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INFRARED THERMOGRAPHY FOR DETERMINING TRAY TEMPERATURE IN LETTUCE PRODUCTION

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KEYWORDS

ambience, protected cultivation, *Lactuca sativa* L., seedlings.

ABSTRACT

This research was carried out in Recife, PE, Brazil, and aimed to assess the variation of the surface temperature of trays and substrate in the production of lettuce seedlings and its influence on the final product. Trays consisted of expanded polystyrene, conventional polyvinyl chloride, polyvinyl chloride painted white, and polyvinyl chloride painted gray. Two cultivars (Solaris and Vanda) were used to register crop biometric variables from seedling stage to the final product (46 days). Tray and substrate temperatures were recorded by means of an infrared thermal imager. The experimental design was a completely randomized design in a 4 × 2 factorial scheme with three replications. The conventional polyvinyl chloride tray presented the highest surface temperature. The substrate temperature in the styrofoam tray was higher when compared to the others. The white tray showed the lowest values of substrate temperature, providing a better seedling development. Seedling quality and the most important agronomic characteristics for commercialization were obtained in the white tray, being the best alternative for lettuce cultivation.

INTRODUCTION

Lettuce (*Lactuca sativa* L.) crop has a consolidated production system, but there are still a number of obstacles to its cultivation under Brazilian conditions. The tropical climate is the main obstacle because this crop has a low tolerance to high air temperatures associated with a high solar radiation availability (Resende et al., 2017).

Lettuce is the most consumed and planted leafy vegetable in Brazil and in the world, considered the first in the classification among the most important ten leafy vegetables in terms of economic value regarding its nutritional characteristic, pleasant taste, and low acquisition value (Watthier et al., 2017). For this reason, understanding the aspects of its production is extremely important.

Lettuce is sensitive to adverse conditions of air temperature and produces better in the coldest times of the year. Short days and mild temperatures favor vegetation. However, long days and high temperatures favor flowering, which results in a great problem for producers in the summer or in high-temperature regions because it favors early bolting (Arantes et al., 2014).

The ideal temperatures for producing leaves and heads with quality are between 20 and 25 °C (Maldonade et al., 2014) and higher temperatures favor an early flowering, which causes the stem elongation, affects head formation, and stimulates latex production, making leaf taste astringent. This leads to a harvest of small plants with a lower weight, which depreciates the product (Okuda et al., 2014).

High availability of solar radiation in tropical regions promotes an increased soil temperature, which causes stress to the plant, accelerates its metabolism, hinders nutrient absorption, and retards root development (Cortez et al., 2015). However, due to increasing demand, it is necessary to reduce the temperature and use resources that minimize the action of stressors such as protected cultivation, which promotes a better quality of the final product (Rebouças et al., 2015).

In the last decades, new tools and techniques have been introduced in agriculture, being one of them the infrared thermography, which has been widely used to identify abnormalities in production systems (Carneiro et al., 2015). Thermography, together with the knowledge of material properties, local microclimate, and productivity indices, is useful information for the re-adaptation of materials used in trays for seedlings production. Nevertheless, few studies assess the types of trays used in agricultural production systems, mainly regarding thermal attributes of materials and their influence on substrate temperature.

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The final quality of an agricultural product is the result of several factors, among them the development of more vigorous seedlings because it is one of the most important stages in agricultural production, with a direct effect on crop cycle and productivity. In this context, crop container care is essential for obtaining quality plants as it directly affects root system growth, influencing nutrient absorption capacity, harvest time, and the number of possible cycles per year (Costa et al., 2012). Thus, the aim of this study was to assess the variation of the surface temperature of trays and substrate in the production of lettuce seedlings and its influence on the final product.

MATERIAL AND METHODS

This study was carried out at the Federal Rural University of Pernambuco (UFRPE), Recife, Pernambuco, Brazil (08°04′03″ S, 34°55′00″ W, and an altitude of 4 m). According to Köppen classification, the regional climate is classified as Am, i.e. a humid tropical climate with precipitations in the winter and dry summer (Alvares et al., 2013). The experiments were conducted in two stages. The first stage was carried out from June 5 to June 29, 2016, being conducted from planting to obtaining the seedlings. The second stage was carried out from seedling transplanting (June 29, 2016) to harvest (July 23, 2016), being conducted in a hydroponic system and totaling 46 days.

Pelleted seeds of the lettuce cultivars Solaris (Semis) and Vanda (Sakata) were used. Seedling production was conducted in trays with different characteristics, thus composing the second factor of variation assessed in the experiment. Trays were distributed at random scheme on the cultivation bench. Four types of trays (white, styrofoam, black, and gray) and two cultivars (Solaris and Vanda) were used.

Trays consisted of expanded polystyrene (styrofoam) with 200 trapezoidal cells with a capacity of 12.3 cm^3, thermal conductivity of 0.040 $W\ m\ K^{-1}$, and emissivity of 0.60; conventional black polyvinyl chloride (PVC) with 200 cells and capacity of 18 cm^3, thermal conductivity of 0.20 $W\ m\ K^{-1}$, and emissivity of 0.97 (Marques et al., 2003; ABNT NBR 15220-2, 2005); and other two PVC trays (white and gray) with the same characteristics of the black tray. These latter trays were filled with sand and painted with white and gray paint so that their internal surfaces were not changed. The emissivity of the white and gray paint was 0.90 and 0.91, respectively (Novo et al., 2014; Akamine et al., 2018).

These trays were placed on a masonry bench and submitted to a subirrigation system operated eight times a day (at 8:00, 9:00, 10:00, 11:00, 12:00, 13:00, 14:00, and 15:00 h). Coconut powder was used as a substrate. Seedlings were fertigated with the nutrient solution of Castellane & Araújo (1995).

The determination of the surface temperature of trays was carried out by means of thermal images using an infrared thermal imager. Records of each sample were obtained consecutively three days a week every two hours (from 8:00 to 16:00 h) during the seedling production period (23 days).

Trays were inserted into a cardboard chamber to standardize the reflected temperature. Then, images from the sides of the trays were recorded 1 m away with the camera positioned at 90° from the target surface. At that moment, the thermo-hygrometric variables were recorded for corrections at the time of analysis.

The determination of the thermal variability of the substrate was carried out by means of thermal images using a thermal imager, adopting the same methodology used to record tray temperature. However, the temperature used was the average of six areas obtained from the diagonal of trays.

The day June 11, 2016, was chosen to highlight the differences in the surface temperature of the substrate. The average values recorded on that day were submitted to analysis of variance by the F-test ($P<0.05$) and later compared by the Tukey's test ($P<0.05$). Statistical analyses were performed in the software SISVAR (Ferreira, 2014).

Seedling development was assessed at the end of the first experimental stage. For this, 15 plants were collected per tray to record their height (H), measured with a graduated ruler from the substrate level to the end of the highest leaf, stem diameter (Ds), measured with a digital caliper, number of definitive leaves in the seedlings (NLs), and root length (RL), determined with a ruler.

Subsequently, the seedlings were removed from trays and washed, being the shoot and roots sectioned. In order to obtain the shoot (SDM), root (RDM), and total dry matter (TDM), the samples were dried in a forced air ventilation oven (65 ± 2 °C) until constant weight and weighed in a precision scale.

The Dickson quality index (DQI) (Dickson et al., 1960) was adopted to assess the qualitative aspect of seedlings. DQI considers the robustness and balance of the seedling phytomass distribution. Thus, the higher the index found, the better the quality standard.

The biometric records from six random plants per plot, characterized by the sample of a tray, were used at the end of the production cycle (46 days after planting) to assess the number of commercial leaves per plant (NL) by counting the number of leaves larger than 3 cm starting from basal leaves; plant diameter (PD) by measuring the distances between opposing margins of the plant (cm); plant height (H) by measuring the distance from the stem base to the inflection of the highest leaf (cm) with a graduated ruler; commercial fresh mass (CFM), measured after cutting the roots close to the stem at harvesting time, with subsequent disposal of leaves unsuitable for commercialization; stem diameter (SD), measured with a digital caliper; and stem length (SL), measured in centimeters after leaf removal.

The commercial classification of lettuce proposed by the Brazilian Program for Horticulture Modernization was adopted for the qualitative assessment of plants. This classification suggests that the main national classification should be carried out according to the lower and upper limits of fresh mass in grams per plant (Hortibrasil, 2016).

The experimental design was a completely randomized design in a 4 × 2 factorial scheme with three replications. For the statistical analysis of the biometric variables of seedlings, the data were submitted to analysis of variance by the F-test ($P<0.05$) to verify the interaction between factors, being then compared by the Scott-Knott (1974) test. All statistical analyses were performed using the program SISVAR (Ferreira, 2014).

RESULTS AND DISCUSSION

The variation of the surface temperature of trays during the day of higher air temperature (June 11, 2016) indicated that the black tray presented a higher temperature when compared to the others ($P<0.05$). The white and gray trays showed no significant difference ($P<0.05$) for the surface temperature at 10:00, 12:00, 14:00, and 16:00 h, with a difference only at 8:00 h, when the white tray had the lowest value. The styrofoam tray presented the lowest surface temperature ($P<0.05$) (Figure 1) due to the higher specific heat of this material (ABNT NBR 15220-2, 2005).

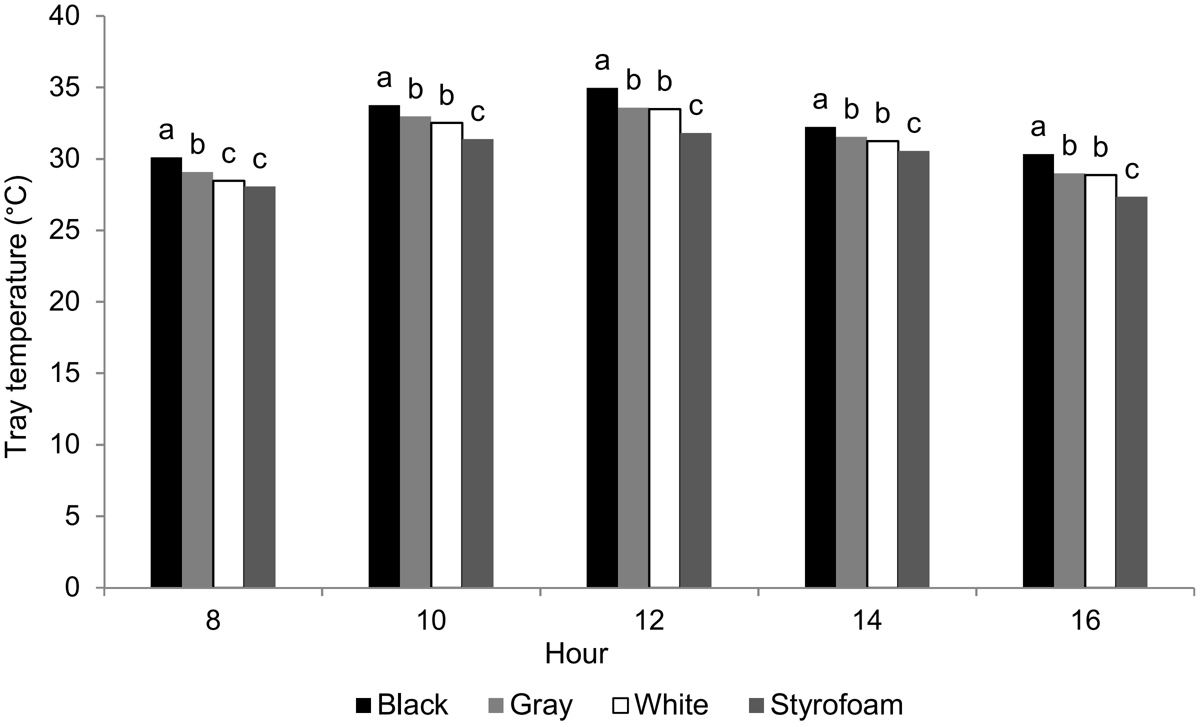

FIGURE 1. Hourly variation of the surface temperature of trays. Means followed by the same letter at each assessment time did not differ from each other by the Tukey's test ($P<0.05$).

Figure 2 shows that in hours of higher radiation availability the surface temperature of substrate reached a higher value in the styrofoam tray because at these times the energy transfer process that most influences the surface temperature of substrate is the solar radiation, besides the material to conserve the absorbed energy (Carneiro et al., 2015).

No difference ($P>0.05$) was observed at 8:00 and 14:00 h between trays, but at 10:00 and 12:00 h, styrofoam and black trays showed a higher surface temperature of the substrate. The lowest substrate temperatures were recorded in gray and white trays, but with no significant effect ($P>0.05$) for the black tray. At 16:00 h, the substrate in the styrofoam tray had the lowest surface temperature ($P<0.05$) due to the energy conservation throughout the day and consequent loss of latent heat, which reduced the surface temperature of the substrate.

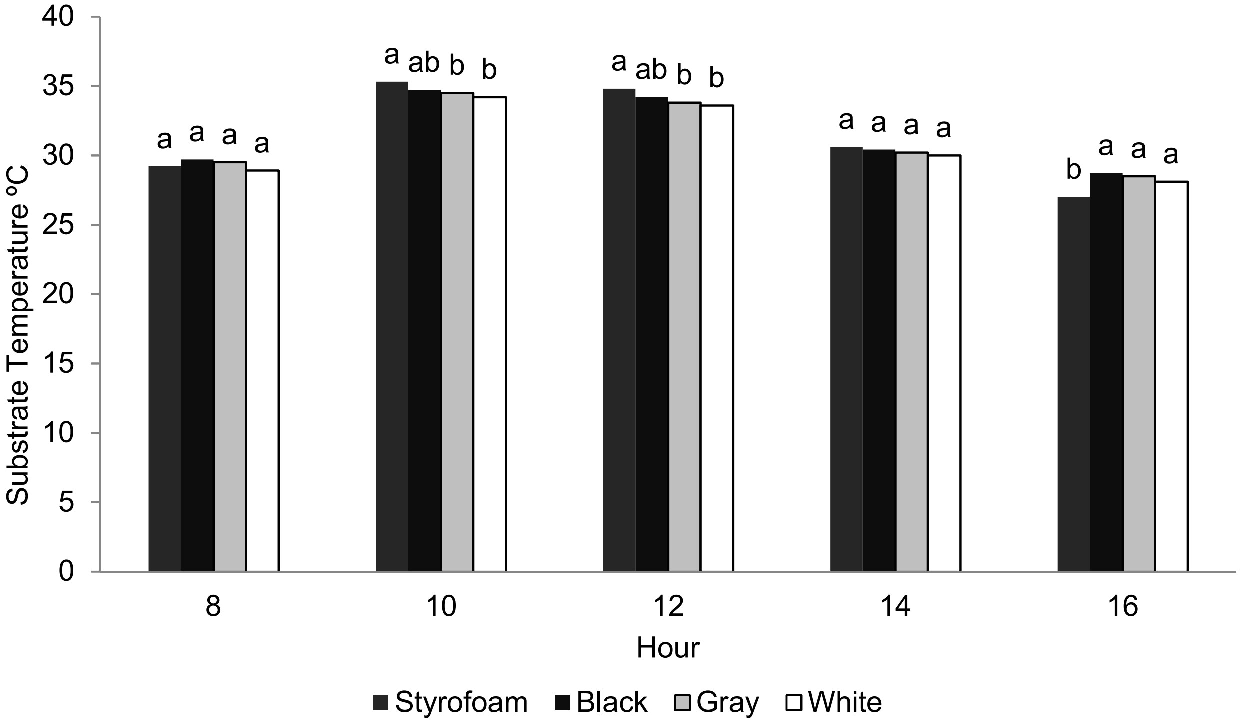

FIGURE 2. Hourly variation of the surface temperature of the substrate. Means followed by the same letter at each assessment time did not differ from each other by the Tukey's test (P<0.05).

The number of leaves did not have significant differences among cultivars (Table 1). However, for seedling height, root length, stem diameter, and shoot, root, and total dry matter, the cultivar Vanda presented higher values when compared to the cultivar Solaris (P<0.05), which denote more vigorous seedlings for transplanting. For the Dickson quality index (DQI) of seedlings, the cultivar Vanda showed more adequate proportions when compared to the cultivar Solaris, i.e. thicker stem and higher root volume (De Freitas et al., 2013).

The variables stem diameter and plant height used for calculating DQI are extremely important because they reveal whether there was any bolting. The equation that determines DQI is balanced and includes, besides the relationship between height and diameter of the stem, the root and shoot dry matter, which characterize a higher accuracy in the determination of seedling quality (Simões et al., 2015).

TABLE 1. Average values of biometric variables, standard deviation, and seedling quality.

Cultivar	NL	H (cm)	RL (cm)	Ds (mm)	SDM (g)	RDM (g)	TDM (g)	DQI
Vanda	3.9 a ± 0.18	14.7 a ± 1.2	12.9 a ± 1.1	2.6 a ± 0.17	77.7 a ± 2.3	48.5 a ± 3.5	126.2 a ± 5.4	17.3 a ± 3.61
Solaris	4.0 a ± 0.13	13.7 b ± 0.9	9.04 b ± 2.5	2.4 b ± 0.19	68.2 b ± 2.5	37.8 b ± 3.3	106.0 b ± 5.9	14.4 b ± 2.97
CV (%)	4.34	7.01	18.05	7.25	13.59	11.32	11.93	12.40

Means followed by the same letter in the column do not differ from each other by the Scott-Knott test (P<0.05). NL – number of leaves, H – height, RL – root length, Ds – stem diameter, SDM – shoot dry matter, RDM – root dry matter, TDM – total dry matter, and DQI – Dickson quality index.

No significant interactions were found for all variables between trays and cultivars (P>0.05). The variation factor trays showed no significant effect (P>0.05) for the number of leaves and stem diameter, but presented significant differences between seedling of their respective cultivation trays for seedling height, root length, and shoot, root, and total dry matter (Table 2).

Seedlings from white and gray trays presented 4.1 and 4.0 definitive leaves, respectively. Those obtained from the black (3.9) and styrofoam trays (3.9) did not reach, on average, four definitive leaves. It is recommended that lettuce seedlings present between four and six definitive leaves to be able to be transplanted (Brito et al., 2017). However, seedlings presented a reasonable condition for transplanting, regardless of the cultivation trays.

The best results of seedling height were found in white (14.89 cm), gray (14.69 cm), and black (14.04 cm) trays, the latter not differing from the styrofoam tray (13.38 cm). These results were similar to those observed by Brito et al. (2017). Seedlings with a height higher than 5.41 cm are suitable for transplanting. In addition, seedling height exceeded the recommended value in all the assessed trays.

Root length showed a better result in seedlings from white, gray, and black trays, but with a significant effect (P<0.05) only between root length of seedlings from white and styrofoam trays, which presented the lowest values. Seedlings presented similar values for stem diameter (P>0.05). Seedlings with a larger stem diameter provide a higher probability of survival and better development of new roots.

The quantification of shoot dry matter (SDM) is extremely important because it indicates that nutrients were assimilated and converted into dry matter. Seedlings that reached the highest SDM were those from white, gray, and black trays, with a significant effect ($P<0.05$) among seedlings from the styrofoam tray, which presented the lowest SDM (Table 2). Root dry matter (RDM) was higher in white, gray, and black trays, with a significant effect ($P>0.05$) only between seedlings from white and styrofoam trays, which presented a lower RDM (Table 2). These results are in accordance with Rouphael et al. (2008), who identified a higher amount of dry matter with a lower temperature.

The total dry matter (TDM) of seedlings from white, gray, and black trays presented the best results and were statistically different ($P<0.05$) from the TDM of seedlings from styrofoam tray, which presented lower assimilate fixation and reduction in the TDM value when compared to seedlings from PVC trays (Table 2). This is due to the higher substrate temperature found in this tray. In addition, the lowest volume of the cell in the styrofoam tray may have contributed to these differences (Silva et al., 2016).

The Dickson quality index (DQI) of seedlings presented values ranging from 16.69 to 14.30. The white tray presented the highest index, which indicates that the seedlings were more vigorous for transplanting. Seedlings from the gray tray did not present a significant effect but were superior to those from the black tray ($P<0.05$). Moreover, seedlings from styrofoam trays presented a lower DQI, differing statistically from the others probably due to higher substrate temperature and lower capacity of tray cells (Table 2). Simões et al. (2015) studied different substrates and found DQI values between 11 and 15, which are lower when compared to those observed in this research, demonstrating the good quality of the produced seedlings.

TABLE 2. Biometric variables, standard deviation, and quality of seedlings from trays.

Tray	NL	H (cm)	RL (cm)	Ds (mm)	SDM (g)	RDM (g)	TDM (g)	DQI
White	4.1a ± 0.1	14.9a ± 0.9	12.7a ± 1.9	2.5a ± 0.1	76.4a ± 3.2	46.8a ± 3.8	123.2a ± 6.9	16.7a ± 0.8
Gray	4.0a ± 0.1	14.6a ± 1.0	11.5ab ± 2.3	2.6a ± 0.1	78.8a ± 2.9	43.3ab ± 4.1	122.1a ± 6.4	16.4ab ± 0.9
Black	3.9a ± 0.2	14.0ab ± 1.4	10.9ab ± 2.1	2.4a ± 0.1	75.7a ± 3.3	43.6ab ± 4.2	119.3a ± 5.6	16.0b ± 0.7
Styrofoam	3.9a ± 0.1	13.3b ± 0.5	9.4b ± 1.4	2.4a ± 0.2	60.6b ± 3.6	38.8b ± 4.8	99.5b ± 5.8	14.3c ± 0.8
CV (%)	4.34	7.01	18.05	7.25	13.59	11.32	11.93	12.40

Means followed by the same letter in the column do not differ from each other by the Scott-Knott test ($P<0.05$). NL – number of leaves, H – height, RL – root length, Ds – stem diameter, SDM – shoot dry matter, RDM – root dry matter, TDM – total dry matter, and DQI – Dickson quality index.

No significant interactions were found for all the variables between trays and lettuce cultivars ($P<0.05$). The highest value of the coefficient of variation was found for stem length (18.56%), a characteristic strongly influenced by the environment, and the lowest value was observed for stem diameter (5.12%), indicating a low dispersion between the data.

The biometric assessment between cultivars did not present significant differences ($P<0.05$) for most of the characteristics. However, a significant difference was observed for the number of leaves (NL), in which the cultivar Vanda had an NL superior to the cultivar Solaris. The cultivars presented a high resistance to early bolting, not statistically differing from each other. These results corroborate those found by Arantes et al. (2014).

Lettuce classification according to the Brazilian Program of Classification Standards (2016), characterized by the commercial fresh mass (CFM), indicates that the cultivars reached an average between 200 and 250 g, i.e. class 20. Under the tropical conditions of Recife, Magalhães et al. (2010) harvested lettuce plants from an NFT hydroponic system with CFM values between 192 and 136 g. Duarte et al. (2012) obtained a maximum CFM value of 96 g. These values were lower when compared to those obtained in our study, which ranged from 206 to 253 g (Table 3).

Plants produced in PVC trays presented a higher commercial fresh mass (CFM), with no significant effect from each other ($P<0.05$). Plants from white and styrofoam trays showed significant differences, the latter presenting the lowest CFM values (Table 3). In general, the plants showed good performance under the climate conditions of Recife, with CFM means adequate for their commercial production (Sala & Costa, 2012).

Table 3 shows that the height of plants coming from gray trays presented a higher value, with a significant effect only between plants from styrofoam trays. Plants from black and white trays did not differ from those grown in styrofoam trays. Moreover, the values of plant diameter (PD) were close to each other. These characteristics provide important information because the main way of packing the plants for transportation is into boxes. Therefore, plants with a diameter over 40 cm can be damaged during transportation, reducing the quality of the product available to the final consumer (Sala & Costa, 2012; Milhomens et al., 2015).

Plants from white and black trays showed the highest number of leaves (NL), with a significant effect for styrofoam tray ($P>0.05$). Plants from gray trays did not differ significantly from those grown in styrofoam trays. NL is an important variable because there is a worldwide tendency to consume processed and packaged leaves (Sala & Costa, 2012).

Stem length (SL) is a characteristic that indicates tolerance to bolting, which is caused under adverse climatic conditions (Jenni et al., 2013). Plants from black and gray trays showed an SL with bolting. Plants from white trays presented the lowest SL values among the PVC trays, but with no significant effect between them ($P>0.05$). The styrofoam tray presented the lowest SL values, but with no significant differences between plants from white trays ($P>0.05$). According to Blind & Silva Filho (2015), a stem length of up to 6 cm is the most adequate.

Plants from white trays presented the largest stem diameter (22.67 mm), followed by black (21.57 mm), gray (21.22 mm), and styrofoam trays (21.03 mm). In addition, no significant difference was observed between plants from white and black trays and between black, gray, and styrofoam trays (Table 3).

TABLE 3. Biometric variables and standard deviation of lettuce plants from trays.

Tray	CFM (kg)	H (cm)	PD (cm)	NL	SL (cm)	SD (mm)
White	0.253 a ± 0.02	16.90 ab ± 0.80	40.17 a ± 2.56	19.58 a ± 2.03	5.41 ab ± 0.87	22.67 a ± 2.17
Gray	0.233 ab ± 0.02	17.53 a ± 1.51	39.17 a ± 2.74	18.56 ab ± 2.25	5.86 a ± 0.95	21.22 b ± 1.19
Black	0.230 ab ± 0.02	17.39 ab ± 1.28	39.14 a ± 2.61	19.25 a ± 2.25	6.14 a ± 0.83	21.57 ab ± 2.16
Styrofoam	0.206 b ± 0.02	15.48 b ± 1.94	38.50 a ± 2.58	16.78 b ± 2.12	4.29 b ± 1.07	21.03 b ± 1.07
CV (%)	11.13	9.6	8.82	9.48	18.56	5.12

Means followed by the same letter in the column do not differ from each other by the Scott-Knott test ($P<0.05$). CFM – commercial fresh mass, H – plant height, PD – plant diameter, NL – number of commercial leaves, SL – stem length, and SD – stem diameter.

The commercial fresh mass (CFM) reached by plants from white trays presented a limit higher than 250 g and lower than 300 g, i.e. class 25. Plants from gray, black, and styrofoam trays presented an average CMF higher than 250 g and lower than 200 g, i.e. class 20. In this context, the white PVC tray showed the lowest surface temperature of the substrate among the studied trays, which provided the best seedling development (Table 3).

CONCLUSIONS

The lowest values of substrate temperature were obtained from white trays, which provided the best seedling development and commercial lettuce plants. The styrofoam tray presented the lowest surface temperature when compared to polyvinyl chloride trays, but with no positive effect on the biometric variables of the crop.

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