Ciência e Agrotecnologia
SCIENCE AND AGROTECHNOLOGY

Ciência e Agrotecnologia, 47:e004423, 2023
http://dx.doi.org/10.1590/1413-7054202347004423

Agricultural Sciences
eISSN 1981-1829

Postharvest quality and coloration of radish roots under organic fertilization in a semi-arid environment

Qualidade pós-colheita e coloração de raízes de rabanete sob adubação orgânica em ambiente semiárido

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Received in March 14, 2023 and approved June 9, 2023

ABSTRACT

The postharvest quality and coloration of radish roots can be compromised by factors such as the type of cropping system and fertilization management. Therefore, the objective of this work was to estimate the postharvest quality indices and color parameters of radish roots in monocropping, as a function of different roostertree (*Calotropis procera*) biomass amounts, in two cropping seasons in a semi-arid environment. The experimental design used was randomized complete blocks with five treatments and five replications. The treatments consisted of different roostertree biomass amounts: 16, 29, 42, 55 and 68 t ha^{-1} on a dry basis, incorporated into the soil. In each block, two additional treatments were added, one without fertilization (control) and the other with mineral fertilizer, for comparison purposes with the maximum efficiency treatment. The radish cultivar planted was Crimson Gigante. The radish characteristics evaluated were: pH, soluble solids content (SS), titratable acidity (TA), SS/TA ratio, total soluble sugar content (TSS), vitamin C (CV) and anthocyanin (A) contents, and roots color parameters (L*, C* and h°). The maximum flavor efficiency (SS/TA) and the total soluble sugar content (TSS) were achieved with the incorporation into the soil of 47.24 and 25.27 t ha^{-1} roostertree biomass, respectively. Higher concentrations of bioactive compounds (CV and A) were obtained when incorporating 35.79 and 45.85 t ha^{-1} green manure biomass. The color parameters values (L*, C* and h°) in the red radish roots were achieved in the biomass amounts of 40.39, 53.14 and 52.71 t ha^{-1} of roostertree.

Index terms: *Raphanus sativus*; *Calotropis procera*; green manuring; post-harvest; food security.

RESUMO

A qualidade pós-colheita e a coloração das raízes do rabanete podem ser comprometidas por fatores como o tipo de sistema de cultivo e manejo da adubação. Portanto, o objetivo deste trabalho foi estimar os índices de qualidade pós-colheita e os parâmetros de cor de raízes de rabanete em monocultivo, em função de diferentes quantidades de biomassa de flor-de-seda (*Calotropis procera*), em duas estações de cultivo em ambiente semiárido. O delineamento experimental utilizado foi blocos ao acaso com cinco tratamentos e cinco repetições. Os tratamentos consistiram de diferentes quantidades de biomassa de flor-de-seda: 16, 29, 42, 55 e 68 t ha^{-1} em base seca, incorporadas ao solo. Em cada bloco foram adicionados dois tratamentos adicionais, um sem adubação (controle) e outro com adubação mineral, para fins de comparação com o tratamento de máxima eficiência. A cultivar de rabanete plantada foi a 'Crimson Gigante'. As características do rabanete avaliadas foram: pH, teor de sólidos solúveis totais (SS), acidez titulável (AT), relação SS/AT, teor de açúcares solúveis totais (AST), teores de vitamina C (VC) e antocianina (A) e os parâmetros de cor das raízes (L*, C* e h°). A máxima eficiência de sabor (SS/AT) e o teor de açúcares solúveis totais (AST) foram obtidos com a incorporação ao solo de 47,24 e 25,27 t ha^{-1} de biomassa de flor-de-seda, respectivamente. Maiores concentrações de compostos bioativos (VC e A) foram obtidas ao incorporar 35,79 e 45,85 t ha^{-1} de biomassa do adubo verde. Os valores dos parâmetros de cor (L*, C* e h°) nas raízes do rabanete vermelho foram alcançados nas quantidades de biomassa de 40,39, 53,14 e 52,71 t ha^{-1} de flor-de-seda.

Termos para indexação: *Raphanus sativus*; *Calotropis procera*; adubação verde; segurança alimentar.

INTRODUCTION

Radish (*Raphanus sativus* L.) is a vegetable crop that has shown high demand for consumption, mainly due to its nutritional quality (Araújo et al., 2020), being a source of vitamins A, complex B and C, iron, folic and nicotinic acid, potassium, dietary fiber, thiamine, riboflavin, with low caloric content (Filgueira, 2013;

Oliveira et al., 2010). In addition, the culture is rich in natural bioactive compounds, anthocyanin and secondary metabolites, which have anticancer and antioxidant properties (Manivannan et al., 2019), giving the vegetable crop greater quality.

In addition to nutritional quality, the appearance, texture, flavor and safety of the food are physical-chemical and aesthetic attributes used in the evaluation of quality, which determine the degree of acceptance of vegetables by the final consumer (Chitarra; Chitarra, 2005). These attributes are related to the titratable acidity (TA), hydrogenic potential (pH), vitamin C content, and soluble solids (ºBrix) which correlates with sugar content (Valero; Serrano, 2010). Color is also a quality parameter, which is related to the anthocyanin content, a phenolic compound acting as a natural pigment, which has a significant action against oxidative stress in human metabolism, which causes chronic non-degenerative diseases and inflammation (Gomes et al., 2022; Le et al., 2019).

However, as it is a nutrient-demanding short-cycle crop, radish quality can be compromised by factors such as the cropping system and fertilization management, involving types and amounts of fertilizers used (Araújo et al., 2020; Sousa, L. et al., 2022). Nutritional disorders trigger alterations in the plant metabolism, modifying the physiology, morphology and, mainly, the biochemical relationships, resulting in the suppression of plant growth, formation of isoporized roots (tasteless and spongy roots) and cracked, affecting its post-harvest quality (Silva, A. et al., 2017; Taiz et al., 2017).

Faced with the impacts of the conventional vegetable production system, caused by the toxicity of pesticide residues and the growing demand for quality foods that guarantee food safety and sustainability (Muniz; Aragão; Souza, 2022), the availability of nutrients through the use of the green manuring becomes an alternative for the production of vegetables. The practice of green manuring promotes the optimization of system conditions, ensuring satisfactory levels of nutrients and favorable conditions for root development (Silva, A. et al., 2017), also contributing to the production of healthier foods, without the addition of agrochemicals (Silva et al., 2021).

In the Caatinga biome, spontaneous species such as roostertree [*Calotropis procera* (Ait.) R. Br.] and hairy woodrose (*Merremia aegyptia* L.) used as green manure, have improved the postharvest quality of leafy and tuberous vegetables in the semi-arid region of the Brazilian Northeast (Barros Júnior et al., 2005; Barros Júnior et al., 2010a; Bezerra Neto et al., 2006). Studies carried out by Barros Júnior et al. (2010b), demonstrated better post-harvest quality of coriander as the amounts of green manures increased, with maximum values of soluble solids 5.98 °Brix, total acidity of 0.227% of citric acid, vitamin C content of 9.09 mg 100 mg^{-1}, in the amount of 15.6 t ha^{-1} of green manure. Guerra et al. (2022), studying the quality of beetroot roots in a system intercropped with lettuce under green fertilization, recorded better post-harvest quality for beetroot when fertilized with amounts of equitable biomass of *M. aegyptia* and *C. procera* between 20 and 55 t ha^{-1} and between population densities of lettuce from 150 to 300 thousand plants per hectare.

Given the above, the objective of this work was to estimate the postharvest quality indices and color parameters of radish roots in monocropping, as a function of different roostertree (*Calotropis procera*) biomass amounts, in two cropping seasons in a semi-arid environment.

MATERIAL AND METHODS

Location and characterization of the experimental area

The experiments were conducted from August to November 2021 (S_1) and from June to September 2022 (S_2), at the Rafael Fernandes Experimental Farm, belonging to the Universidade Federal Rural do Semi-Árido (UFERSA), located in the district of Alagoinha, 20 km away from the seat of the municipality of Mossoró, RN (5° 03 ‘37 “S, 37 ° 23 ‘50 “W, altitude of 80 m).

The local soil is classified as Dystrophic Red Yellow Latosol with sandy texture (Santos et al., 2018). The climate of the region where the experiments were carried out, according to the Köppen Geiger classification, is BShw, dry and very hot, with two seasons: a dry one, which generally occurs from June to January, and a rainy one, from February to May (Beck et al., 2018).

The average meteorological data for the period in which the experiments were carried out are shown in Table 1 (Laboratório de Instrumentação Meteorologia e Climatologia - LABIMC, 2022).

The daily minimum and maximum temperatures and daily relative humidity after radish sowing during the 2021 (S_1) and 2022 (S_2) cropping seasons, are shown in Figure 1.

Table 1: Average meteorological data, during the radish growth and development period in the 2021 (S_1) and 2022 (S_2) cropping seasons in Mossoró, RN.

Cropping seasons	Temperature (ºC)			Relative humidity (%)	Solar radiation (MJ m^{-2}/day)	Wind speed (m s^{-1})
	Minimum	Mean	Maximum			
2021 (S_1)	24.47	29.51	36.45	60.70	274.80	2.80
2022 (S_2)	20.54	27.78	35.73	62.87	256.41	1.71

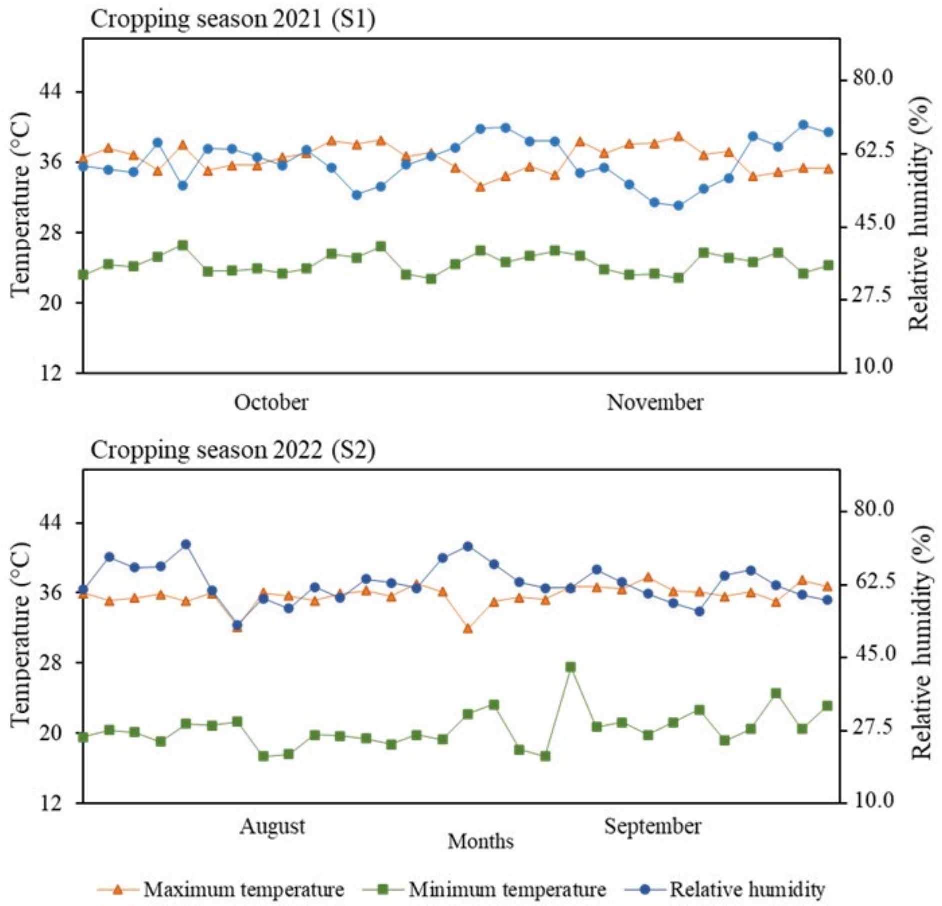

Figure 1: Data on daily averages of minimum and maximum temperatures and relative humidity during the period of radish growth and development, in the 2021 (S_1) and 2022 (S_2) cropping seasons.

Before installing the experiments, simple soil samples were collected in the 0-20 cm depth layer, which were homogenized in order to obtain a composite sample. Subsequently, these were air-dried, sieved through a 2 mm sieve, and sent to the Laboratory of Water, Soil and Plant Tissue Analysis of the Federal Institute of Education, Science and Technology of Ceará - Campus Limoeiro do Norte, for determination of their chemical attributes. The results of these analyzes are shown in Table 2.

The experimental design used was complete randomized blocks, with five treatments and five replications. The treatments consisted of roostertree biomass amounts of 16, 29, 42, 55 and 68 t ha^{-1} on a dry basis. In each experiment, a treatment with radish without fertilization (control) and another treatment with mineral fertilization were added for comparison with the treatment of maximum efficiency of the physical chemistry characteristics.

Treatment with mineral fertilizer was carried out as recommended by Trani and Raij et al. (1997) for the radish crop, with application of N, P_2O_5, K_2O in the foundation in the amounts of 20, 240 and 120 kg ha^{-1}, respectively, and in coverage 60 kg ha^{-1} of N and 40 kg ha^{-1} of K_2O, applied at 7, 14 and 21 days after germination. As a source of NPK the following simple commercial fertilizers were used: Urea: 45% of N, simple superphosphate (SS): 18% of P_2O_5 and potassium chloride (KCl): 60% of K_2O.

The total area of each plot of the experiments was 1.44 m², with a useful area of 0.80 m², with the radish planted at a spacing of 0.20 m x 0.10 m (Nunes et al., 2020), making a total estimated population of 500,000 plants per hectare. The harvest area consisted of the four central rows of plants, with 10 plants in each row, as shown in Figure 2.

Installation and conduct of experiments

The roostertree used as green manure was collected from native vegetation near the urban and rural areas of the municipality of Mossoró-RN, before the beginning of its flowering, a period that coincides with the highest accumulation of fresh matter. Subsequently, they were crushed in a conventional forage machine, in fragments of

Table 2: Soil chemical analysis before the incorporation of the green manure, in the first (S_1) and the second (S_2) cropping season.

Cropping seasons	C	OM	pH	EC	K	Ca	Mg	Na	P	Cu	Fe	Mn	Zn	B
	--- g kg^{-1}---		(H_2O)	dS m^{-1}	---------------- mmol$_c$ dm^{-3} ----------------					---------------- mg dm^{-3} ----------------				
2021 (S_1)	7.92	12.97	6.60	0.56	2.59	23.70	6.50	2.30	32.00	0.30	4.80	6.10	2.70	0.50
2022 (S_2)	7.20	12.41	7.10	0.19	1.16	20.10	6.10	0.43	7.00	0.20	6.80	12.70	1.70	0.48

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

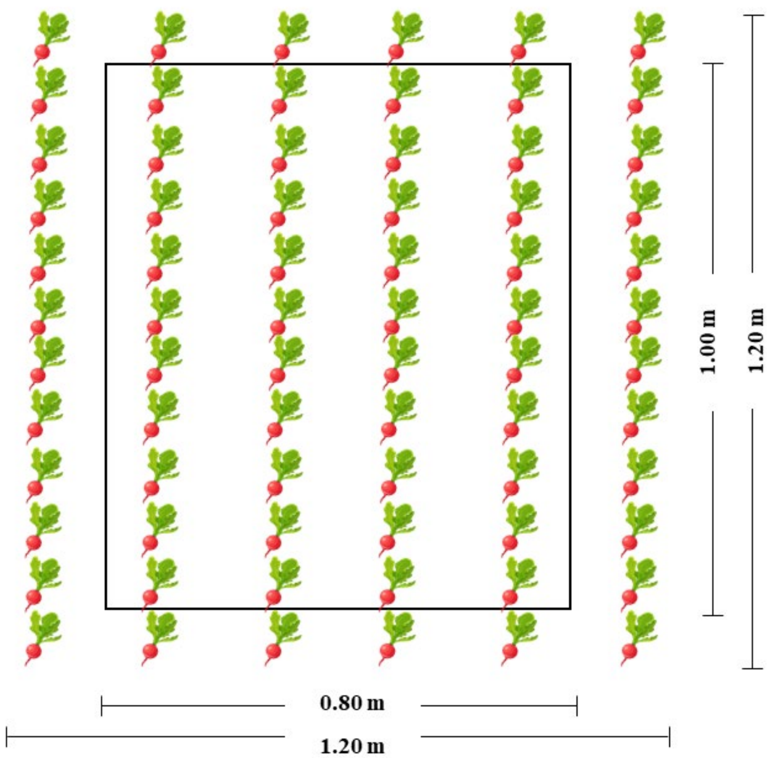

Figure 2: Representation of an experimental plot of radish in monocropping sown at spacing of 0.20 m × 0.10 m.

two to three centimeters and dehydrated under sunlight, for a period of 5 to 7 days, until reaching a moisture content of around 10%. From this material, samples were taken and sent for laboratory analysis, whose chemical compositions obtained were: N= 14.09 g kg^{-1}; P= 1.54 g kg^{-1}; K= 22.72 g kg^{-1}; Ca= 0.98 g kg^{-1}; Mg= 1.98 g kg^{-1} and C: N= 27:1 ratio.

Before installing the experiments, soil preparation was carried out. This consisted of mechanically cleaning the area with plowing and harrowing, followed by raising the beds, with the aid of a rotary tiller. Pre-planting solarization was carried out for 30 days, with 30 µm transparent plastic (Vulca Brilho Bril Fles), in order to combat nematodes, phytoparasites and weeds in the 0-10 cm layer of the soil, which could harm the development of culture (Amaral; Araújo, 2021). After the solarization period, twenty days before radish sowing, the biomass amounts of the green manure were incorporated into the soil in the 0-20 cm layer, manually with the aid of hoes, in each plot, following the specified amounts in the treatments tested.

The radish cultivar planted was 'Crimson Gigante', recommended for conditions in the Brazilian Northeast. This presents plants with large leaves, rounded roots, with an intense red color, very white and firm pulp, with a diameter ranging from 4-5 cm. The planting of the first cropping season was carried out on 10/05/2021 and the second season on 08/08/2022. In both seasons, planting was carried out by direct sowing, in holes three centimeters deep, placing two to three seeds per hole and covered with commercial substrate. At seven days after sowing (DAS), thinning was performed, leaving one plant per hole.

The cultural treatments carried out along of each cropping consisted of manual weeding to control weeds and radish hilling. Daily irrigations by micro sprinkler were carried out, in two irrigation shifts (morning and afternoon), providing a water depth of approximately 8 mm day^{-1} (Alves et al., 2017), in order to maintain the field capacity of the soil, favor the activity of soil microorganisms and mineralization of organic matter. The harvest of the first cropping season was carried out at 30 DAS, while that of the second season was carried out at 29 DAS.

Evaluated characteristics

The postharvest quality characteristics determined in the radish were carried out in a sample of 24 plants, randomly harvested in the useful area of each plot. These were sent to the Post-Harvest Laboratory of the Centro de Production Vegetal do Semi-Árido at UFERSA, where they were washed in running water, dried in the environment and classified into commercial and non-commercial. Commercial roots were those free of cracks, bifurcations, nematodes and mechanical damage, with a diameter ≥ 20 mm (Souza et al., 2020). The analyzes were carried out from the roots classified as commercial, these were crushed using a Juice Extractor Processor Juiceman 3 in 1 JM3000, until obtaining 50 mL of juice that was subsequently fractionated for each specific analysis. The number of roots to reach this volume ranged from 3 to 6, depending on the weight and size of the commercial roots, for each treatment and repetition.

The measurement of the hydrogenionic potential (pH) was performed using a model 016A benchtop pH meter. The total soluble solids (SS) content was determined by refractometry in samples of two drops of the juice, using a portable digital refractometer model 104-D, with automatic temperature correction, and the results are expressed in °Brix; The titratable acidity (TA) was performed by titration using an aliquot of 1 mL of the juice diluted in 49 mL of distilled water and, later, two drops of phenolphthalein 1% were added and titration was performed until the turning point (pink clear) with previously standardized NaOH (0.1N) solution. The results were expressed in % of malic acid calculated from Equation 1. After these determinations, the ratio between total soluble solids and titratable acidity (SS/TA) was calculated (Association Official Analytical Chemists - AOAC, 2012; Instituto Adolfo Lutz -IAL, 2008).

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

The 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 used, which was added to a volumetric flask and completed to 100 mL with 0.5% oxalic acid. From this solution, 5 mL was taken and diluted in 45 mL of distilled water, then titration was performed to the turning point (light pink) with previously standardized Tillman's solution (2,6-dichlorophenolindophenol sodium 0.2%) and, the result expressed in mg of ascorbic acid 100g-1 of juice, calculated from Equations 2, 3 and 4.

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

$$Concentration\ (mg) = \left(\frac{Volume\ spent\ in\ the\ titration(ml) * Tillman\ Factor(\mu g)}{1\ mL}\right) \div 1000 \quad (3)$$

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

The total soluble sugars (TSS) content was determined by the anthrone method (antrone solution C_4H_{100} + sulfuric acid H_2SO_4), proposed by Yemn and Willis (1954). For the determination, an aliquot of 1 mL of the juice was diluted in distilled water in a volumetric flask, until the volume of 100 mL. From this solution, 50 µL were sampled, which were added in a test tube together with 950 µL of distilled water. Then, the tubes were placed in an ice bath, where they remained while 2 mL of the anthrone solution were added, being removed only to shake the tubes. Subsequently, they were taken to a boiling water bath for eight minutes 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, 35 and 40 µg L^{-1}. The readings were performed in a spectrophotometer at 620 nm and the results were expressed in (%), being calculated by Equations 5, 6 and 7.

$$Concentration = \frac{Absorbance \pm b}{a}, \text{where a and b refer to curve} \quad (5)$$

$$Material\ mass = \left(\frac{Sample\ weight(g)*aliquot(\mu g)}{dilution(mL)}\right) \quad (6)$$

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

The total anthocyanin content was obtained by the method recommended by Francis (1982). A 1 mL sample of juice and 30 mL of ethanol-HCL solution (1.5N; 85:15%) previously prepared were added to a 75 mL Erlenmeyer flask covered with aluminum foil. Soon after, it was homogenized in a tissue homogenizer for 2 min at speed 1. Then, the volume of the solution was completed to 50 mL with ethanol-HCL and taken to the refrigerator, where it rested for 12 hours. After this period, the material was filtered through a No. 1 Whatman filter and transferred to a 50 mL beaker wrapped in aluminum foil, and then read in a spectrophotometer at a wavelength of 535 nm. The "blank" was considered, reading performed only on the ethanol-HCL solution (1.5N). Total anthocyanin was calculated in mg 100 g^{-1} using Equation 8.

$$Total\ anthocyanin\left(mg\ 100g^{-1}\right) = \left(\frac{Absorbance*dilution\ factor}{98.2}\right) \quad (8)$$

Radish roots color was determined by averaging two readings. To read the external color, the radishes were cut lengthwise with a stainless steel knife, and the parts were arranged on the optical glass so as not to leave empty spaces. The reading was performed with a Minolta colorimeter, model CR-410, calibrated on a white porcelain surface, under lighting conditions and expressed in the coordinates module L*, a* and b*, which describe the uniformity of the color in the three-dimensional space. The L* coordinate corresponds to how light and how dark the analyzed product is (0: black; 100: white); the coordinate of a* corresponds to the scale from green (-a*) to red (+a*); and the coordinate is related to the scale of blue (-b*) and yellow (+b*). The a* and b* values were converted to h° hue (Hue angle) and C* saturation (Chroma) indices, according to Equations 9 and 10 (McGuire, 1992):

$$h^{o} = arctan\left(b^*/a^*\right) \quad (9)$$

$$C^* = \sqrt{a^{*2} + b^{*2}} \quad (10)$$

The evaluated variables were subjected to a univariate analysis of variance, in a complete randomized block design, using the SAS software (SAS, 2015). Following the assumptions of Pimentel-Gomes (2009), a joint analysis of each characteristic or parameter was also carried out to find out whether or not there was interaction between the tested treatments and the cropping seasons. Given the homogeneity of the variances of the characteristics pH, total acidity, total soluble solids content, vitamin C content and color parameters (L*, C* and h°) in the cropping seasons, an average of these variables of the two cropping seasons was performed. Then, a regression analysis was performed on each variable, using the Table Curve software (Systat Software, 2022), where a curve adjustment was performed to estimate the behavior of each post-harvest characteristic, as a function of the green manure amounts roostertree studied.

The selected models were carried out based on the following criteria: biological logic (BL) of the variable, that is, when it is verified that after a certain maximum amount of fertilizer there is no increase in the variable; on the significance of the mean square of the regression residue (MSRR); in the high value of the coefficient of determination (R^2); and in the significance of the parameters of the regression equation (Ferreira et al., 2022). The F test was used to compare the average values between cropping seasons, between the average value of maximum efficiency of postharvest quality characteristics or color parameters, between the average value of the treatments fertilized with green manures and between the treatment fertilized with mineral fertilizer and the control treatment (not fertilized).

RESULTS AND DISCUSSION

The results of the analysis of variance of the characteristics evaluated in the radish, pH, titratable acidity (TA), total soluble solids (SS), SS/TA ratio and vitamin C content, are shown in Table 3. Significant interactions were not observed between treatment-factors, biomass amounts of roostertree and cropping seasons for these postharvest quality characteristics of radish. Significant differences were observed between the treatments, for all the characteristics evaluated in the radish crop, except for the titratable acidity.

The average values of the maximum efficiency treatment (ME) and of the treatments that received green manure (T_{gm}) differed significantly from the control treatment (T_c) in the pH and in vitamin C content. In these variables, these values were respectively 1.03 and 1.02 and 1.16 and 1.11 times the T_c values. The average value of mineral treatment also surpassed that of T_c in vitamin C content, however, it did not differ from the values of ME treatment and T_{gm}. The opposite behavior was recorded in the pH, where T_c surpassed T_{mf} (Table 3).

The mean titratable acidity (TA) value of the mineral treatment differed significantly from the ME treatment, of the treatments fertilized with green manure and of the T_c. An inverse behavior was registered in the total soluble solids (SS) content and in the SS/TA ratio, where the average values of the ME treatment, of the treatments fertilized with green manure and of the T_c surpassed that of the mineral treatment. In these variables, the values of the ME treatment and the treatments fertilized with green manure (T_{gm}) were respectively 1.10 and 1.07 and 1.32 and 1.24 times the values of (T_{mf}) (Table 3).

Studying the amounts of green manure in the quality characteristics of radish, an increasing polynomial behavior was observed as a function of the increase in the amounts of *C. procera* incorporated into the soil in all of them, except for the titratable acidity (Figure 3).

The values of maximum efficiency (ME) of the pH and of the total soluble solids (SS) content were 6.67 and 4.80 °Brix, respectively, in the biomass amounts of *C. procera* of 45.55 and 43.84 t ha^{-1} added to the soil, decreasing thereafter until the last biomass amount of the incorporated fertilizer (Figures 3A and 4C). On the other hand, the titratable acidity (TA) content decreased with the amounts of green manure incorporated into the soil, reaching the maximum efficiency of 0.12% in the biomass amount of 16.00 t ha^{-1} of *C. procera* added to the soil (Figure 3B). Results similar to those found were recorded by Barros Júnior et al. (2005), for carrot intercropped with lettuce, under organic fertilization with cattle manure.

According to Chitarra and Chitarra (2005), the decrease in acidity increases the flavor of the fruits and vegetables. The pH is an indicator of flavor, while acidity indicates the presence of organic acids in plant tissues, which are used as substrate for the respiration process or for conversion into sugars during ripening (Ayub; Spinardi; Gioppo, 2013; Viana et al., 2015). The decreasing in pH observed after the maximum point may be related to the increase in the concentration of acids during root development, which may have been influenced by the potassium (K) content of the green manure, since the levels of organic acids associate with potassium salts, regulate the enzymatic activity of the vegetable (Chitarra; Chitarra, 2005).

Table 3: Mean values of pH, titratable acidity (TA), soluble solids (SS), SS/TA ratio and vitamin C content of radish in the 2021 (S_1) and 2022 (S_2) seasons, for the control treatment (T_c), maximum efficiency treatment (ME), treatments fertilized with green manure (T_{gm}) and treatment with mineral fertilizer (T_{mf}).

Comparison of treatments	pH	TA (Malic acid %)	SS (°Brix)	SS/AT ratio (°Brix/Malic acid %)	Vitamin C (mg 100^{-1})
Control treatment (T_c)	6.49b*	0.12b	4.70a	39.09a	61.05b
ME treatment	6.67a	0.12b	4.80a	44.29a	70.57a
Fertilized treatments (T_{gm})	6.63a	0.11b	4.71a	41.52a	67.67a
Mineral treatment (T_{mf})	6.36c	0.13a	4.38b	33.52b	68.31a
CV (%)	1.02	5.04	2.93	6.37	5.56

* Means followed by the same lowercase letter in the column do not differ statistically by the F test at the 5% probability level.

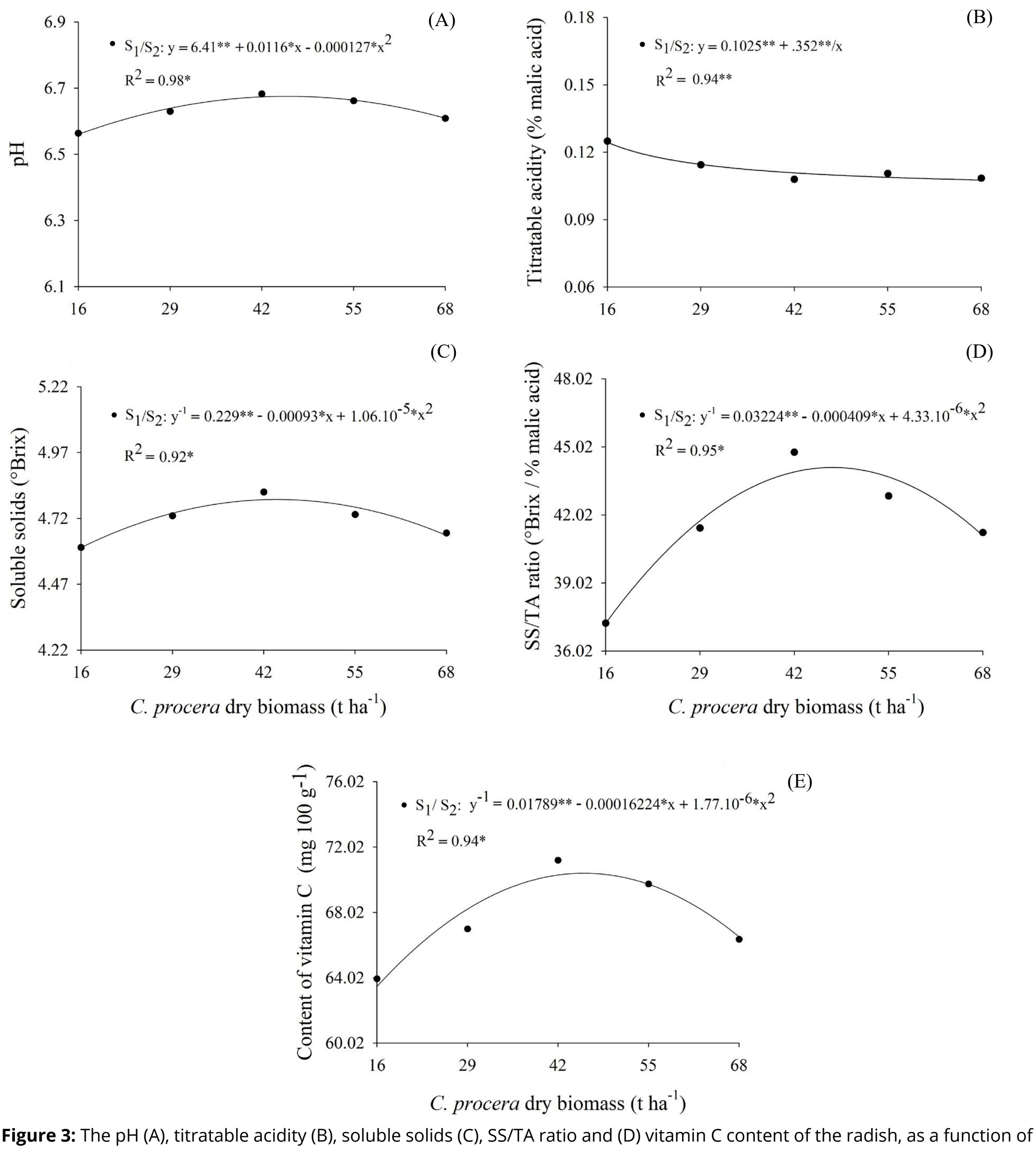

Figure 3: The pH (A), titratable acidity (B), soluble solids (C), SS/TA ratio and (D) vitamin C content of the radish, as a function of the biomass amounts of *C. procera* incorporated into the soil, in the cropping seasons of 2021 (S_1) and 2022 (S_2).

For the SS/TA ratio and vitamin C content, the maximum efficiencies were 44.28 (°Brix/% malic acid) and 70.56 mg 100g^{-1}, obtained from the amounts of roostertree biomass of 47.24 and 45.85 t ha^{-1}, respectively, decreasing until the values of the last amount of green manure tested (Figures 3D and 3E). Total soluble solids is one of the parameters used to assess the degree of sweetness of products, and its relationship with TA in the ratio (SS/

TA) reflects the balance between sugars and organic acids, determining their flavor (Chitarra; Chitarra, 2005; Pacheco et al., 2021). The higher the SS/TA ratio the greater the sensation of sweetness on the palate.

Barros Junior et al. (2010a) working with lettuce under different types of green manures (hairy woodrose, oneleaf senna and roostertree), obtained 4.57 °Brix in the hardwood under green fertilization with roostertree. In turn, Sousa, L. et al. (2022a), growing radishes in a semi-arid environment, obtained a maximum ratio (SS/TA) of 21.5 °Brix/% malic acid, when they fertilized the radish with 37.8 t ha^{-1} of cattle manure. These results demonstrate that the type and amount of organic fertilizer used in the radish crop can interfere with the total soluble solids (SS) content and, consequently, the SS/TA ratio.

With regard to the increasing vitamin C content up to the maximum efficiency value as a function of ascending amounts of roostertree, it may be related to the K levels that the green manure provided, since, depending on the cultivation conditions, the potassium can increase the synthesis of metabolic intermediates precursors of ascorbic acid (Chitarra; Chitarra, 2005; Taiz et al., 2017).

The vitamin C values ranged from 63.95 to 71.22 mg 100 g^{-1}, close to those found by Soares et al. (2020) in the radish crop under conventional fertilization and by Ferreira et al. (2020) in the culture of beet fertilized with cattle biofertilizer, and higher than the values found by Lu et al. (2008), who observed values between 14.16 and 33.41 mg 100 g^{-1} of vitamin C in 42 radish cultivars under inorganic fertilization.

The vitamin C is an essential non-enzymatic antioxidant for humans, which acts in the fight against excess free radicals in cells, being associated with the functioning of the organism, prevention and treatment of diseases such as hypertension, cardiovascular diseases, cancer and Alzheimer's diseases (Santos et al., 2019). However, it is not metabolized by the human body, but is found mainly in fruits and vegetables (Cotrim; Carvalho Filho, 2022). In this sense, based on the results, it is important to include this vegetable in the diet, being, therefore, a source of bioactive compounds with significant antioxidant action.

The results of the analysis of variance for total soluble sugars (TSS) and total anthocyanin contents are shown in Table 4. Significant interactions were observed between treatment-factors, biomass amounts of roostertree and cropping seasons for these postharvest quality characteristics of radish.

Studying the cropping seasons within each tested treatment, it was observed that the second cropping season (S_2) surpassed the first season (S_1) in terms of total sugars and total anthocyanins. Possibly, the different climate conditions and, mainly, the soil between the cropping seasons, influenced the concentration of these compounds in the radish roots, since the incidence of light energy and the nutritional status of the soil influence the biosynthesis of secondary metabolites (Caron al., 2014; Gobbo-Neto; Lopes, 2007).

Different biochemical responses to climate conditions and cultivation environment were observed by Nascimento et al. (2021) in curly lettuce cultivars and by Cruz et al. (2017) in black berry. The synthesis of the phenolic compounds is linked to the protection of plants in response to stressful conditions, such as nutritional stress, where the low concentration of nitrogen, phosphorus, sulfur and potassium, results in higher concentrations of phenolic substances, such as anthocyanin (Gobbo-Neto; Lopes, 2007; Karimi et al., 2021).

On the other hand, studying the treatments tested within each cropping season, it was observed that the average values of the maximum efficiency treatment (ME) and the treatments that received green manure (T_{gm}) differed significantly from the control treatment (T_c) in the two cropping seasons (S_1 and S_2) in the contents of total sugars and total anthocyanin. Regarding the average value of mineral treatment, it was also observed that it differed significantly from T_c in S_1 in total sugar content and in S_1 and S_2 in total anthocyanin content. However, the average value of the mineral treatment was similar to the T_c in S_2 in the total sugar content (Table 4).

Analyzing the behavior of the ME treatment in relation to the control treatment (T_c) over the cropping seasons, it was 1.32 and 1.30 times the value of the control treatment in terms of total sugars and anthocyanin contents, respectively (Table 4). These results show the potential of green manuring, when performed correctly, to improve the postharvest quality of radish.

Studying the amounts of green manure in these characteristics (TSS and total anthocyanin content), a polynomial behavior of these characteristics was observed as a function of the increase in the biomass amounts of *C. procera* incorporated into the soil (Figure 4). The maximum efficiency values obtained within each cropping season were 1.35 (S_1) and 1.77% (S_2) in TSS content and 11.71 (S_1) and 12.52 (S_2) mg 100g^{-1} in total anthocyanin content by adding to the soil, respectively, of 25.51 (S_1) and 25.06 (S_2); 35.22 (S_1) and 36.38 (S_2) t ha^{-1} of roostertree biomass, then decreasing until the amount of 68 t ha^{-1} (Figure 4A and 4B).

Table 4: Mean values of the control treatment (T_c), of the maximum efficiency treatment (ME), of the treatments with green manure (T_{gm}) and of the treatment with mineral fertilizer (T_{mf}) in the contents of total soluble sugars (TSS) and of total anthocyanin of the radish in the cropping seasons of 2021 (S_1) and 2022 (S_2).

Comparison of treatments	Total soluble sugars (TSS) (%)			Total anthocyanin (mg 100^{-1})		
	2021	2022	2021/2022	2021	2022	2021/2022
	(S_1)	(S_2)	(S_1/S_2)	(S_1)	(S_2)	(S_1/S_2)
Control treatment (T_c)	1.17bB*	1.22bA	1.19	8.84cB	9.71cA	9.27
ME treatment	1.35aB	1.77aA	1.57+	11.71aB	12.53aA	12.10+
Fertilized treatments (T_{gm})	1.31aB	1.72aA	1.51+	10.57aB	11.87bA	11.20+
Mineral treatment (T_{mf})	1.35aB	1.23bA	1.29	7.46bB	12.64aA	10.05+
CV (%)	9.33	9.25	9.32	6.36	6.13	6.25

* Means followed by the same lowercase letter in the column do not differ statistically by the F test at the 5% probability level. +The mean of the treatments with green manure, treatment with mineral fertilizer or the MEF treatment are significantly different from the mean of the control treatment by the F test at the 5% probability level.

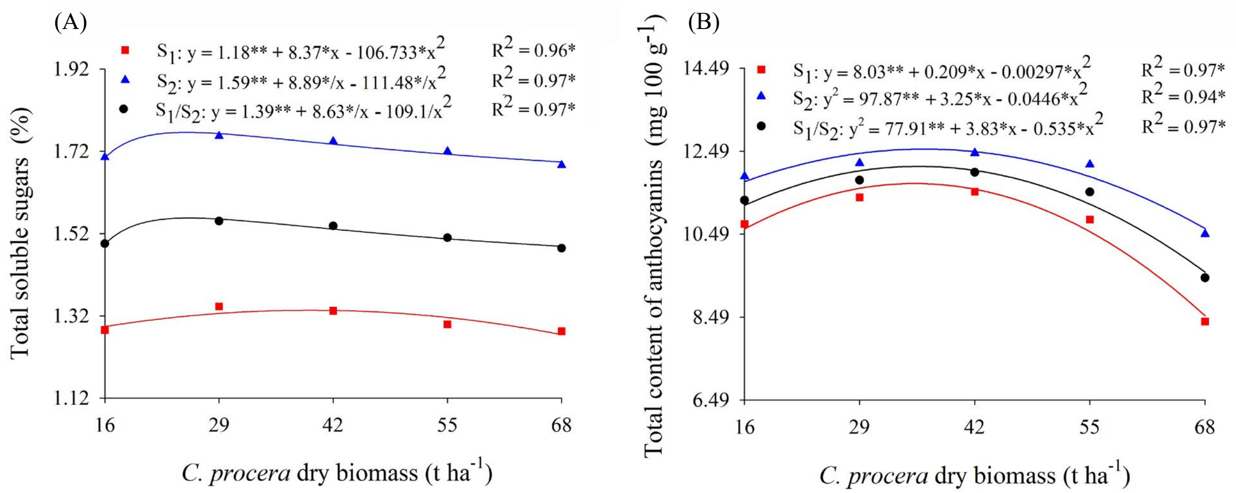

Figure 4: Total soluble sugar (A) and total anthocyanin (B) contents of radish, as a function of increasing biomass amounts of *C. procera* incorporated into the soil in the 2021 (S_1) and 2022 (S_2) cropping seasons.

By estimating the maximum efficiencies of these characteristics over the cropping seasons (S_1/S_2), a polynomial behavior was also observed, as a function of the increase in the amounts of green manure up to the maximum values of 1.57% (TSS) and 12, 10 mg 100 g^{-1} (total anthocyanin content), in the amounts of green manure of 25.27 and 35.79 t ha^{-1}, then decreasing until the highest amount of fertilizer tested (Figures 4A and 4B).

The behavior of TSS is similar to that observed in total soluble solids, since sugars make up 80 to 90% of the compounds of total soluble solids (Costa et al., 2017). The observed results may also be related to the levels of potassium (K) and nitrogen (N) made available by the green manure throughout the cycle. K participates in the processes of formation and translocation of sugars, while N increases the concentration of sucrose, acting on the composition of amino acids (Taiz et al., 2017), thus influencing the accumulation of sugars and, consequently, the increase in °Brix. Studies carried out by Soares et al. (2020) and Bonfim-Silva (2021) showed the influence of these nutrients on the post-harvest quality of radish. However, as observed in this work and by Guerra et al. (2022), the optimization of the accumulation of soluble solids and, consequently, the levels of sugars, does not always refer to a greater amount of fertilizer incorporated into the soil.

The increasing polynomial behavior observed in the total anthocyanin content may be related to the mineralization of the nutrients provided by the green manure, especially nitrogen (N). The slow availability of N can lead to the accumulation of carbohydrates, which, because they are not used in N metabolism, can be used in the synthesis of anthocyanin, causing the accumulation of this bioactive compound (Taiz et al., 2017). Anthocyanins have antioxidant activity with benefits to human health, adding higher food quality to vegetables (Arruda et al., 2022; Rodriguez-Amaya, 2019).

Works developed by Carrillo et al. (2019) and Lo Scalzo et al. (2013), demonstrate a greater accumulation of secondary metabolites in organically grown vegetables, when compared to conventional cultivation, results observed in this work. However, contrary results were found by Knap et al. (2014). Deus et al. (2019), emphasizes that the absence of the use of chemical pesticides and, consequent exposure of the plant to biotic stresses, leads to an increase in natural plant defense substances (bioactive compounds). In addition to the cultivation system, the levels of polyphenols in vegetables can be influenced by factors such as plant variety, soil, growing seasons, biotic and abiotic stresses (Deus et al., 2019; Silva et al., 2017b).

The results of the analysis of variance of the radish color parameters are presented in Table 5. The average values of maximum efficiency (ME), of the treatments that received green manure (T_{gm}) and of the control treatment (T_c), differed from the mineral treatment (T_{mf}) in the parameters L* and h°. Higher values of luminosity, saturation and hue were observed when radish roots were fertilized with green manure. There was no significant difference between the treatments tested in the parameter Chroma (C*) (Table 5).

It is known that colorimetry is based on three elements: luminosity (L), indicating lighter or darker colors; saturation (C*), which refers to the concentration of the coloring element, and hue (h°), a qualitative attribute of colors defined as reddish, greenish e etc (Ferreira; Spricigo, 2017).

Studying the amounts of green manure in the color parameters, a polynomial behavior was observed as a function of the increasing amounts of roostertree incorporated into the soil, reaching the values of maximum efficiency of 32.30, 38.67 and 0.28, respectively, for L*, C* and h° at biomass amounts of 40.39, 53.14 and 52.71 t ha^{-1} of *C. procera*, then decreasing up to the highest amount tested (Figure 5A to 5C).

The results of the radish roots fertilized with roostertree showed a red/reddish color, which is the most attractive and most acceptable color to the consumer (Figure 6). According to Sakr et al. (2019), red radish cultivars have been used in studies as a potential source of natural dye due to the presence of highly stable anthocyanins. Guerra et al. (2022) observed that the beet color attribute was influenced both by the amount of green manure applied and also by the population densities tested.

The increasing responses and the optimizations achieved in the quality attributes evaluated in the radish crop, as a function of the biomass amounts of roostertree, are related to the benefits of green manuring on the physical-chemical and biological characteristics of the soil, resulting in an increase in the organic matter content, maintenance of soil moisture and temperature, thus favoring the balanced absorption of nutrients throughout the crop cycle (Abranches et al., 2021; Silva et al., 2017a). On the other hand, it is known that the satisfactory availability of nutrients directly impacts the natural physiological processes of the plant, as they play an important role in biochemical reactions, synthesis of photoassimilates, phytochemical compounds and enzymatic maintenance (Taiz et al., 2017), which ultimately become will reflect on the quality of the vegetable crops.

Table 5: Mean values of the color parameters luminosity (L*), Chroma (C*) and Hue Angle (h°) of the radish in the control treatment (T_c), in the maximum efficiency treatment (ME), in the treatments with green manure (T_{gm}) and in the treatment with mineral fertilizer (T_{mf}).

Comparison of treatments	L*	C*	h°
Control treatment (T_c)	32.21a*	37.81a	0.26ab
ME treatment	32.31a	38.67a	0.29a
Fertilized treatments (T_{gm})	31.85a	36.15a	0.28a
Mineral treatment (T_{mf})	29.69b	36.44a	0.23b
CV (%)	4.95	7.26	11.34

* Means followed by the same lowercase letter in the column do not differ statistically by the F test at the 5% probability level.

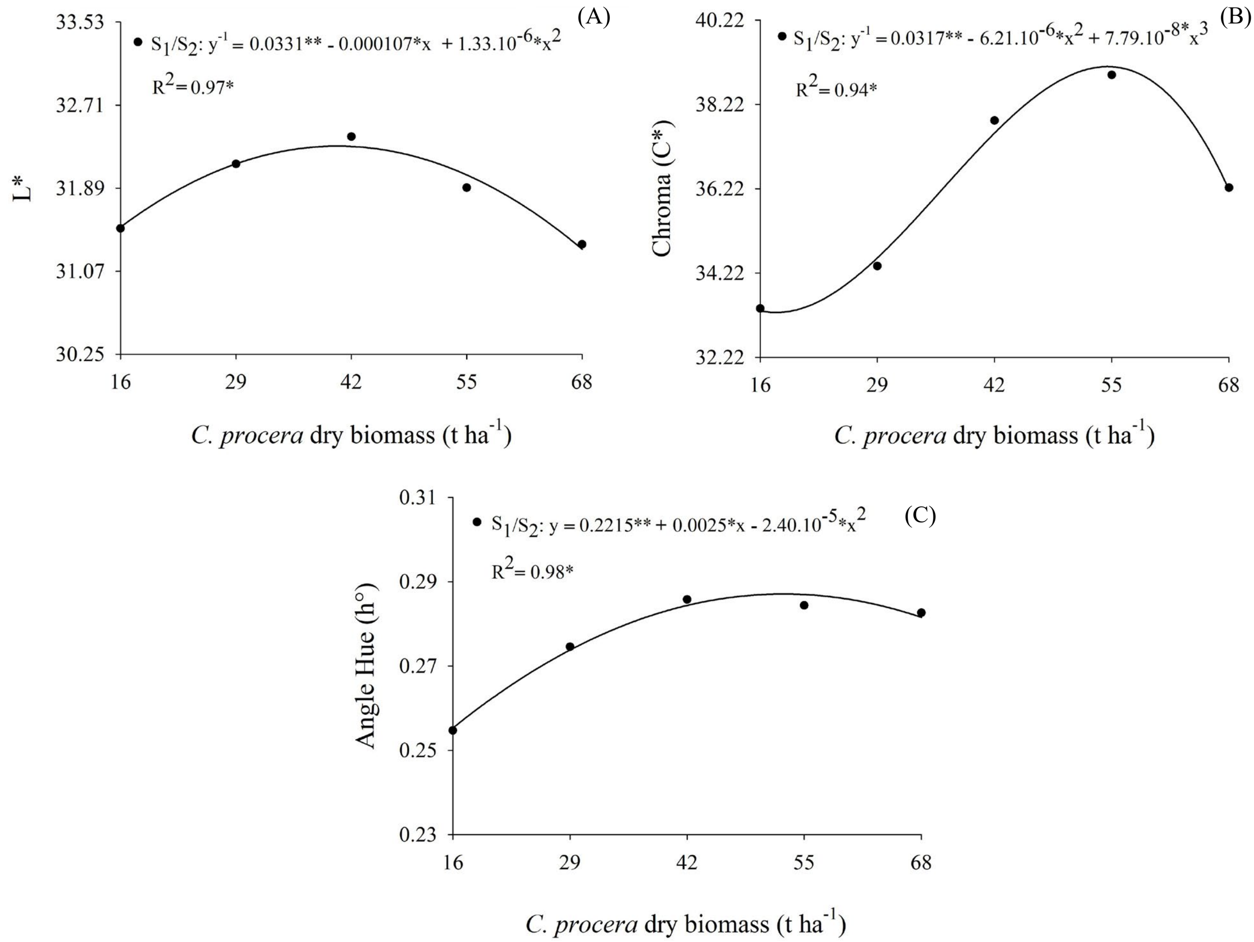

Figure 5: Color parameters L*, C* and h° of radish, as a function of increasing biomass amounts of *C. procera* incorporated into the soil, in the cropping seasons of 2021 (S_1) and 2022 (S_2).

The polynomial response in the postharvest characteristics of radish, with a reduction in value after the maximum point, can be explained by the synchronization between the decomposition and mineralization of the organic matter of the roostertree biomass added to the soil, and also by the Law of Maximum, where the excess of a nutrient can cause toxicity and/or decrease the effectiveness of others (Almeida et al., 2015; Silva et al., 2021), thus causing a limiting effect of essential nutrients for the metabolism of the plant, impacting on its post-harvest quality.

It should be noted that the term food quality groups conditions such as: production system, nutritional, organoleptic, sanitary and environmental quality (Rumiato; Monteiro, 2017). Thus, in view of the results obtained, it can be stated that the organic production of radish in a semi-arid environment, using spontaneous species from the Caatinga biome, increased the post-harvest quality of tuberous vegetables such as radish, improving their physical-chemical characteristics and quantity of compounds bioactive. Allied to this, it is known that the practice of green manuring is an alternative production for the vegetable, which reduces production costs and external dependence on chemical fertilizers and meets the premises of the Sustainable Development Goals (SDGs) of the 2030 agenda, of the United Nations (UN), which provides for the achievement of food security and nutritional improvement, promotion of sustainable agricultural systems that guarantee biodiversity and efficient use of natural resources (Organizações das Nações Unidas - ONU, 2015).

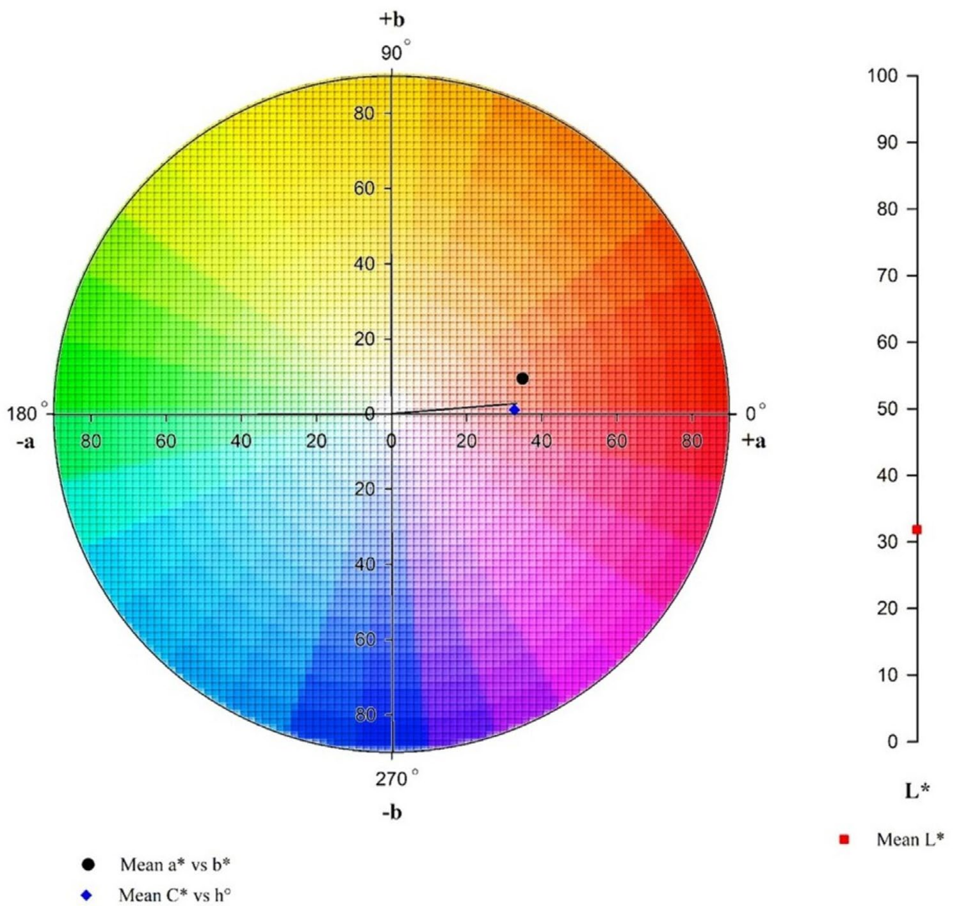

Figure 6: Representation of the color space section of radish roots, under green fertilization with *C. procera*, from the averages of coordinates L*, a*, b* and parameters C* and hº.

CONCLUSIONS

The maximum flavor efficiency (°Brix/% malic acid) and the total soluble sugar content were achieved with the incorporation into the soil of 47.24 and 25.27 t ha^{-1} of roostertree biomass, respectively. Higher concentrations of bioactive compounds of vitamin C and anthocyanin were obtained when incorporating 35.79 and 45.85 t ha^{-1} of green manure biomass. Higher color parameters values in the red radish roots were achieved in the biomass amounts of 40.39, 53.14 and 52.71t ha^{-1} of roostertree.

AUTHOR CONTRIBUTION

Conceptual idea: Silva, J.P.P., Santos, E.C., Methodology design: Santos, E.C., Bezerra Neto, F., Lima, J.S.S., Data collection: Frutuoso, R.M. S., Carmo, I.D.J.S., Silva, J.P.P., Data analysis and interpretation: Bezerra Neto, F., Silva, J.P.P., Santos, E.C., Lima, J.S.S., and Writing and editing: Silva, J.P.P., Bezerra Neto, F., Santos, E.C.

ACKNOWLEDGEMENT

The authors thank the National Council for Scientific and Technological Development (CNPq/ Brazil), for the research financial support (process nº 305222/2019-8) and the Coordination for higher Education Staff Development (CAPES/Brazil) for master's degree grant number 88887.610286/2021-00 for the student.

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