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Agronomic characteristics and quality of lettuce cultivars in different crop seasons in western Alagoas, Brazil

Características agronômicas e qualidade de cultivares de alface em épocas de cultivo no oeste alagoano

Dalbert de F. Pereira[1]*, Thiago P. da Silva[2], Winandy. A. Freire[2], Ênio G. F. Souza[2], Ellen A. da Cruz[2], Regilane M. Feitosa[2]

[1]Department Agronomic and Forestry Sciences, Universidade Federal Rural do Semi-Árido, Mossoró, RN, Brazil. [2]Instituto Federal de Educação, Ciência e Tecnologia de Alagoas, Piranhas, AL, Brazil.

ABSTRACT - Growing lettuce under high temperatures and light incidence, as in the Alagoas State hinterland, Brazil, induces early tasseling and decreases the quality of the product. Thus, the objective of this work was to evaluate the production and post-harvest quality of lettuce cultivars in different crop seasons in western Alagoas, Brazil. A randomized block experimental design was used, with four replications. The treatments consisted of lettuce cultivars: Baba-de-Verão, Cinderela, Elba, Mônica, Solaris, and Veneranda. The winter crop was more favorable for plant diameter, except for Baba-de-Verão, whose performance was similar in both seasons and stood out in the summer. The winter crop resulted in better performance in plant height, stem diameter, and fresh matter yield, whereas summer plants reached larger number of leaves. The cultivar Mônica presented longer stem length, denoting lower tolerance to early tasseling and, therefore, it is not indicated to be grown in the region. The cultivar Baba-de-Verão (Lisa group) reached higher fresh matter yield, number of leaves per plant, and stem diameter, and it was the most adequate cultivar to be grown in western Alagoas. Elba, Solaris, and Veneranda were the lettuce cultivars from the Crespa group that stood out. Baba-de-Verão was the cultivar that presented the best performance for chlorophyll *a*, *b*, and total. The cultivar Solaris presented the highest carotenoid contents. Plants grown in the winter reached higher chlorophyll *a* and total, carotenoid contents, pH, and soluble solid (SS) to titratable acidity (TA) ratio, whereas the lettuce grown in the summer had higher SS and TA.

Keywords: *Lactuca sativa*. Performance. Post-harvest. Semiarid. Northeast region.

RESUMO - A alface, quando produzida em altas temperaturas e elevada luminosidade, como as encontradas no Sertão Alagoano, é induzida ao pendoamento precoce e à baixa qualidade. Em função disso, o objetivo foi avaliar a produção e a qualidade pós-colheita de cultivares de alface em função de épocas de cultivo distintas no oeste do Estado de Alagoas. O delineamento experimental foi em blocos ao acaso, com quatro repetições, sendo os tratamentos referentes às cultivares Babá-de-Verão, Cinderela, Elba, Mônica, Solaris e Veneranda. Para diâmetro de planta, o cultivo de inverno foi mais favorável, com exceção da Babá-de-Verão que manteve o desempenho semelhante nas duas épocas e destaque da cultivar no verão. O cultivo de inverno proporcionou melhor desempenho de altura de planta, diâmetro de caule e produtividade de massa verde, enquanto no verão as plantas atingiram maior número de folhas. A cultivar Mônica obteve maior comprimento do caule, indicando menor tolerância ao pendoamento precoce, não sendo indicada para o cultivo na região. A Babá-de-Verão (lisa) atingiu maior produtividade de massa verde, número de folhas por planta e diâmetro de caule, sendo a cultivar mais adequada para o cultivo no oeste de Alagoas. Dentre as crespas, destacaram-se as cultivares Elba, Solaris e Veneranda. A cultivar que apresentou melhor desempenho para clorofilas *a*, *b* e totais foi a Babá-de-Verão. A Solaris obteve maior teor de carotenoides. As plantas de inverno alcançaram maiores clorofilas *a* e totais, carotenoides, pH e relação sólidos solúveis totais (SS) e acidez total titulável (TA), enquanto a alface de verão obteve maior SS e TA.

Palavras-chave: *Lactuca sativa*. Desempenho. Pós-colheita. Semiárido. Nordeste.

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***Corresponding author:**
<dalbert.freitas@gmail.com >

INTRODUCTION

Lettuce (*Lactuca sativa*) is an herbaceous plant that has leaves fixed to a small stem and is sensitive to light and temperature. It is currently among the most important vegetables consumed fresh in Brazil, and a source of fibers, provitamin A, complex B vitamins, calcium, and ascorbic acid (SANTOS et al., 2015).

In the Northeast region of Brazil, the possibility of successive crops in the same year makes this vegetable the preferred by small farmers, presenting significant economic and social importance (SALA; COSTA, 2012). However, lettuce production in the Semiarid region of the Northeast of Brazil is lower when compared to regions with milder climates (YURI et al., 2017). It occurs because lettuce is directly affected by variations in temperature and light, which can change its development cycle (HAO et al., 2021).

Lettuce grown in adverse environmental conditions may present physiological changes that accelerate its reproduction stage (HAO et al., 2021). Lettuce flowering is marked by stem stretching, decreased number of leaves, emission of tassel, and accumulation of latex in their veins (which makes them bitter), devaluing the product (FILGUEIRA, 2008).

Lettuce production depends on the genotype × environment interaction; thus, the choice of a cultivar is important for the success of the crop (SILVA et al., 2019a). The use of little adapted cultivars is the main responsible for low production and quality (GUIMARÃES et al., 2016). The use of cultivars adapted to regional conditions and the use of practices that focus on reducing the effects of high temperatures and light incidence can increase the yield of vegetables (SILVA et al., 2015; YURI et al., 2017; SOUZA et al., 2018; SILVA et al., 2019b). One of the challenges for lettuce production in the Semiarid region of Brazil is to know which cultivars present better yield and low susceptibility to early tasseling (MAGALHÃES et al., 2015).

Silva (2014) evaluated the performance and quality of 12 lettuce cultivars (Crespa, Lisa, Americana, and Mimosa groups) in different crop seasons under a semiarid climate region (Mossoró, Rio Grande do Norte, Brazil) and found that plants grown in the winter (maximum temperature of 34.17 °C and minimum of 21 °C) presented larger diameter (27.30 to 30.30 cm) and higher height (15.85 to 18.21 cm) and yield (16.27 to 23.19 Mg ha^{-1}) than those grown in the summer (maximum temperatures of 36.46 °C and minimum of 24.53 °C), which presented diameters from 21.46 to 25.31 cm, plant height from 11.64 to 14.83 cm, and yield from 6.89 to 9.49 Mg ha^{-1}). In addition, they showed that plants grown in the winter presented lower pH (5.94 to 5.99), higher acidity (2.19% to 2.25%), and lower soluble solid contents (3.78 to 4.16 °Brix) when compared to those grown in the summer (6.14 to 6.16, 1.67% to 1.98%, 4.22 to 5.13 °Brix, respectively).

However, little information is found on the performance of lettuce cultivars in the Semiarid region of the Northeast of Brazil, and few lettuce cultivars are recommended for growing under high temperature and light incidence conditions, as in western Alagoas. The planting of little adapted lettuce cultivars has made growers to harvest small plants with low commercial value or tasseled, which present a bitter flavor (SOUZA et al., 2018).

Studies have shown that farmers can increase the production and income in lettuce fields, offering a better-quality product and meeting the demands of the vegetable market. In this context, the objective of this study was to evaluate agronomic characteristics and post-harvest quality of lettuce cultivars grown in different crop seasons in western Alagoas, Brazil.

MATERIAL AND METHODS

Field experiments were conducted in two crop seasons: winter of 2019 (June 21 to August 9) and summer of 2020 (January 10 to February 27), at the Experimental Area of the Federal Institute of Alagoas (IFAL), Piranhas campus, western Alagoas, Brazil (9°37'22.42"S, 37°46'1.51"W, and 178 m of altitude). The climate of the region of Piranhas is BSh, tropical, semiarid, with a rainy season from April to July, according to the Köppen classification; the mean annual rainfall depth is 492.2 mm, with relative air humidity of approximately 74.4% and mean air temperatures varying from 23.5 to 28.2 °C (SANTOS et al., 2017).

Mean air temperature (°C), relative air humidity (%), and accumulated rainfall depth (mm) were monitored during the experiment through an automatic meteorological station of the Brazilian National Institute of Meteorology (INMET, 2020), in the IFAL, Piranhas campus (Figure 1).

A randomized block experimental design was used, with four replications. The treatments consisted of lettuce cultivars: Baba-de-Verão (Lisa group), and Cinderela, Elba, Mônica, Solaris, and Veneranda (Crespa group). The area of the experimental units was 1.00 m^2 (25 lettuce plants spaced 0.20 × 0.20 m) and the evaluation area was 0.36 m^2 (9 plants).

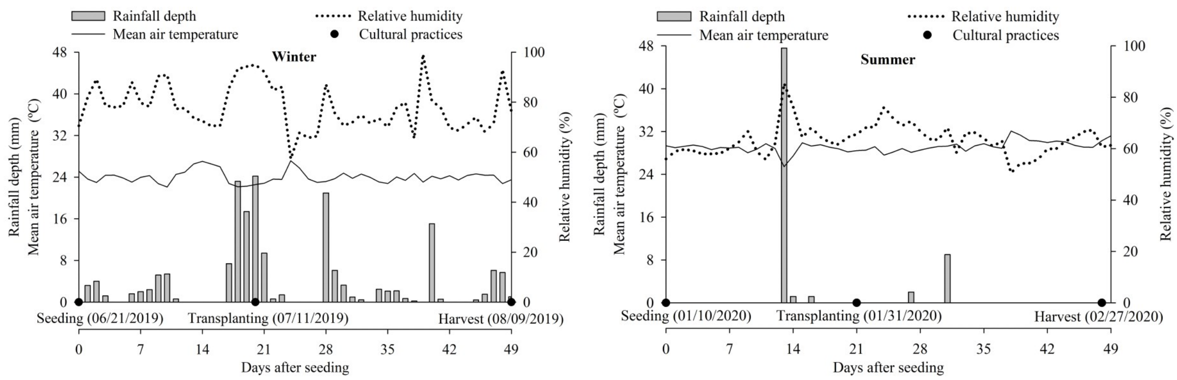

Figure 1. Mean air temperature (°C), relative air humidity (%), and rainfall depth (mm), and identification of cultural practices carried out for lettuce crops grown in the winter of 2019 and in the summer of 2020.

The cultivar Baba-de-Verão presents light-green smooth leaves, plant diameter between 20 cm and 30 cm, harvest time at 50 days after planting (DAP) in the summer and 70 DAP in the winter, and tolerance to heat (ISLA, 2022). The cultivar Cinderela has light-green curly leaves, harvest time between 60 and 65 DAP, and tolerance to early tasseling (FELTRIN, 2022a). The cultivar Elba has light-green curly leaves, mean diameter of 40 cm, harvest time at 65 DAP, and tolerance to early tasseling (AGRISTAR, 2022). The cultivar Mônica has green curly leaves and tolerance to high temperatures and to early tasseling (FELTRIN, 2022b). The cultivar Solaris has light-green leaves and harvest times between 40 and 50 DAP (SEMINIS, 2022). The cultivar Veneranda has light-green curly leaves, harvest times between 60 and 70 DAP, and tolerance to early tasseling (FELTRIN, 2022c).

The soil was prepared using two cross harrowing to a mean depth of 0.20 m, followed by manually raising of beds of 1.00 m width. Samples of the 0-0.20 m soil layer were analyzed before the planting in each experiment. The results before the winter crop were: pH H_2O = 6.70; P (mg dm^{-3}) = 220.00; K^+ ($cmol_c$ dm^{-3}) = 0.43; Ca^{2+} ($cmol_c$ dm^{-3}) = 10.80; Mg^{2+} ($cmol_c$ dm^{-3}) = 3.50; Na^+ ($cmol_c$ dm^{-3}) = 0.13; Al^{3+} ($cmol_c$ dm^{-3}) = 0.00. The results before the summer crop were: pH in H_2O = 7.15; P (mg dm^{-3}) = 40.55; K^+ ($cmol_c$ dm^{-3}) = 0.39; Ca^{2+} ($cmol_c$ dm^{-3}) = 11.95; Mg^{2+} ($cmol_c$ dm^{-3}) = 4.60; Na^+ ($cmol_c$ dm^{-3}) = 0.12; Al^{3+} ($cmol_c$ dm^{-3}) = 0.00. The soil fertilizers were applied based on technical recommendations for lettuce crops in the state of Pernambuco (SOUSA; SILVA; SILVA, 2008) and on the soil analysis of the experimental area.

The soil fertilizer applied at planting consisted of 30 kg ha^{-1} of N, 60 kg ha^{-1} of P_2O_5, and 30 kg ha^{-1} of K_2O, using ammonium sulfate (21% N), simple superphosphate (18% P_2O_5), and potassium chloride (60% K_2O), and 5 L m^{-2} of cured bovine manure. Topdressing consisted of application of 40 kg ha^{-1} of N (ammonium sulfate) at 15 days after transplanting (DAT), in both crop seasons.

Lettuce seeds were sown on June 21, 2019 (winter) and January 10, 2020 (summer), in 200-cell plastic trays arranged on a bench at one meter height, under a nursery screen (50% shade) in the IFAL, Piranhas campus. The trays were filled with a commercial substrate (Vivatto® Plus; TECHNES, 2021) based on pinus bark, charcoal, and expanded vermiculite.

Transplanting was carried out on July 11, 2019 and January 31, 2020, at 21 DAP, when the lettuce seedlings had three to four definitive leaves. Weed control was carried out through manual weeding on July 26, 2019 (winter) and February 12 and 20, 2020 (summer). The plants were irrigated by using a micro-sprinkler system and applying daily water depths according to the climate conditions and needs of the plants (MAROUELLI; SILVA; SILVA, 2008).

The harvests and evaluations were carried out on August 9, 2019 (29 DAT) in the winter, and on February 27, 2020 (27 DAT) in the summer, when the plants presented commercial standard, with the maximum vegetative development. Plant height (cm) was evaluated in the field, by measuring the plant with a ruler from the ground level to the end of the highest leaf; and plant diameter (cm) was measured with a ruler, considering the distance between the opposite margins of the leaf disc.

The plants were then harvested and taken to the Laboratory of Plant Production to evaluation of the following parameters: number of leaves per plant, determined by direct counting of number of leaves with lengths greater than 5 centimeters, non-senescent, and with no apparent damages; stem length (cm), determined by the distance between stem ends using a ruler; stem diameter (cm), measured in the center of the stem with a digital caliper; fresh matter yield (Mg ha^{-1}), estimated from the shoot fresh weight of all plants in the evaluation area, discarding 30% of the area (traffic between beds); and dry matter yield (Mg ha^{-1}), estimated from the shoot dry weight of plants in the evaluation area, after drying them in a forced air circulation oven at 65 °C, until constant weight (also discarding 30% of the area used for traffic between beds).

Soluble solid (SS) (°Brix) was determined directly in the homogenized leaf extract through readings in a manual refractometer (Model GT427, Lorben); pH was measured in an aliquot of leaf extract (approximately 10 g of leaves) with 100 mL of distilled water, with the aid of a pHmeter (Model LUCA-210, Lucadema). Titratable acidity (TA) (%) was determined in the same extracts used to determine pH, using potentiometric volumetry, based on potentiometric titration of samples with sodium hydroxide solution, which determines the equivalence point by measuring the solution pH; the titration was carried out in a 0.1 M sodium hydroxide solution up to a pH range of 8.2 to 8.4, according to analytical procedures described by the Adolfo Lutz Institute (IAL, 2008). Soluble solid to titratable acidity ratio (SS/TA) was determined by the quotient between these two characteristics.

Chlorophylls and carotenoids (μg g^{-1}) were also evaluated (LICHTENTHALER; WELLBURN, 1983). Leaf samples of approximately 200 mg were placed in a mortar and 0.2 g of $CaCO_3$ and 3 mL of 80% acetone were added. It was homogenized and 2 mL of 80% acetone was added to a final volume of 5 mL. This procedure was carried out in a dark environment. The extract was centrifuged in chilled centrifuge (Universal 320R, Hettich) for 10 minutes at a temperature of 10 °C and rotation of 3,000 rpm. The supernatant was then transferred to a 10 mL graduated cylinder and the volume was determined. Aliquots were taken and read in a spectrophotometer (New 2000, Femto) at wavelengths of 470 nm, 646 nm, and 663 nm. The chlorophyll and carotenoid concentrations were calculated through the following formulas (LICHTENTHALER; WELLBURN, 1983): Chlorophyll *a* (μg g^{-1}) = $20.13A_{663} - 2.81A_{646}$; Chlorophyll *b* (μg g^{-1}) = $20.13A_{663} - 5.03A_{646}$; Total Chlorophyll (μg g^{-1}) = Chlorophyll *a* + Chlorophyll *b*; Carotenoids (xanthophylls + carotenes) (μg g^{-1}) = $1{,}000A_{470}$ - 3.27 Chlorophyll *a* - 104 Chlorophyll *b*) / 229.

Analyses of variance were carried out for the evaluated characteristics in the Sisvar 5.6 program (FERREIRA, 2011). The joint analyses were carried out for the characteristics with homogeneity of variance between the crop seasons, according to Pimentel-Gomes (2009). The Tukey's test ($p<0.05$) was used for comparison of means.

RESULTS AND DISCUSSION

Considering the agronomic characteristics evaluated, the interaction between crop seasons and lettuce cultivars was significant for plant diameter. Isolate effect of cultivars was found on plant height, number of leaves per plant, stem length, stem diameter, and fresh matter yield, whereas the crop seasons had significant effect on plant height, number of leaves per plant, stem diameter, and fresh matter yield.

In the winter crop, there was no difference between the lettuce cultivars for plant diameter, presenting a mean of 27.14 cm (Table 1). In the summer, Baba-de-Verão (23.39 cm) differed significantly from the cultivar Mônica (19.43 cm), and was statistically equal to the cultivars Cinderela (22.35 cm), Elba (21.64 cm), Solaris (22.14 cm), and Veneranda (22.56 cm). The winter crop resulted in a larger plant diameter when compared to the summer crop, except for Baba-de-Verão, which had similar performance.

Table 1. Means for plant diameter of lettuce cultivars grown in two crop seasons in western Alagoas, Brazil.

Cultivars	Plant diameter (cm)	
	Crop Seasons	
	Winter	Summer
Baba-de-Verão[1]	25.75 aA	23.39 aA
Cinderela	27.71 aA	22.35 abB
Elba	27.43 aA	21.64 abB
Mônica	29.43 aA	19.43 bB
Solaris	25.90 aA	22.14 abB
Veneranda	26.62 aA	22.56 abB

[1]Means followed by the same lowercase letter in the columns, or uppercase letters in the rows, are not significantly different from each other by the Tukey's test at 5% probability level.

Diameter is a characteristic connected to photosynthetic and water retention capacities of cultivars, reflecting the adaptability of plants to the crop region (PORTO et al., 2014). Silva (2014) evaluated the performance of 12 lettuce cultivars in different crop seasons in Mossoró, Rio Grande do Norte (RN), Brazil, and found that the cultivars presented similar diameters in winter and summer crops, with means of 28.76 cm and 23.30 cm, respectively. They also found that the lettuce from the groups Lisa, Crespa, Americana, and Mimosa reached larger diameters (28.86, 27.37, 29.01, and 30.32 cm, respectively) during the winter, with a decrease in the summer for all groups (25.31, 21.46, 23.37, and 24.37 cm, respectively). These results are consistent with those found for plant diameter of the evaluated cultivars in each crop seasons, except for Baba-de-Verão.

The cultivar Mônica presented mean plant height of 20.50 cm (Table 2), which was higher than that of Solaris (15.94 cm) and Veneranda (15.93 cm) and a similar result to those found for Baba-de-Verão (17.65 cm), Cinderela (16.70 cm), and Elba (17.99 cm). The winter crop resulted in higher lettuce plants than the summer (Table 3).

The mean temperature was 23.9 °C in the winter and 29.2 °C in the summer (Figure 1). The higher temperatures in the summer probably caused changes in the metabolism and speeds of biochemical reactions in the plants (HAO et al., 2021). An accelerated crop cycle results in formation of plants with lower sizes due to an early reproduction stage (YURI et al., 2017). Silva (2014) reported that the plant height of lettuce from the groups Crespa, Mimosa, Americana, and Lisa were 15.85, 18.21, 16.85, and 17.44 cm in the winter crop, with higher results than those found in the summer, 11.64, 12.58, 12.44, and 14.83 cm, respectively.

Table 2. Means for plant height (PH), number of leaves (NL), stem length (SL), stem diameter (SD), and fresh matter yield (FMY) of lettuce cultivars grown in two crop seasons in western Alagoas, Brazil.

Cultivars	PH (cm)	NL (leaves plant^{-1})	SL (cm)	SD (cm)	FMY (Mg ha^{-1})
Baba-de-Verão	17.65 ab[1]	27.60 a	5.33 b	2.17 a	26.93 a
Cinderela	16.70 ab	17.81 b	4.78 b	1.65 b	17.40 b
Elba	17.99 ab	17.72 b	4.01 b	1.65 b	19.81 ab
Mônica	20.50 a	14.65 b	10.69 a	1.62 b	20.04 ab
Solaris	15.93 b	14.72 b	3.46 b	1.51 b	20.72 ab
Veneranda	15.94 b	15.01 b	3.36 b	1.52 b	19.34 ab

[1]Means followed by the same lowercase letter in the columns are not significantly different from each other by the Tukey's test at 5% probability level.

Table 3. Means for plant height (PH), number of leaves (NL), stem diameter (SD), and fresh matter yield (FMY) of lettuce cultivars grown in two crop seasons in western Alagoas, Brazil.

Crop seasons	PH(cm)	NL (leaves plant^{-1})	SD (cm)	FMY (Mg ha^{-1})
Winter	19.46	16.44	1.81	25.68
Summer	15.44	19.39	1.56	15.73

The number of leaves varied between 14.65 and 27.60 leaves per plant; Baba-de-Verão (Lisa) had larger number than the other Crespa cultivars, which did not significantly differ from each other (Table 2). These results are consistent with those found by Souza et al. (2018), who evaluated lettuce cultivars with different ages at harvest during the spring-summer in Mossoró, RN, Brazil (Semiarid region) and found 32.92, 31.60, and 32.17 leaves per plant for Lisa lettuce cultivars (Baba-de-Verão, Livia, and Aurelia), respectively, at 30 DAT, with larger numbers than the Crespa cultivars.

Number of leaves is probably a genetic attribute of each cultivar; Lisa cultivars present larger number of leaves under experimental conditions, although the sensitivity to high temperatures can lead to an early tasseling, limiting the genetic potential for production of leaves (AQUINO et al., 2017; DALASTRA et al., 2016; FIORINI et al, 2016).

The mean number of leaves per plant grown in the summer was 19.39, differing from that in the winter, which was 16.44 leaves (Table 3). In addition to the genetic factor, there is a linear correlation between increases in air temperature and leaf emission rate in these plants (TEZZA; MINUZZI, 2019). In the present study, the highest temperatures during the summer (29.2 °C), compared to the winter (23.9 °C), probably affected the leaf emission, resulting in a larger number of leaves, but in plants with lower mean diameters (Table 1).

Lower results were found by Sousa et al. (2018), who evaluated Americana lettuce in different crop seasons and reported that the mean number of leaves per plant in the summer and winter in Mossoró was 11 leaves per plant, with no difference between crop seasons. Lettuce is a leaf vegetable; thus, the consumer focuses on the product appearance, such as number of leaves and volume (DIAMANTE et al., 2013). The market in Brazil has followed the trend of focusing on fresh products, and plants with larger number of leaves are desirable to meet this demand (SALA; COSTA, 2012).

The cultivar Mônica reached a mean stem length of 10.69 cm, higher than the other cultivars (Table 2). Plants with longer stems probably result in taller plants (Table 2); thus, lettuce plants of the cultivar Mônica presented low adaptability to the edaphoclimatic conditions of Piranhas, Alagoas, Brazil. However, Pinto et al. (2017) found shorter stem length for the cultivar Mônica (6.3 cm) when evaluating the development and production of Crespa lettuce in Crato, Ceará, Brazil, under experimental conditions and maximum mean temperature of 35 °C.

Lettuce cultivars may present specific growth and morphology characteristics and changes due to environmental factors, such as temperature and light incidence (NEVES et al., 2016). Long times with temperatures higher than those tolerated by the plant (15.5 to 18.3 °C), as occurs in western Alagoas, can cause acceleration of the reproduction stage, marked by stem stretching, emission of tassel, and accumulation of latex in leaf veins, which is responsible for a bitter flavor (FILGUEIRA, 2008).

Baba-de-Verão presented larger stem diameter (mean of 2.17 cm) than the other cultivars, which did not differ from each other (Table 2). Plants grown in the winter reached a mean stem diameter of 1.81 cm, which was higher than that found in the summer (1.56 cm) (Table 3). Information on stem diameter and length are important from the commercial point of view, as they affect the crop quality and tolerance to adverse climate conditions; smaller stems are preferred for the marketing and present resistance to flowering (RESENDE et al., 2010).

Porto et al. (2014) evaluated the dynamics of lettuce cultivars in western Rio Grande do Norte, Brazil, in an ecological system with minimum and maximum temperatures of 27.4 °C and 32.1 °C, respectively; they reported stem diameters of 1.89 cm (Winslow American), 1.76 cm (Maravilha 4 Estacões Roxa Manteiga), 13.87 cm (Mimosa Red Salad Bowl), 1.82 cm (Scarlat), 2.03 cm (Maravilha de Verão Manteiga), 2.53 cm (Elba), and 2.13 cm (Grand Rapids TBR). Sousa et al. (2018) evaluated the performance of Crespa lettuce grown in the summer in the Central-West region of Brazil (Jataí, Goiás), under temperatures of 19.6 °C (minimum), 26.1 °C (mean), and 34.9 °C (maximum), with harvest at 45 DAT; they found larger stem diameter for the cultivars Solaris and Veneranda, which presented a mean of 2.50 cm.

The fresh matter yield varied from 17.40 Mg ha^{-1} to 26.93 Mg ha^{-1}. The cultivar Baba-de-Verão reached the highest yield, statistically differing from the cultivar Cinderela, which presented the lowest production (Table 2). Baba-de-Verão presented a similar fresh matter yield to those of the cultivars Elba (19.81 Mg ha^{-1}), Mônica (20.04 Mg ha^{-1}), Solaris (20.72 Mg ha^{-1}), and Veneranda (19.34 Mg ha^{-1}). Similarly, Souza et al. (2018) found 28.08 Mg ha^{-1} for Baba-de-Verão when harvested at 35 DAT in Mossoró, which differed from the cultivars Livia (23.38 Mg ha^{-1}), Aurelia (20.12 Mg ha^{-1}), Jullie (23.22 Mg ha^{-1}), Elba (23.16 Mg ha^{-1}), and Maravilha 4 Estações (22.80 Mg ha^{-1}). The higher yield of Baba-de-Verão may be connected to its adaptability to the high temperature of the region (SOUZA et al., 2018).

The winter conditions improved the lettuce mean fresh matter yield (25.68 Mg ha^{-1}) when compared to the summer crop (15.73 Mg ha^{-1}) (Table 3). Lettuce plants are native to Mediterranean temperate regions; thus, they have an ideal growth from approximately 15.5 °C to 18.3 °C, can tolerate short periods between 26.6 and 29.4 °C and mild night temperatures (YURI et al., 2017). Therefore, crop seasons with lower temperatures favor the development of lettuce plants (SALA; COSTA, 2012).

Soares et al. (2020) evaluated lettuce production in hydroponic system in different crop seasons in Lagoa Seca, Paraíba, Brazil, and found fresh matter yield of 27.19 Mg ha^{-1} for the cultivar Regiane in the winter crop, with a decrease in the summer crop (19.87 Mg ha^{-1}), as found in the present study.

The dry matter yield presented no significant differences, with a mean of 1.04 Mg ha^{-1}. Growing lettuce under high light incidence conditions results in higher dry matter accumulation due to a lower water potential in the leaves (SOUZA et al., 2018). In the summer, the dry matter content was 7.02%, higher than that in the winter (4.28%). Thus, the dry matter yield in the summer was equivalent to that in the winter, despite the lower fresh matter yield. Dry matter is an important information on the amount consumed and metabolized by the organism (SOUZA et al., 2018).

Regarding the post-harvest characteristics, according to the joint analysis, there was an isolate effect of cultivars on chlorophylls *a*, *b* and total, carotenoids, and soluble solid (SS). Chlorophylls *a* and total, carotenoids, SS, pH, titratable acidity (TA)**,** and SS to TA ratio were affected by the crop seasons.The cultivar Baba-de-Verão stood out with a mean chlorophyll *a* content of 7.73 µg g^{-1} (Table 4), whereas the other cultivars did not differ from each other.

The chlorophyll *a* content was higher in the winter crop (6.62 µg g^{-1}) (Table 5). Freire et al. (2019) evaluated chlorophyll *a*, *b*, and total in Crespa lettuce in different crop seasons in Palmas, Tocantins, Brazil, and found higher values, with mean chlorophyll *a* of 13.72 µg g^{-1} and 14.33 µg g^{-1}, respectively, for conventional and organic crop systems. Chlorophyll *a* is a main photosynthetic source, responsible for conversion of light into chemical energy in plants (OLIOSI et al., 2017). In the present study, a higher chlorophyll *a* than chlorophyll *b* was found (Table 4), which confirms the results of Rosa et al. (2014), who reported a higher abundance of chlorophyll *a*, corresponding to approximately 75% of green pigments in plants.

The cultivar Baba-de-Verão presented the highest means for chlorophyll *b* (5.16 µg g^{-1}) and total chlorophyll (12.89 µg g^{-1}); the values found for the other cultivars were lower and did not differ from each other (Table 4). Total chlorophyll content was higher in the winter (10.46 µg g^{-1}) than in the summer (9.21 µg g^{-1}) (Table 5).

Table 4. Means for chlorophylls *a*, *b*, and total, carotenoids, and total soluble solids (SS) of lettuce cultivars grown in western Alagoas, Brazil.

Cultivars	Chlorophyll *a* (µg g^{-1})	Chlorophyll *b* (µg g^{-1})	Total chlorophyll (µg g^{-1})	Carotenoids (µg g^{-1})	SS (°Brix)
Baba-de-Verão	7.73 a[1]	5.16 a	12.89 a	0.54 b	4.98 a
Cinderela	5.76 b	3.73 b	9.49 b	0.86 ab	4.82 a
Elba	5.84 b	3.63 b	9.47 b	0.86 ab	4.84 a
Mônica	5.95 b	3.62 b	9.57 b	0.91 ab	4.81 a
Solaris	5.40 b	3.26 b	8.66 b	1.02 a	4.51 a
Veneranda	5.45 b	3.47 b	8.92 b	0.94 ab	4.37 a

[1]Means followed by the same lowercase letter in the columns are not significantly different from each other by the Tukey's test at 5% probability level.

Table 5. Means for chlorophylls *a* and total, carotenoids, total soluble solids (SS), pH, titratable acidity (TA), and soluble solid to titratable acidity ratio (SS/TA) of lettuce plants grown in different crop seasons (winter and summer) in western Alagoas, Brazil.

Crop season	Chlorophyll *a* (µg g^{-1})	Total chlorophyll (µg g^{-1})	Carotenoids (µg g^{-1})	SS (°Brix)	pH	TA (%)	SS / TA
Winter	6.62	10.46	1.01	4.48	6.24	0.56	8.14
Summer	5.42	9.21	0.69	4.97	6.13	0.68	7.28

Chlorophyll *b* is an important characteristic for plant adaptability, as it absorbs energy at different wavelengths than chlorophyll *a* and transfers it to reaction centers, thus maximizing the capture of energy that effectively acts in photochemical reactions (TAIZ; ZEIGER, 2004). According to Cazzonelli (2011), the amount of chlorophyll *b* is connected to the photosystem II; the concentration of this pigment is higher than chlorophyll *a* in this photosystem, enabling the plants to adapt to environments with low incidence of light.

The summer crop of lettuce may have caused oxidative stress, resulting in a higher total chlorophyll in the winter (Table 5). Some climatic and genetic factors may interfere with the good development of crops by affecting photosynthesis, which can cause variations in total chlorophyll contents. The depigmentation of lettuce leaves under an unsaturated atmosphere may be connected to a high exposure to light, oxygen, and low relative air humidity (SCHMITZ et al., 2020). Regarding the genetic factor, Rosa et al. (2014) found differences between chlorophyll contents in Mimosa Roxa and Mimosa Verde lettuces under the same crop environment.

The cultivar Solaris had the highest mean carotenoid contents (1.02 µg g^{-1}), which was a similar result to those found for the cultivars Veneranda, Mônica, Elba, and Cinderela (Table 4). The winter crop resulted in higher carotenoid contents: 1.01 μg g^{-1} (Table 5).

The carotenoid bioavailability is associated with environmental and genetic factors and with the nutritional status of the plant; the carotenoid content is highly correlated with solar radiation, as plants grown under full sun produce greater amounts of this pigment, which acts as a photoprotector molecule by dissipating excited states of chlorophyll (TAIZ; ZEIGER, 2004). However, this information diverges from the results obtained in the present study, in which the solar radiation and mean air temperature were higher in the summer (Figure 1) and the carotenoid contents were lower when compared to those found in plants grown in the winter (Table 5).

The biosynthesis of carotenoids is regulated dynamically throughout the plant development and controlled by several factors, such as plant developmental stage and environmental conditions (CAZZONELLI, 2011). Martins (2016) found similar values, varying from 0.56 to 0.71 μg g^{-1} of fresh sample, when evaluating lettuce cultivars under hydroponic, conventional, and organic systems; they explained that this difference in relation to the other results can be attributed to variations in edaphoclimatic and other conditions that affect bioactive compound contents and the size and number of leaves per plant.

Despite the significant effect of cultivars, the Tukey's test showed no differences between the means of SS in the cultivars, which presented an overall mean of 4.72 °Brix (Table 4). SS contents are responsible for the sweet flavor of the food and can be affected by climatic and genetic factors (SILVA et al., 2016). Vicentini-Polette et al. (2018) found a mean SS of 2.6 °Brix for the lettuce cultivar Crocantela grown in hydroponic system, which is lower than that found in the present study. SS contents may vary from species to species, according to soil fertilizer/nutritive solution used, climate, and plant genetics (SILVA et al., 2011).

The summer lettuce crop presented higher mean SS (4.97 °Brix) than the winter (4.48 °Brix) (Table 5). It can be explained by the higher mean air temperature (29 °C), lower relative air humidity (63.4%), and lower rainfall depth (60 mm) in the summer crop when compared to the winter (24 °C, 78.1%, and 178.9 mm, respectively) (Figure 1). According to Brecht (2010), environments with high temperatures tend to increase the SS contents, since the heat activates the respiratory metabolism. Similarly, Porto et al. (2014) evaluated the dynamics of lettuce cultivars (Elba, Grand Rapids TBR, Maravilha de Verão Manteiga, Scarlat, Mimosa Red Salad Bowl, Maravilha 4 Estações Roxa Manteiga, and Winslow Americana) in western Rio Grande do Norte (Governador Dix-Sept Rosado, RN, Brazil) and found SS contents varying from 3.55 to 5.07 °Brix.

The pH of lettuce plants in the winter was 6.24, which was higher than that in the summer (6.13) (Table 5). Similarly, Sanches et al. (2017) found pH within this range (5.33 to 6.30) for lettuce cultivars (Alcione, Amanda, and Caipira) when evaluating days of storage of minimally processed lettuce grown in hydroponic system.

The mean TA found for the winter and summer seasons were 0.56% and 0.68%, respectively (Table 5). The highest TA was found for plants grown in the summer, which can be explained by the fact that lettuce plants begin the tasseling process earlier than in the winter, storing more organic acids due to climate factors (Figure 1). The proportion of acids in food is important after the harvest period, as the accumulated acid serves as a reserve source and is also responsible for the acid flavor of the food (CHITARRA; CHITARRA, 2005). According to Pelosi and Azevedo-Meleiro (2014), organic acids are important for respiratory metabolism and as compounds of reserve in vegetables.

The mean soluble solid to titratable acidity ratio (SS/TA) in lettuce plants was higher in the winter crop (8.14) than in the summer (7.28) (Table 5). This ratio is consistent with the amounts of sugars and acids present in the food; the higher the ratio, the better the maturation point of the food. SS/TA is important for inferring the sugar and acid contents in the food, which result in the flavor of fresh plants (NENNING et al., 2019). It is also an important parameter among the variables analyzed at post-harvest, as it determines the time that the product can have ideal organoleptic characteristics for consumption (CHITARRA; CHITARRA, 2005).

CONCLUSIONS

Baba-de-Verão was the most productive lettuce cultivar when grown in western Alagoas, Brazil, followed by the cultivars Elba, Solaris, and Veneranda. The cultivar Mônica presented longer stem length, denoting lower tolerance to early tasseling. Baba-de-Verão presented the highest chlorophyll contents and Solaris presented the highest carotenoid contents. The winter crop season resulted in higher yield and post-harvest quality for the lettuce crops grown in western Alagoas.

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