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ORIGINAL RESEARCH ARTICLE

Growth analysis in lettuce cultivars under the conditions of southern Piauí

Alan Mario Zuffo[1]*, Joacir Mario Zuffo Júnior[2], Luana Maria Alves da Silva[3], Roberto Lustosa da Silva[3], Karen Oliveira de Menezes[3]

*[*1] Universidade Federal de Lavras, Lavras, Minas Gerais, Brazil. E-mail: alan_zuffo@hotmail.com*

[2] Universidade do Estado de Mato Grosso, Nova Xavantina, Mato Grosso, Brazil.

[3] Universidade Federal do Piauí, Bom Jesus, Piauí, Brazil.

ABSTRACT

The objective of this study was to evaluate the growth of four lettuce cultivars in Southern Piauí to recommend the best ones for the region. The experiment was conducted in a greenhouse with randomized blocks, with evaluation in subdivided time plots, evaluated in six seasons (20, 24, 28, 32, 36, 40 days after sowing—DAS) and with treatments corresponding to four cultivars (Americana Rafaela®, Grand Rapids TBR®, Crespa Repolhuda® and Repolhuda Todo ano®) with five repetitions. Leaf area, number of leaves, collar diameter, aboveground fresh mass, aboveground dry mass, root dry mass and total and the physiological indices of growth analysis were evaluated. The lettuce cultivars interfered significantly in the studied parameters, being that Americana Rafaela® and Repolhuda todo ano®, in the conditions that they were submitted, presented better performances and bigger morphophysiological indexes, cultivated in pot. The cultivars Americana Rafaela® and Repolhuda todo ano® can be produced under the conditions of the south of Piauí.

Keywords: Vegetables; Physiological Indices; *Lactuca Sativa* L.

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1. Introduction

Lettuce (*Lactuca sativa* L.) stands out among the most consumed leafy vegetables in Brazil, for its importance as a source of vitamins, minerals and fiber[1,2].

Although the lettuce culture is explored throughout the national territory, in the Northeast region the production is low, if compared to other regions with a mild climate, not meeting the internal demand, given the growing consumption of the vegetable and its low production[3]. Among the factors related to low yields, the lack of research on cultivars adapted to the region, as well as technical information on plant growth, to better manage the crop under these conditions stand out[4].

The study of growth analysis is widely used to follow the growth pattern of the plant or parts of it, allowing to infer the contribution of different physiological processes to plant growth, being useful in the study of variations between plants genetically different or under different environmental conditions[5,6]. This study is based on photosynthetic production along the ontogenetic development of the crop, allowing to know the accumulation of organic matter in plants, its distribution and efficiency in natural or controlled environment[7].

The relationships between climatic conditions and agricultural production are complex, because they directly affect the growth and development of the plants, in different ways, in the various stages of the cultures[8]. For Gomes *et al*.[9], lettuce cultivation has limitations, mainly because of its sensitivity to adverse conditions of temperature, humidity and rain. Among them, air temperature is the main variable that determines the growth rate of the crop, changing the total period for growth needed to reach the harvest point[10]. However, the photoperiod is also a limiting factor, in relation to which the plant requires short days, during the vegetative phase, and long days, so that the setting occurs; when there is an association between long days and high temperatures, it further accelerates the setting[11–13].

Cultivar recommendations have been made by seed producing companies, but these materials are not always adapted to a wide range of environments[14]. The adaptation of a cultivar to a wide range of environments is considered of interest to the producer, when he proposes to increase cultivation[15]. Difficulties arise when different environmental factors affect the growth and development of the lettuce crop. Therefore, several studies have been conducted to evaluate the performance of cultivars in different regions of Brazil[16–21], with significant results.

The south of the state of Piauí, specifically in Bom Jesus, is characterized by high temperatures, with an average of 26.5 °C, although temperatures close to 40 °C are common during the year[22]. Considering that the biggest challenge is to select cultivars that show high productivity under high temperatures, this study aimed to evaluate the growth of four lettuce cultivars in the conditions of southern Piauí to recommend the best ones for the region.

2. Material and methods

The experiment was conducted in a vegetation house, covered by shading screen, with 50% light interception, on the Campus of the Federal University of Piauí (UFPI), in Bom Jesus, PI (09°04′28″ S, 44°21′31″ W and with an average altitude of 277 m), from August 13 to September 22, 2012.

The climate of the region is type Aw, according to Koppen's global climate classification, with two well-defined seasons, being a dry season from May to September and a wet season from October to April. The climatic data (**Figure 1**) were collected at the weather station of the National Institute of Meteorology, located approximately 200 meters from the experimental site, at 10 am, 12 noon and 3 pm, and the average values between the three periods were calculated.

The soil used in the experiment was identified as yellow dystrophic Latosol and was collected in the 0–0.20 m layer. The soil had the following granulometric composition: 640, 80 and 280 $g \cdot kg^{-1}$ of sand, silt and clay, respectively. The chemical composition is presented in **Table 1**.

The experimental design used was a randomized block design, with evaluation done in plots subdivided in time. The treatments consisted of four lettuce cultivars (plots): Americana Rafaela®, Grand Rapids TBR®, Crespa Repolhuda® and Repolhuda Todo ano®, evaluated at six sampling times for crop growth analysis (subplots): 20, 24, 28, 32, 36, 40 days after sowing (DAS), making up 24 treatments, with five repetitions, with each treatment consisting of three pots with one plant each.

The lettuce cultivars were sown directly into rigid black polyethylene pots filled with 5 dm^3 of substrate, consisting of a mixture of soil (60%), tanned bovine manure (30%) and carbonized rice hulls (10%). The sowing was performed with five seeds per pot, with subsequent thinning, leaving only one seedling per pot. During the experiment, daily irrigations were performed to replace the evapotranspirated water and maintain the field capacity of the soil. The soil pH was corrected to increase the base saturation to 80%[23].

Successive collections of three plants per plot were made from the twentieth DAS, at regular intervals of four days, until the point of harvest, which had its cycle reduced due to high temperatures and the fact that sowing was done directly at the growing site, without transplanting. In each collection, the following variables were evaluated: leaf area (LA) (cm^2): by the electronic leaf area meter (Li-Cor, L1-3100®); number of leaves (NL) (unit); co-bullet diameter (CD) (mm): measured at the height of the neck of the plant soil surface by means of readings in digital Clarke pachymeter®; fresh

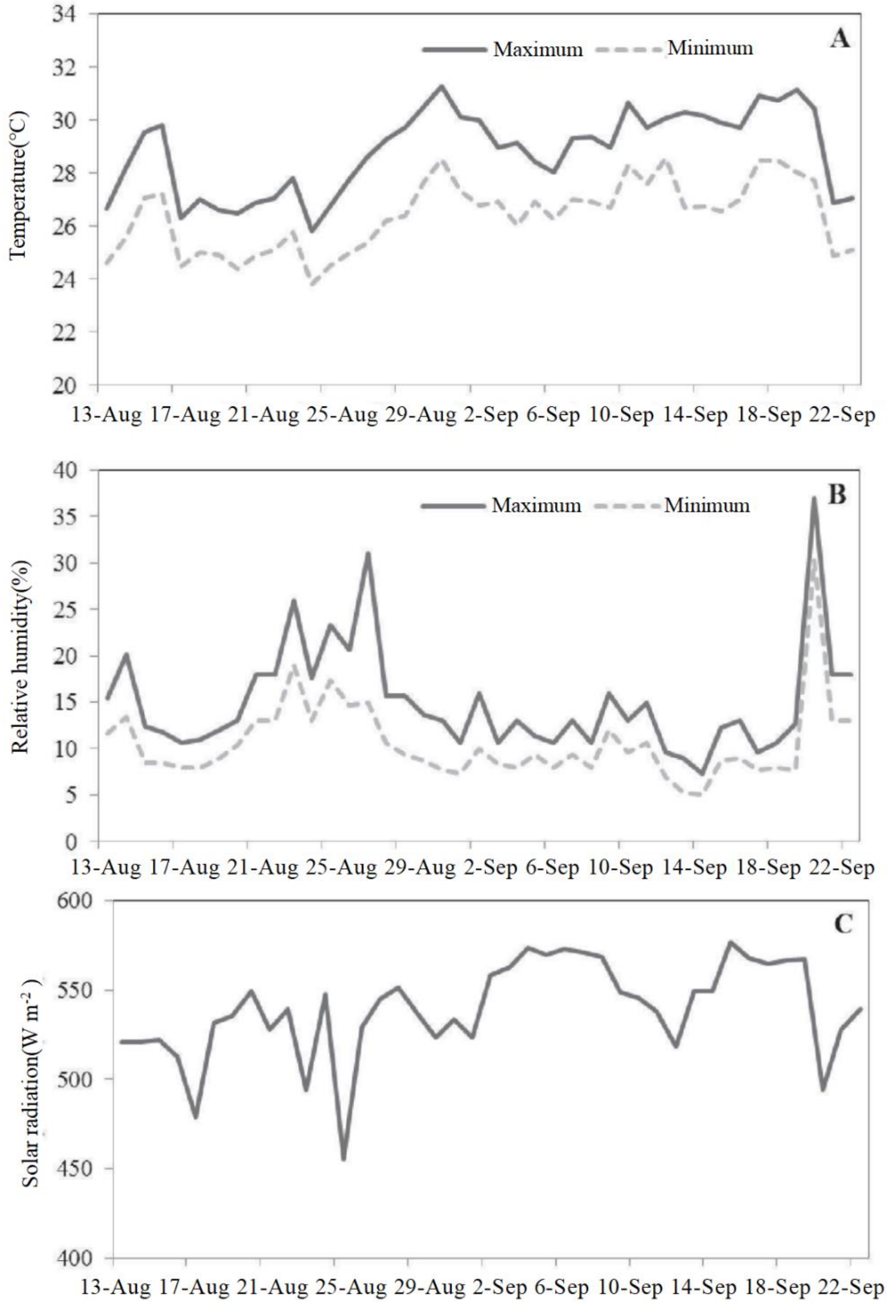

Figure 1. Average values of air temperature, maximum and minimum **(A)**; relative humidity, maximum and minimum **(B)**; solar radiation **(C)** in Bom Jesus, PI, data collected at 10, 12 and 15 hours, between August 13 and September 22, 2012.
Note: Average solar radiation ($W \cdot m^{-2}$) corresponds to an average of the three hours of observation per day (INMET meteorological station—Bom Jesus station, PI).

Table 1. Chemical composition of soil collected in the layer (0–0.20 m) of the experimental area, before installation of the experiment

pH $CaCl_2$	Ca^{2+}	Mg^{2+}	Al^{3+}	$H^+ + Al^{3+}$	SB	CTC	P	K	MO	V
	$cmol \cdot dm^{-3}$						$mg \cdot dm^{-3}$		$g \cdot kg^{-1}$	%
4.60	2.10	1.00	1.10	3.10	2.80	6.39	47.00	74.00	15.00	51.49

H +Al: potential acidity; SB: sum of bases; CEC: cation exchange capacity at pH 7.0; MO: organic matter; V: base saturation.

mass of the aerial part (MFPA), dry mass of the aerial part (MSPA), root (MSR) and total (MST) (g): material submitted to drying in an oven with forced air circulation, at a temperature of 60 °C, for 72 hours, weighed in a digital scale (precision 0.01 g).

With these data, the physiological indices of growth analysis were calculated, according to Benincasa[7]. The absolute growth rate (AGR), the relative growth rate (RGR), the net assimilation rate (NAR), the leaf area ratio (LAR), the leaf weight ratio (LWR), and the relative growth rate of leaf area (RGR-AF) were determined for each evaluation.

The AGR, in g·d^{-1}, is calculated by the formula AGR = $(MST_2 - MST_1)/(T_2 - T_1)$, where MST_2 is the current total dry mass of the aerial part (g); MST_1 is the initial total dry mass of the aerial part (g); $T_2 - T_1$ is the time interval between two collections (4 days). The rate of RGR, in g·g^{-1} per·d^{-1}, is calculated by the formula RGR = $(\ln MST_2 - \ln MST_1)/(T_2 - T_1)$, where, ln is the Neperian logarithm. NAR is calculated by the formula NAR = $[(MST_2 - MST_1)/(T_2 - T_1)][(\ln AF_2 - \ln AF_1)/(AF_2 - AF_1]$, where AF_2 and AF_1 correspond to the current total leaf area of the aerial part (cm^2) at times T_2 and T_1, respectively. The LAR, in cm^{-2}·g^{-1} is calculated by the formula LAR = AF/MST, where AF is the actual leaf area (cm^2); MST is the actual total dry mass (g). The LWR is calculated using the formula LWR = SFM/MST, where SFM is the current leaf dry matter (g) and MST is the current total dry mass (g), its value expressed in g·d^{-1}. The RGR-AF, in cm²·d^{-1}, is calculated by the formula RGR-AF = $(\ln AF_2 - \ln AF_1)/(T_2 - T_1)$, where AF_2 is the current total leaf area of the aerial part (cm^2) and ln is the Neperian logarithm.

The comparison between the means for the sources of variations and their interactions was performed by the Tukey test at 5% probability, using the statistical program Sisvar®[24]. The variables studied throughout the growing cycle were analyzed by polynomial regression, in which the equations were adjusted, using the correlation and determination parameters for the variables evaluated, as a function of the growing seasons and the lettuce cultivars, using the statistical program SigmaPlot®. As for the physiological parameters calculated in the growth analysis, no analysis of variance was performed. According to Banzatto & Kronka[25], one cannot affirm that the calculated variables obey the basic assumptions for this type of analysis.

3. Results and discussion

Table 2 shows the abstract of the analysis of variance (F values) of the characteristics AF, NF, DC, MFPA, MSPA, MSR, MST of lettuce cultivars as a function of the evaluation periods. In general, it was verified that the evaluated parameters were significantly ($p < 0.01$) influenced by the cultivars and the evaluation periods (**Table 2**). It is also possible to verify significant interactions ($p < 0.01$) among the factors studied, indicating that there is interdependence among them.

Table 2. F values for leaf area (AF), number of leaves (NF), neck diameter (DC), aboveground fresh mass (MFPA), aboveground dry mass (MSPA), root dry mass (MSR), total dry mass (MST) of lettuce cultivars (*Lactuca sativa* L.) grown in pots, as a function of cultivars and evaluation periods

Sources of Variation -	**AF (cm^2)**	**NF (units)**	**DC (mm)**	**MFPA (g)**	**MSPA**	**MSR**	**MST**
Cultivars (C)	157.24**	79.74**	17.76**	94.00**	29.45**	25.55**	30.57**
Kohlrabi Cabbage Curly®	495.35 B	8.58 C	5.84 B	27.75 B	1.52 B	0.09 B	1.62 B
Grand Rapids TBR®	412.33 C	8.95 C	6.04 B	22.44 C	1.23 C	0.08 B	1.32 C
American Rafaela®	829.59 A	12.87 A	6.88 A	42.27 A	2.16 A	0.11 A	2.28 A
Repolhuda Every year®	774.32 A	14.25 A	7.22 A	38.42 A	1.97 A	0.12 A	2.09 A
Season (E)	1,028.29**	438.04**	362.12**	1439.95**	486.49**	463.12**	531.11**
C x E	48.81**	15.49**	10.50**	52.43**	12.38**	8.98**	12.98**
Block	0.20	1.11	0.64	1.30	0.39	2.53	1.22
CV 1 (%)	12.76	13.48	11.81	14.16	22.05	17.61	21.25
CV 2 (%)	15.08	10.58	12.12	12.92	21.80	23.79	20.94

** significant at 1% probability; means followed by the same letter in each column are not statistically different by Tukey's test at 5%. CV = coefficient of variation.

Comparing the results of the evaluated parameters (AF, NF, DC, MFPA, MSPA, MSR and MST), it can be seen that the American Rafaela® and Head lettuce® did not differ among themselves, being superior to the other cultivars, Grand Rapids TBR® and Crespa Repolhuda® (**Table 2**). This may be related to the genetic improvement of the culture, which made some cultivars more tolerant to high temperatures, as documented by Feltrim *et al*.[26].

Through the distribution of PA in the different seasons (**Figure 2(A)**), it was verified that the growth of PA was lenient until 28 DAS, for all cultivars, compared to the final PA at 40 DAS, a common fact in vegetables that are in stages of growth and development. It is also possible to observe that after 28 DAS, Americana Rafaela® and Repolhuda Todo ano® showed higher values of AF.

In general, all parameters were quadratic with high coefficient of determination (**Figure 2(F)**). We observed maximum values of leaf number (LE) and collar diameter (CD) of 27 units and 14.47 mm, respectively, for the cultivar Repolhuda Todo ano® (**Figures 2(B)** and (**C**)).

With the exception of the NC and CD, which showed linear behavior (**Figures 2(B)** and (**C**)), the other parameters showed the highest accumulation of mass for the cultivar Americana Rafaela®, and the growth was slow until 28 DAS. The highest MFPA was observed in the Americana Rafaela cultivar® (**Figure 2(D)**), with significant growth after 28 DAS until the end of the growing cycle (40 DAS), reaching 146.70, 89.45, 81.35 and 64.34 g^{-1}, respectively, for the cultivars Americana Rafaela®, Crespa Repolhuda®, Repolhuda Todo ano®, Grand Rapids TBR® (**Figure 2(D)**). Thus, it can be seen that lettuce follows the trend of increasing production of PA and mass throughout its ontogeny, as also observed for the radish crop[27,28].

The greater accumulation of MSPA and MST (**Figure 2(E)** and (**G**)) in the Americana Rafaela® cultivar is a reflection of the greater AF, because the value of this variable is directly associated with the photosynthetic area of the plant. Plants with a greater photosynthetic area, consequently, will have a greater production of photo-assimilates, resulting in growth and development. Guimarães *et al*.[19], working with 20 lettuce accessions for organic production in pots, obtained dry mass production results similar to those obtained in this experiment.

The dry mass of plants is directly associated with the ability to fix atmospheric CO_2 by photosynthesis, and this is higher the higher the AF. However, the gain in mass cannot be attributed only to PA, but also to the ability to use light energy, which involves, above all, the mechanism of carbon fixation, which is primarily responsible for governing plant growth and development[29].

The development of lettuce is greatly influenced by environmental conditions[30], among which air temperature stands out. According to Taiz and Zeiger[31], temperature affects the speed of chemical reactions and internal processes of transport of solutes and the normal development of plants.

During the experiment, the average, minimum and maximum temperatures recorded were, respectively, 23.80 and 31.27 °C, values higher than those considered ideal for the culture (15 and 24 °C[32], 7 to 27 °C[33], 20 and 25 °C[34]). These values allow stating that the temperature negatively influenced the AF, DC, NF, MFPA, MSPA, MSR, MST. These results corroborate those found by Santos *et al*.[17], when they verified that lettuce cultivars exposed to high air temperatures, with minimum and maximum averages of 20.3 and 35.3 °C, respectively, showed significant reductions in MST, ranging from 52.5 to 111.5 $g \cdot plant^{-1}$.

Additionally, during the experiment, the relative humidity (RH) values were below those considered ideal for lettuce cultivation. Cermeñozs[35] reports that the ideal RH values for the cultivation of lettuce vary from 60 to 80%.

The ATT is the variation or increment in growth between two samples, over the period[7]. **Figure 3(A)** shows an accelerated vegetative growth from 36 to 40 DAE, in the order of the cultivars Americana Rafaela® > Repolhuda Todo ano® > Crespa Repolhuda® > Grand Rapids TBR®, which may be related to the intrinsic characteristics of the cultivars.

The RGR represents the increment of existing dry matter per unit of existing dry matter in a given period[7]. It was observed that Americana Rafaela® showed the highest RGR at 20 DAS (**Figure 3(B)**). In this period, there was a maximum accumulation of RGR by the cultivars Americana Rafaela®, Repolhuda Todo ano®, Grand Rapids TBR®, Crespa Repolhuda®, with the rates of 3.06, 2.94, 2.83, 2.68 $g \cdot g^{-1} \cdot d^{-1}$, respectively. Later, at 20 DAS, in general, regardless of the cultivars, there was a sharp reduction until 32 DAS, stabilizing after this period until the end of the cycle. The Americana Rafaela® cultivar showed a higher efficiency of dry mass conversion than the other cultivars in all the periods evaluated. Probably, the reduction was caused by increased respiratory activity and autoshading, which increases according to the age of the plant[36], and at the end of the cycle, growth may become negative, due to the death of plant organs such as leaves and buds[10].

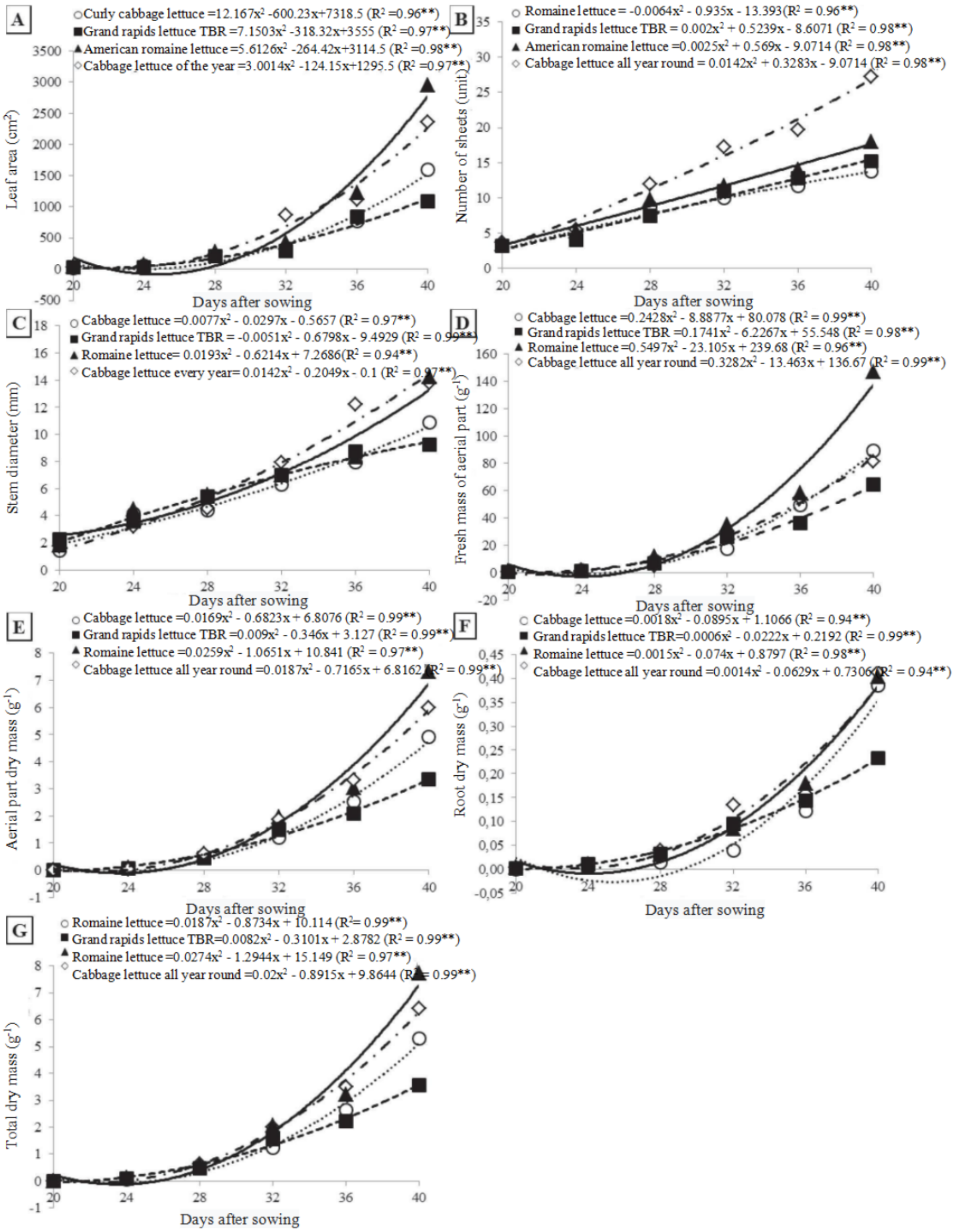

Figure 2. Leaf area **(A)**, number of leaves **(B)**, collar diameter **(C)**, aboveground fresh mass **(D)**, aboveground dry mass **(E)**, root dry mass **(F)** and total dry mass **(G)** of lettuce (*Lactuca sativa* L.) plants grown in pots, as a function of cultivars and evaluation periods.

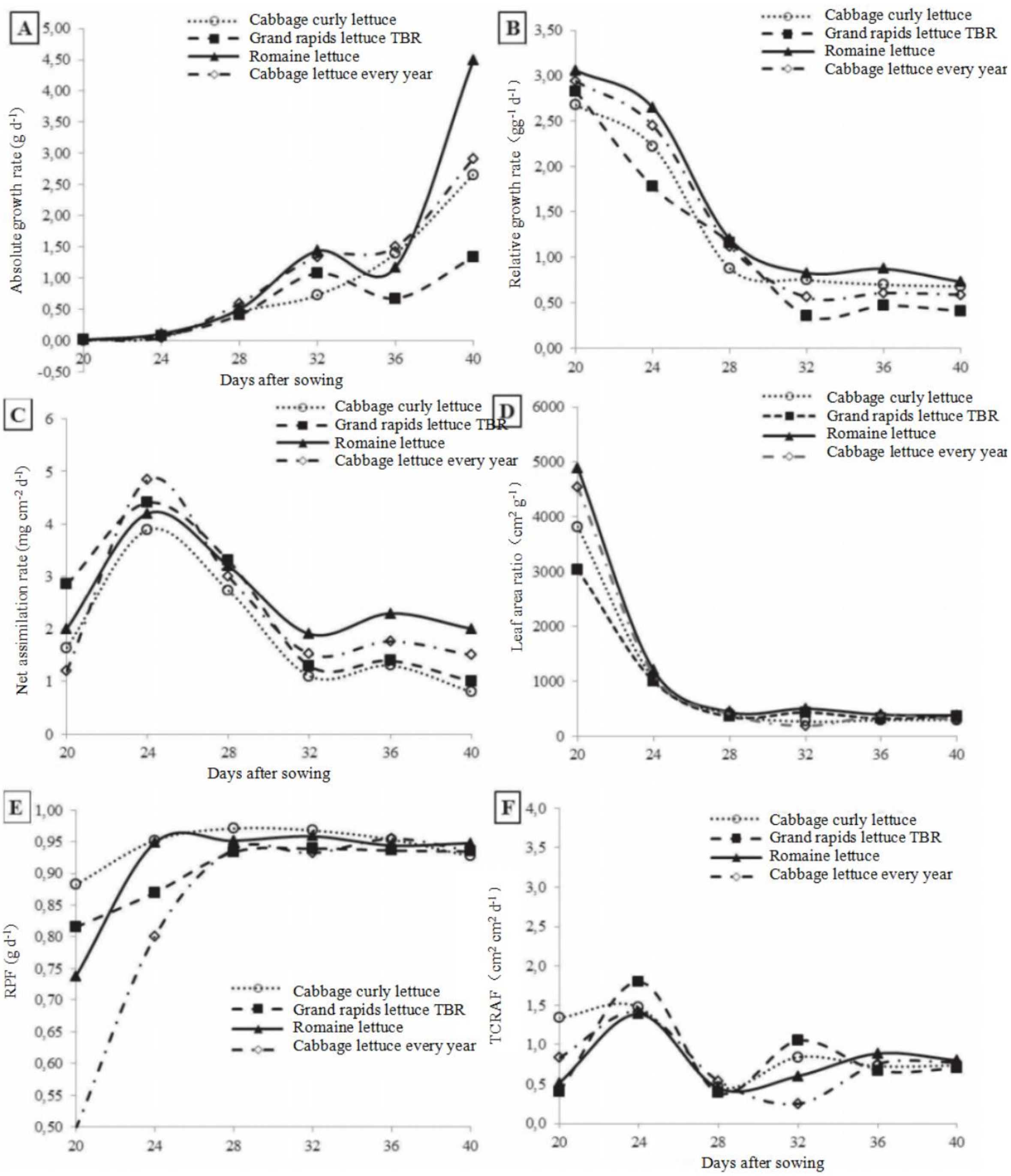

Figure 3. Absolute growth rate **(A)**, relative growth rate **(B)**, net assimilation rate **(C)**, leaf area ratio **(D)**, leaf weight ratio **(E)** and relative leaf area growth rate **(F)** of lettuce (*Lactuca sativa* L.) plants, grown in pot, as a function of cultivars and evaluation seasons.

The LAR reflects the photosynthetic efficiency of the leaves. **Figure 3(C)** shows that the cultivars Repolhuda Todo ano® and Grand Rapids TBR® presented the highest LAW at 24 DAS, with rates of 4.84 and 4.40 $mg \cdot cm^{-2} \cdot d^{-1}$, respectively. Later, at 24 DAS, in general, regardless of cultivars, there was a sharp reduction until 32 DAS, stabilizing after this period until the end of the crop cycle.

The reduction in TAL is a consequence of the photosynthetic rate, the leaf size, the length of the vegetative period, the distribution of leaves in the canopy, the leaf angle and the distribution of assimilates[28]. For Milthorpe and Moorby[36], the decline is due to the effect of shading of the lower leaves. Thus, the ACR tends to be higher in the early stages, because of less self-shading[37]. Thus, TAL tends to be higher at the beginning of the cycle, when self-shading is reduced. Its decrease is expected as the leaf area useful to photosynthesis is reduced[38]. These results are similar to those of Pedó *et al.*[28], who observed a reduction in TAL, in radish cultivars, by increasing the AF, due to greater autoshading of the lower leaves.

The RAF, as a function of time, was higher at 20 DAS and showed a sharp decline after this period until 24 DAS, stabilizing until harvest (**Figure 3(D**). For Caron *et al.*[8], this indicates that, at this stage, most of the photosynthesized material is accumulated in the aerial phytomass of lettuce, to better capture the available solar radiation. From this period there were subsequent decreases in the phenological development of the crop, due to the appearance of non-assimilatory tissues and structures, such as flowers and seeds, in addition to autoshading, drying and leaf fall, as the plant ages.

The highest values of RAF correspond to the cultivars Americana Rafaela® and Repolhuda Todo ano®, regardless of the period evaluated, a fact proven by having presented higher MSPA, MST, and AF. Although both cultivars did not present statistical difference, the curves of both were equal after 24 DAS. The lower RAF of the cultivar Repolhuda todo ano® may be due to its intrinsic characteristics, which give it greater efficiency of the leaves to perform photosynthesis and produce phytomass. For Benincasa[7], the RAF expresses the leaf area useful for photosynthesis, the ratio between the leaf area and the total dry mass. According to the author, the decline in the RAF occurs due to the increased interference of the upper leaves over the lower leaves, as the plant grows, with a tendency for the useful AF to decrease according to the stage of development of the plant. These results corroborate those obtained by Beckmann-Cavalcante *et al.*[10], in experiments with the development of chrysanthemum with nutritive solutions.

The RPF presented the highest values for the cultivar Cres-pa Repolhuda® (**Figure 3(C)**). Because this variable corresponds to the amount of dry matter stored in the leaves and the dry mass retained throughout the plant, it is possible to infer that the cultivar Crespa Repolhuda® has greater RPF, as it grows, because of the smaller amount of mass that is retained in the leaves, with greater export to the other drains of the plant. For the TCR_{AF} it was found that in the first weeks, the cultivars presented a growth impulse, with higher values, and from 32 DAS, the cultivar Americana Rafaela® was the best.

In general, it is verified that the best growths refer to the Americana Rafaela® and Repolhuda Todo ano® lettuce cultivars, for presenting higher AF, AD, NC, MFPA, MSPA, MSR, MST and, in the growth analysis, of TCA, TCR, TAL, RAF and TCR_{AF}.

4. Conclusions

The American lettuce cultivars Rafaela® and Repolhuda todo ano® are more efficient than Grand Rapids TBR® and Crespa Repolhuda®, in the conditions of southern Piauí, for presenting better performance and higher morphophysiological indexes for the lettuce culture, cultivated in pots.

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Conflict of interest

The authors declared no conflict of interest.

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