021 and 2022 cropping seasons are presented in Table 3.

The radish cultivar ‘Crimson Gigante’ and coriander cultivar ‘Verdão’ were used, and both crops were sown on November 3, 2021, in the first cropping season and on October 27, 2022, in the second season, in pits of approximately 3 cm deep with 2 – 3 seeds per hole and covered with organic substrate. At 7 days after sowing (DAS), radish was thinned, leaving 1 plant per hole. The coriander was thinned at 15 DAS, leaving two plants per hole to reach the desired density. Weed control was carried out manually and whenever necessary. No chemical pest or disease control methods were used. In the first year of cultivation, coriander was harvested at 30 DAS, and radish was harvested at 34 DAS. In the second year of cultivation, coriander was harvested at 33 DAS, while radish was harvested at 30 DAS.

**Table 3.** Chemical analyses of the macronutrients present in the dry biomass of green manures *M. aegyptia* and *C. procera* in the two cropping seasons.

| Green manure | Green manure macronutrient content (g kg$^{-1}$) | | | | | |
|---|---|---|---|---|---|---|
| | N* | P | K | Mg | Ca | C:N |
| Cropping season 2021 | | | | | | |
| *M. aegyptia* | 20.56 | 2.83 | 37.08 | 7.05 | 19.35 | 25:1 |
| *C. procera* | 15.14 | 2.96 | 24.84 | 9.20 | 17.00 | 27:1 |
| Cropping season 2022 | | | | | | |
| *M. aegyptia* | 18.55 | 1.89 | 38.68 | 7.03 | 9.30 | 25:1 |
| *C. procera* | 14.09 | 1.54 | 22.72 | 13.50 | 16.30 | 27:1 |

*N: nitrogen; P: phosphorus; K: potassium; Ca: calcium; Mg: magnesium and C/N: carbon/nitrogen ratio.

## Evaluated characteristics

Postharvest quality characteristics were determined in the shoots of coriander plants and in radish roots in a sample of 20 plants randomly collected in the harvest area of each plot. Plants were sent to the Post-Harvest Laboratory of the Semi-Arid Plant Production Center at UFERSA, where they were washed in running water and dried at room temperature. For radish, the roots classified as commercial were analyzed to obtain the juice from the crop, where they were crushed using a Juiceman 3 in 1 JM3000 Processor Juice Extractor, until 50 mL of juice was obtained, which was subsequently fractionated for each analysis. In both cultures, analyses were carried out to determine the following: hydrogen ionic potential (pH), carried out using a model 016A bench pH meter; total soluble solids (SS) content, determined using a portable digital refractometer model 104-D with automatic temperature correction, using two drops of juice, and the results expressed in °Brix; and titratable acidity (TA), carried out by titration using an aliquot of 1 mL of juice diluted in 49 mL of distilled water, to which 2 drops of 1% phenolphthalein were added, and for titration, a standardized solution of hydroxide was used. A solution of 0.99 N sodium (NaOH) until reaching the turning point (light pink). The results were expressed as % malic acid, as calculated using Equation 1.

$$Malic\ acid\ \% = \frac{10\ x\ acid\ factor\ x\ NaOH\ factor\ x\ NaOH\ spent\ (ml)}{sample\ weight\ (g)} \quad (1)$$

The soluble solids/titratable acidity ratio (SS/AT ratio) was obtained as an indication of the fruit flavor and expressed in °Brix/% malic acid (Association Official Analytical Chemists [AOAC], 2012). The ascorbic acid (vitamin C) content was quantified by titration according to the methodology proposed by Strohecker and Henning (1967). A 1 mL aliquot of the juice was added to a volumetric flask and made up to 100 mL with 0.5% oxalic acid. A volume of 5 mL of this solution was removed and diluted in 45 mL of distilled water. Titration was carried out to the turning point (light pink) with previously standardized Tillman's solution (2,6-dichlorophenolindophenol sodium, 0.2%), and the result were expressed in mg of ascorbic acid 100 g$^{-1}$ of juice, as calculated using Equations 2, 3 and 4.

$$Material\ mass\ (g) = \frac{Sample\ weight\ (g) \times aliquot\ (ml)}{diluition\ (ml)} \quad (2)$$

$$Concentration\ (mg) \frac{Volume\ spent\ in\ the\ titration\ (ml) \times Tilman\ factor\ (\mu g)}{1\ ml} + 1000 \quad (3)$$

$$Vitamin\ C\ (mg\ 100\ g^{-1}) = \left(\frac{Concentration\ (mg) \times 100}{material\ mass\ (g)}\right) \quad (4)$$

The content of total soluble sugars (TSS) was determined using the anthrone method (anthrone solution ($C_{14}H_{10}O$) + sulfuric acid ($H_2SO_4$)) proposed by Yemn and Willis (1954). For determination, a 1 mL aliquot of the broth was diluted in distilled water in a volumetric flask, up to a volume of 100 mL, and 50 µL of this solution was sampled, which was added to a test tube containing 950 µL of distilled water. Then, the tubes were placed in an ice bath, where they remained while 2 mL of the anthrone solution was added, only being removed to shake the tubes. Afterwards, they were placed in a boiling water bath for 8 min. and cooled in ice water. To obtain the standard curve, a glucose solution was used at concentrations of 0, 5, 10, 15, 20, 25, 30, and 35 µg L$^{-1}$. The absorbance was evaluated on a spectrophotometer at 620 nm, and the results were expressed in % and calculated using equations 5 - 7.

$$Concentration = \frac{Absorbance\ \pm b}{a} \quad (5)$$

where a and b refer to the glucose standard curve.

$$Material\ mass = \frac{Sample\ weight\ (g) \times aliquot\ (\mu g)}{diluition\ (ml)} \quad (6)$$

$$TSS\% = \left(\frac{Cocentration \times 100}{material\ mass\ (\mu g)}\right) \quad (7)$$

In addition to these evaluated characteristics, the levels of chlorophyll *a* (λ = 663 nm), chlorophyll *b* (λ = 646 nm), total chlorophyll pigments, and total carotenoids (λ = 470 nm) (Lichtenthaler, 1987) in the coriander were determined using equations 8 – 11:

$$Chlorophyll\ a = [(12.21 \times A663) - (2,81 \times A646)] \quad (8)$$

$$Chlorophyll\ b = [(20.13 \times A646) - (5.03 \times A663)] \quad (9)$$

$$Total\ chlorophyll = [(17.3 \times A646) + (7.18 \times A663)] \quad (10)$$

$$Total\ carotenoids = (1000 \times A470 - 1.82 \times Cl\ a - 85.02 \times Cl\ b)/198 \quad (11)$$

where: A is the absorbance at the indicated wavelength and the content of each characteristic expressed in mg of pigment per g of fresh tissue (mg $g^{-1}$).

### Data analysis

Univariate analysis of variance for a randomized block design in a factorial scheme was used to evaluate the postharvest characteristics of coriander leaves and commercial radish roots. Due to the homogeneity of variances between cropping seasons, these characteristics were averaged between cropping seasons (Pimentel-Gomes, 2009). Then, regression analysis was carried out for all of these postharvest characteristics. A response surface adjustment procedure was carried out for each characteristic as a function of the equitable amounts of *M. aegyptia* and *C. procera* biomass incorporated into the soil and the coriander population densities using Table Curve 3D software (Systat Software, 2021).

## Results and discussion

### Radish culture

The analysis of variance and regression of postharvest characteristics evaluated in radish roots, namely pH, SS, TA, SS/TA ratio, TSS, and vitamin C content, are presented in Table 4. No significant interactions were observed between the studied treatment factors (equitable amounts of *M. aegyptia* and *C. procera* biomass and coriander population densities) for any of the evaluated characteristics (Table 4).

**Table 4.** F values for pH, soluble solids (SS), titratable acidity (TA), SS/TA ratio, total soluble sugars (TSS) and vitamin C content in radish roots intercropped with coriander in different equitable biomass amounts of *M. aegyptia* and *C. procera* incorporated into the soil and coriander population densities.

| Sources of variation | DF | pH | Soluble solids | Titratable acidity | SS/TA ratio | Total soluble sugars | Vitamin C content |
|---|---|---|---|---|---|---|---|
| Blocks | 3 | $1.17^{ns}$ | $1.81^{ns}$ | $2.04^{ns}$ | $2.37^{ns}$ | $1.03^{ns}$ | $2.48^{ns}$ |
| Amounts of *M. aegyptia* and *C. procera* biomass (A) | 3 | $3.60^{*}$ | $7.04^{**}$ | $0.99^{ns}$ | $0.68^{ns}$ | $3.22^{*}$ | $20.99^{**}$ |
| Population densities of lettuce (D) | 3 | $1.24^{ns}$ | $5.76^{**}$ | $12.53^{**}$ | $10.67^{**}$ | $12.99^{**}$ | $140.57^{**}$ |
| A × D | 9 | $0.59^{ns}$ | $0.64^{ns}$ | $0.21^{ns}$ | $0.21^{ns}$ | $1.23^{ns}$ | $0.25^{ns}$ |
| Regression (Response surface) | | $12.69^{**}$ | $9.41^{**}$ | $46.61^{**}$ | $26.94^{**}$ | $14.92^{**}$ | $29.42^{**}$ |
| Reg. Error | | 0.00187 | 0.00727 | 0.00010 | 0.75341 | 0.00639 | 16.24159 |
| CV (%) | | 2.03 | 3.85 | 15.95 | 12.21 | 13.98 | 5.44 |

*p < 0.05; ** p < 0.01; ns p > 0.05; DF – Degree of freedom.

However, the response surface was adjusted for all these radish postharvest characteristics as a function of the treatment factors in radish–coriander intercropping, where maximum values of 4.43 °Brix for SS, 0.25% malic acid for TA and 1.35% for TSS were achieved with equitable amounts of green manure biomass of 39.35, 20, and 40.65 t $ha^{-1}$, respectively, and a coriander population density of 1,000 thousand plants $ha^{-1}$ (Figure 3B, C, and E). The maximum pH value of 6.36, SS/TA ratio of 23.37 °Brix/% malic acid and vitamin C content of 79.17 mg 100 $g^{-1}$ were obtained with 65 t $ha^{-1}$ green manure at coriander densities of 830, 555, and 601 thousand plants $ha^{-1}$ (Figure 3A, D, and F).

Factors nutritional management of plants and population densities of component crops in intercropping interfere with the production of sugars and acids in the agricultural products produced in the cultivation system (Batista et al., 2016; Portela et al., 2012). Thus, SS, TA and TSS of radish were more affected by a higher coriander population density of 1,000 thousand coriander plants $ha^{-1}$ (Figure 3B, C, and E). These results partially agree with those obtained by Lino et al. (2023) when intercropping arugula and beetroot with different amounts of green fertilizers and arugula population densities. They found the same behavior in the TSS content of beetroot roots at the highest population density of 1,000 thousand arugula plants ha$^{-1}$ with 40 t ha$^{-1}$ green fertilizers incorporated into the soil. The behavior of TSS is similar to that observed in SS, since sugars constitute 80 - 90% of the compounds in TSS (Costa et al., 2017).

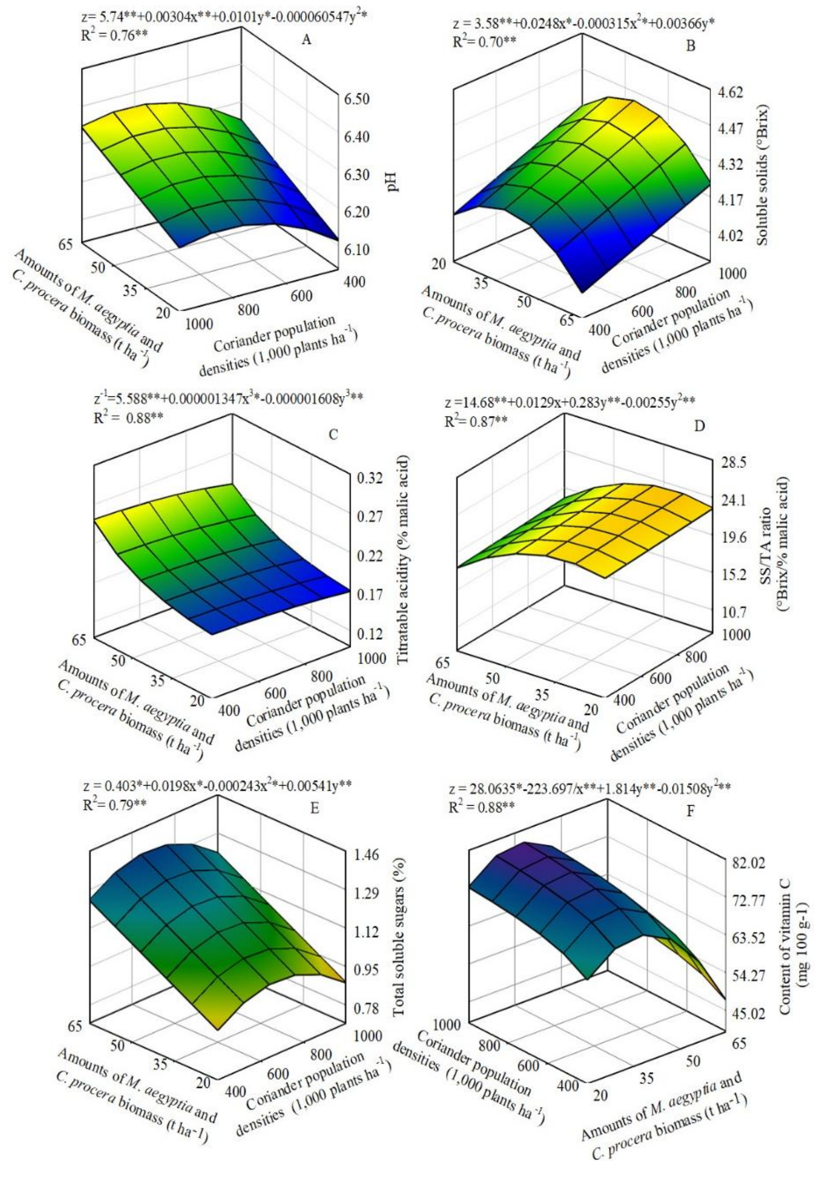


**Figure 3.** pH (A), soluble solids (B), titratable acidity (C), SS/TA ratio (D), total soluble sugars (E), and vitamin C content (F) of radish intercropped with coriander with different combinations of equitable amounts of *M. aegyptia* and *C. procera* biomass and coriander population densities.

The results observed in the research may be related to the potassium (K) and nitrogen (N) contents made available by green manure throughout the cycle, as K participates in the formation and translocation of sugars and N increases the sucrose concentration, acting on the amino acid composition (Taiz et al., 2017), thus influencing the accumulation of sugars and, consequently, increasing °Brix. For vitamin C in radish, a maximum content was obtained (79.17 mg 100 g$^{-1}$) in this study when radish was fertilized with 65 t ha$^{-1}$ of green fertilizers, presenting around 8 times the value determined in the composition of vitamin C (9.6 mg) from the vegetables in 100 g of edible product, as determined by NEPA/UNICAMP (2011), thus providing a product of high nutritional quality. This vitamin C content was also higher than the maximum value obtained by Soares et al. (2020) for radish cultivation in a single crop fertilized with K and different N sources. The guideline for humans is to ingest 75 mg of vitamin C daily. Therefore, radish cultivated with green manure can improve vitamin C levels by proximate composition.

## Coriander culture

The variance and regression analyses of the evaluated postharvest characteristics in the coriander plant shoots intercropped with radish are presented in Table 5. No significant interactions were observed between the studied treatment factors (equitable amounts of *M. aegyptia* and *C. procera* biomass and coriander population densities) in any characteristic evaluated (Table 5).

**Table 5.** F values for pH, soluble solids (SS), titratable acidity (TA), SS/TA ratio, total soluble sugars (TSS), and vitamin C content in coriander intercropped with radish in different equitable biomass amounts of *M. aegyptia* and *C. procera* incorporated into the soil and coriander population densities.

| Sources of variation | DF | pH | Soluble solids | Titratable acidity | SS/TA ratio | Total soluble sugars | Vitamin C content |
|---|---|---|---|---|---|---|---|
| Blocks | 3 | 1.70$^{ns}$ | 1.99$^{ns}$ | 0.19$^{ns}$ | 0.20$^{ns}$ | 0.29 $^{ns}$ | 0.93$^{ns}$ |
| Amounts of *M. aegyptia* and *C. procera* biomass (A) | 3 | 6.70$^{**}$ | 1.68 $^{ns}$ | 3.23$^{*}$ | 4.45$^{**}$ | 3.04$^{*}$ | 2.71$^{ns}$ |
| Population densities of lettuce (D) | 3 | 1.83$^{ns}$ | 7.95$^{**}$ | 9.01$^{**}$ | 9.84$^{**}$ | 18.37$^{**}$ | 3.82$^{*}$ |
| A × D | 9 | 0.18 $^{ns}$ | 0.94 $^{ns}$ | 1.10$^{ns}$ | 0.49 $^{ns}$ | 1.02$^{ns}$ | 0.74$^{ns}$ |
| Regression (Response surface) | | 48.64$^{**}$ | 8.74$^{**}$ | 7.43$^{**}$ | 13.44$^{**}$ | 29.52$^{**}$ | 13.67$^{**}$ |
| Reg. Error | | 0.00060 | 0.04176 | 0.00017 | 6.01211 | 0.00282 | 1.19530 |
| CV (%) | | 1.47 | 7.89 | 15.62 | 14.03 | 13.66 | 8.69 |

*p < 0.05; ** p < 0.01; ns p > 0.05; DF – Degree of freedom.

However, the response surface was adjusted for all postharvest characteristics of coriander as a function of treatment factors in radish–coriander intercropping. The maximum values of 5.70 °Brix for SS, 41.08 °Brix/% malic acid for SS/AT, 0.94% for TSS content and 33.84 mg 100 g$^{-1}$ for vitamin C content were achieved with equitable amounts of green manure biomass of 42.68, 65, 65, and 65 t ha$^{-1}$, respectively, with a coriander population density of 1,000 thousand plants ha$^{-1}$ (Figure 4B, D, and F). The maximum pH value of 6.91 and TA of 0.19% malic acid were obtained with 20 t ha$^{-1}$ green manure at densities of 401 and 826 thousand coriander plants ha$^{-1}$ (Figure 4A and C).

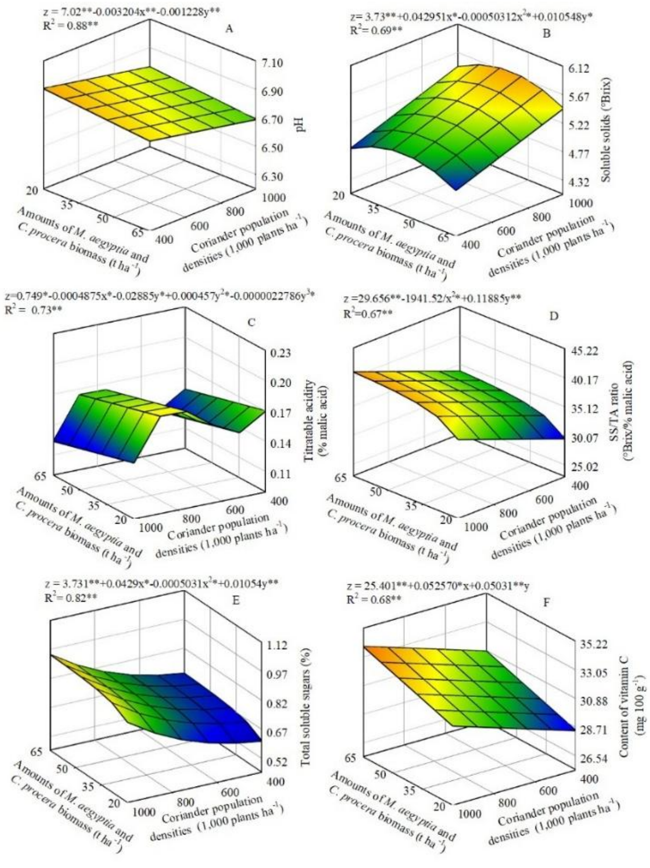


**Figure 4.** pH (A), soluble solids (B), titratable acidity (C), SS/TA ratio (D), total soluble sugars (E), and vitamin C content (F) of coriander intercropped with radish with different combinations of equitable amounts of *M. aegyptia* and *C. procera* biomass and coriander population densities.

SS, SS/TA ratio, TSS, and vitamin C content were most affected by coriander population densities, reaching the maximum value at the highest population density of 1,000 thousand coriander plants ha$^{-1}$, when the amounts of incorporated green manure varied from 42 to 65 t ha$^{-1}$ (Figure 4B, D, and F).

According to Chitarra and Chitarra (2005), the decrease in acidity increases the flavor of fruits and vegetables. In this research, the pH of coriander decreased with the increase in the amount of green manure added to the soil and with an increase in the coriander population density. This decrease in the pH is probably due to the intense competition promoted by the high coriander population density of 1,000 thousand plants ha$^{-1}$. SS is one of the indices used to evaluate the degree of sweetness of products, and its relationship with TA in the SS/TA ratio reflects the balance between sugars and organic acids, thus determining its flavor (Pacheco et al., 2021; Chitarra & Chitarra, 2005). The higher the SS/TA ratio, the greater the sweetness on the palate. For chlorophyll *a* and *b* pigments and coriander carotenoids, analysis of variance did not show a significant interaction between the studied treatment factors (Table 6).

**Table 6.** F values for chlorophyll *a*, chlorophyll *b*, total chlorophyll, and carotenoids in coriander intercropped with radish with different equitable amounts of *M. aegyptia* and *C. procera* biomass incorporated into the soil and diverse coriander population densities.

| Sources of variation | DF | Chlorophyll *a* | Chlorophyll *b* | Total chlorophyll | Carotenoid content |
|---|---|---|---|---|---|
| Blocks | 3 | $0.55^{ns}$ | $0.37^{ns}$ | $1.99^{ns}$ | $1.24^{ns}$ |
| Amounts of *M. aegyptia* and *C. procera* biomass (A) | 3 | $2.89^{*}$ | $5.63^{**}$ | $6.85^{**}$ | $2.03^{ns}$ |
| Population densities of lettuce (D) | 3 | $4.63^{**}$ | $3.96^{*}$ | $10.34^{**}$ | $2.31^{ns}$ |
| A × D | 9 | $0.26^{ns}$ | $0.45^{ns}$ | $0.50^{ns}$ | $0.25^{ns}$ |
| Regression (Response surface) | | $7.93^{**}$ | $8.43^{**}$ | $21.09^{**}$ | $54.81^{**}$ |
| Reg. Error | | 0.01708 | 0.00263 | 0.02074 | 0.05935 |
| CV (%) | | 20.48 | 24.27 | 13.76 | 26.53 |

$^{*}$ $p < 0.05$; $^{**}$ = $p < 0.01$; ns = $p > 0.05$; DF – Degree of freedom.

The response surface was adjusted for all of these pigments, reaching maximum values of 44.19, 3.80, 47.64, and 1.60 mg g$^{-1}$ in the contents of chlorophyll *a* and *b*, total chlorophyll, and carotenoids, achieved with equitable amounts of green manure biomass of 43, 53, 43, and 65 t ha$^{-1}$ and coriander population densities of 726, 733, 726, and 701 thousand plants ha$^{-1}$ (Figure 5A, B, C, and D).

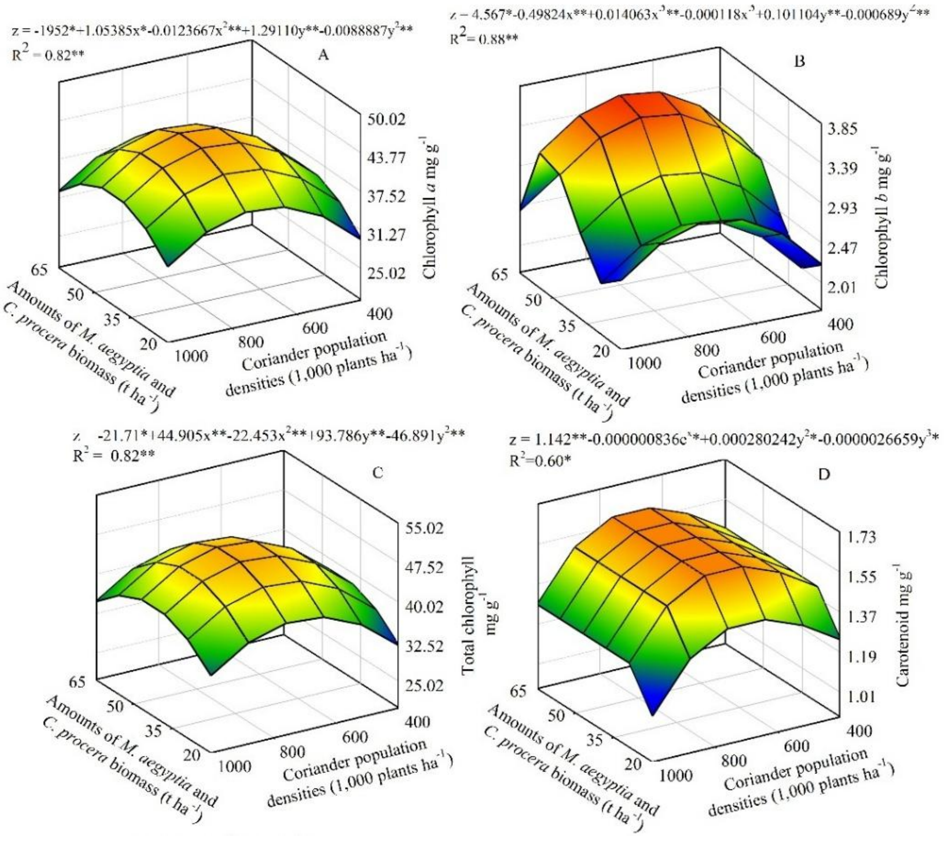


**Figure 5.** Chlorophyll *a* (A), chlorophyll *b* (B), total chlorophyll (C), and carotenoid (D) content of coriander intercropped with radish with different combinations of equitable amounts of *M. aegyptia* and *C. procera* biomass and coriander population densities.

Evaluating the yield and growth of coriander in single cultivation as a function of doses of organic fertilizer (bovine manure), Cerqueira et al. (2019) observed significant coriander growth, and the total chlorophyll content increased quadratically up to a dose of 4.76 L $m^{-2}$ of manure, with a maximum value of 34.9 mg $g^{-1}$. This maximum content is below that obtained in this coriander–radish intercropping study when the crops were fertilized with green manure, as the maximum value achieved was 47.64 mg $g^{-1}$. According to Taiz and Zeiger (2004), chlorophyll is the pigment used to carry out photochemistry (the first stage of the photosynthetic process), while the other pigments help in the absorption of light and the transfer of radiant energy to the reaction centers, being so-called accessory pigments. The green intensity is a notable characteristic, especially in leafy vegetables (coriander), which the consumer evaluates when choosing bunches; that is, a greater brightness and intensity of green is associated with a fresh product and better quality, increasing acceptance by the consumer and thus facilitating its commercialization. Bowman et al. (2002) found that the chlorophyll content in the leaves indirectly reflected the amount of N absorbed by the plants, explaining why green manure was significant for the total chlorophyll content. Lopes and Vieira (2018) evaluated leafy vegetables, coriander and parsley, in single cultivation and obtained carotenoid content values of 8.2 and 5.4 mg $g^{-1}$. The carotenoid content in coriander in this cultivation system was five times higher than that obtained in coriander–radish intercropping (1.60 mg $g^{-1}$). The synthesis of carotenoids is inversely related to that of chlorophyll. Therefore, the higher chlorophyll content obtained in coriander in the intercrop with radish may justify the lower carotenoid content in coriander in this system. Finally, given the results obtained in this study, it can be inferred that the organic production of radish and coriander vegetables in an intercropping system in a semi-arid environment increases the postharvest quality of these vegetables when using spontaneous species from the Caatinga biome, *M*, *aegyptia* and *C. procera*, as green fertilizers under adequate management of population density of the leafy crop.

## Conclusion

Fertilization with the green manures *M. aegyptia* and *C. procera* promoted increases in radish postharvest indices, SS, TA and TSS, reaching maximum values with biomass amounts of 39.35, 20, and 40.65 t $ha^{-1}$, respectively, demonstrating an improvement in the quality of radish roots when intercropped with coriander. This same practice with these green fertilizers also promoted improvements in the quality of coriander pigments, expressed by increases in chlorophyll *a* and *b*, total chlorophyll, and carotenoid contents with the biomass amounts of 43, 53, 43, and 65 t $ha^{-1}$, respectively.

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