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Physiological and productive performance of three safflower cultivars in the Brazilian semiarid region

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A B S T R A C T
Carthamus tinctorius L. is an oilseed with high oil content, recently listed as crop for biofuels production. The present investigation aimed to study germination, physiological and anatomical aspects, as well as the yield of three safflower cultivars (IMAMT 894, IMAMT 946 and IMAMT 1750) to identify the one with the best performance in the field under semiarid conditions. The IMAMT 894 cultivar had the highest germination percentage, photosynthetic rate, intrinsic efficiency in water use, lowest transpiration rate, highest number of capitulum per plant and final seed yield when compared with other cultivars. The IMAMT 1750 cultivar showed the worst performance, with lower germination percentage, photosynthetic activity, water use efficiency, number of capitulum per plant and final seed production. The IMAMT 946 cultivar, on the other hand, did not stand out in any of the parameters analyzed and presented higher transpiration rate. Thus, the IMAMT 894 cultivar showed the best anatomical, physiological and productive performance, being the most appropriate among the three cultivars for production in semiarid conditions. This research contributes to the understanding of the performance of safflower cultivars in the field, thus helping producers to choose the best alternative for production under semiarid conditions. Since here we show for the first time data on the phenological and productive development of the IMAMT 894, IMAMT 946 and IMAMT 1750 safflower cultivars in the semi-arid region of Rio Grande do Norte.

Keywords: Water use efficiency, Germination, Seed yield.

Produtividade e desempenho fisiológico de três cultivares de cártamo na região semiárida brasileira

R E S U M O (PT-BR)
Carthamus tinctorius L. é uma oleaginosa com alto teor de óleo, recentemente incluída na lista de culturas para a produção de biocombustíveis. O presente estudo teve como objetivo investigar a germinação, os aspectos fisiológicos e anatômicos, bem como a produtividade de três cultivares de cártamo (IMAMT 894, IMAMT 946 e IMAMT 1750) para identificar aquela com melhor desempenho em campo, em condições semiáridas. A cultivar IMAMT 894 apresentou a maior porcentagem de germinação, taxa fotossintética, eficiência intrínseca no uso da água, menor taxa de transpiração, maior número de capítulos por planta e maior produtividade final de sementes, quando comparada às demais cultivares. A cultivar IMAMT 1750 apresentou o pior desempenho, com menor porcentagem de germinação, atividade fotossintética, eficiência no uso da água, número de capítulos por planta e produção final de sementes. A cultivar IMAMT 946, por sua vez, não se destacou em nenhum dos parâmetros analisados e apresentou maior taxa de transpiração. Assim, a cultivar IMAMT 894 apresentou o melhor desempenho anatômico, fisiológico e produtivo, sendo a mais adequada dentre as três cultivares para produção em condições semiáridas. Esta pesquisa contribui para o entendimento do desempenho de cultivares de cártamo no campo, auxiliando os produtores na escolha da melhor alternativa para produção em condições semiáridas. Apresentamos aqui, pela primeira vez, dados sobre o desenvolvimento fenológico e produtivo das cultivares de cártamo IMAMT 894, IMAMT 946 e IMAMT 1750 na região semiárida do Rio Grande do Norte.

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Palavras-Chaves: Eficiência hídrica, Germinação, Produtividade de Sementes.

Rendimiento fisiológico y productivo de tres cultivares de cártamo en la región semiárida brasileña.

R E S U M E N (SPANISH)
Carthamus tinctorius L. es una oleaginosa con alto contenido de aceite, recientemente incluida en la lista de cultivos para la producción de biocombustibles. Este estudio tuvo como objetivo investigar la germinación, los aspectos fisiológicos y anatómicos, así como la productividad de tres cultivares de cártamo (IMAMT 894, IMAMT 946 e IMAMT 1750) para identificar el que presenta el mejor desempeño en campo bajo condiciones semiáridas. El cultivar IMAMT 894 mostró el mayor porcentaje de germinación, tasa fotosintética, eficiencia intrínseca en el uso del agua, menor tasa de transpiración, mayor número de cabezas florales por planta y mayor productividad final de semillas en comparación con los otros cultivares. El cultivar IMAMT 1750 mostró el peor desempeño, con el menor porcentaje de germinación, actividad fotosintética, eficiencia en el uso del agua, número de cabezas florales por planta y producción final de semillas. El cultivar IMAMT 946, por su parte, no destacó en ninguno de los parámetros analizados y presentó una mayor tasa de transpiración. Así, el cultivar IMAMT 894 mostró el mejor desempeño anatómico, fisiológico y productivo, siendo el más adecuado entre los tres cultivares para la producción en condiciones semiáridas. Esta investigación contribuye a la comprensión del desempeño de los cultivares de cártamo en campo, ayudando a los productores a elegir la mejor alternativa para la producción en condiciones semiáridas. Aquí presentamos, por primera vez, datos sobre el desarrollo fenológico y productivo de los cultivares de cártamo IMAMT 894, IMAMT 946 e IMAMT 1750 en la región semiárida de Rio Grande do Norte.

Palabras clave: Eficiencia hídrica, Germinación, Productividad de las semillas.

1. Introduction

Safflower (*Carthamus tinctorius* L.) is an oleaginous plant from Asteraceae family that stands out due to its high oil content about 20 % – 30 % to variety grown in Iran (Zafari et al. 2020), 44% grown in USA, 26 % -28% grown in India (Kadirvel et al. 2020) and quality of its seeds. Owing to the high commercial value added, safflower cultivation presents itself as a source of innovation in the energy sector for the production of renewable and environmentally compatible fuels, such as biodiesel (Lôbo et al. 2009; Pinho and Suarez 2017). The specific oil is rich in oleic 84.67% (Anjani and Praduman 2022) and linoleic acids 71. 59% (Kadirvel et al. 2020). The high content of linoleic acid in safflower oil provides a good quality of the biodiesel produced, expressed in the clogging point, cloud point and fluidity (Mihaela et al. 2013). The crop was recently included in the innovation agenda for the biodiesel production chain of the Ministry of Agriculture, Livestock and Supply of the Federal Government of Brazil, as a priority indication for cultivation in the northeastern semiarid region, both in irrigated and dryland systems (Mapa 2019).

The Brazilian semiarid region is characterized by low precipitation and high evapotranspiration, which are limiting factors for the growth of many plant species. The climate in the semiarid regions of Brazil is characterized by annual rainfall equal to or less than 800 mm, high evapotranspiration, an aridity index equal to or less than 0.50 on the Thornthwaite Aridity Scale, the dominant climate is semiarid, as pointed out by the National Institute of the Semi-Arid – INSA. This condition is restricted to the Northeast region and a small portion of the state of Minas Gerais, which is also part of the Drought Polygon (Troleis and Silva, 2019). Water scarcity in this region is one of the factors that most effects crop seed development and productivity (Yari et al. 2014; Santos et al. 2015). In this context, safflower is considered a tolerant species to edaphoclimatic conditions of semiarid regions, showing little sensitivity to low water availability and saline soils (Bonamigo et al. 2013; Espanani et al. 2019). According to Tian et al. (2019), the tolerance threshold of C. tinctorius seedlings to NaCl is 180 mm. Ebrahimi et al. (2016) have reported that genotypes originating from the USA and Tajikistan have high tolerance to drought conditions.

Safflower is produced in 20 countries with a cultivated area around 839,423 ha in 2020, with the main seed producing countries being Kazakhstan with 226,739 tons, followed by the Russian Federation with 96,632 tons, Mexico with 86,793 tons, USA with 67,040 tons, India with 44,000 (FAO 2022). Currently, safflower is not yet cultivated on a commercial scale in Brazil, however, pilot crops for feasibility analysis and cultivar selection are being developed at Mato-Grossense Cotton Institute. Thus, safflower cultivation in Brazil should be investigated, mainly under semiarid conditions in the Northeast, with the aim of to select the safflower variety with the best development and high productivity, to identify the variety tolerant end to make viable projection of future grow in commercial scale.

Crops grown in semiarid environments are subject to various abiotic stresses, such as drought, heat and high light (Ulguim et al. 2017; Troleis and Silva 2019; Nóbrega et al. 2020). One of the most immediate responses to elevated temperature is increased transpiration (Ulguim et al. 2017) and strain on the xylem can lead to cavitation (Nóbrega et al. 2020). However, if heat is accompanied by lack of soil water and high luminosity, stomatal conductance is usually reduced to save water but can restrict photosynthesis and promote oxidative stress (Nóbrega et al. 2020). In response to these stresses, safflower demonstrates anatomical changes in parenchymal tissue (Batista et al. 2010), and xylem tissue with reduced area (Kulkarni and Phalke 2009). For commercial-scale cultivation, knowledge of safflower responses under specific conditions is essential for the selection of more tolerant varieties, avoiding financial losses in production (Paludo et al. 2017).

It is known that there are differences in the development for several safflower cultivars grown in different soil and climatic conditions, and it is necessary to carry out studies that show the parameters of development and productivity of the culture in the Brazilian semi-arid region, since there is no study carried in the region. Currently, safflowers have been widely studied as a potential for the production of biofuels with a focus on diversifying the plant matrix to supply the biofuels sector. Thus, safflower cultivation in Brazil should be investigated, especially in the semi-arid region of the Northeast, socioeconomically deprived. Based on the above, this investigation aimed to study the initial development, physiological and anatomical aspects and productivity of three safflower cultivars (IMAMT 894, IMAMT 946 and IMAMT 1750), as well as to understand their potential for acclimatization to the Brazilian semiarid region for the production of biofuels.

2. Material and Methods

2.1 Plant material

The seeds used in the experimental field cultivation were freshly harvested of safflower cultivars IMAMT 894, IMAMT 946 and IMAMT 1750, from the germplasm bank of the Mato-Grosso Cotton Institute (IMAMT), Cuiabá, Mato Grosso, Brazil. They were produced under tropical climate and temperature averange of 23.3 ºC, and precipitation of 1498 mm clima dete. After the field experiment and harvesting, the seeds were storage at the Research Laboratory of Energy Crops, Federal University of Rio Grande do Norte for one month and used in a germination test under controlled conditions.

2.2 Germination test

The four replicates of 60 achenes were manually selected, totaling 240 for each cultivar, were sanitized in 0.5% sodium hypochlorite (m/v) and submitted to a germination test in an adapted germitest paper roll system (Gama et al. 2019), conducted in a BOD TE-4013 model under a photoperiod of 12 h and a temperature of 35ºC, seeking to simulate conditions similar to those in the field. Germinated seeds were counted daily, using radicle protrusion equal to or greater than 2 mm as a criterion. After seven days of incubation, the final germination percentage was measured, and the germination speed index was calculated by equation, where n = number of seeds germinated and *d*= the day about seeding according to Maguire (1962).

$$GSI = \frac{G_1}{d_1} + \frac{G_2}{d_2} + \cdots + \frac{G_n}{d_n}$$

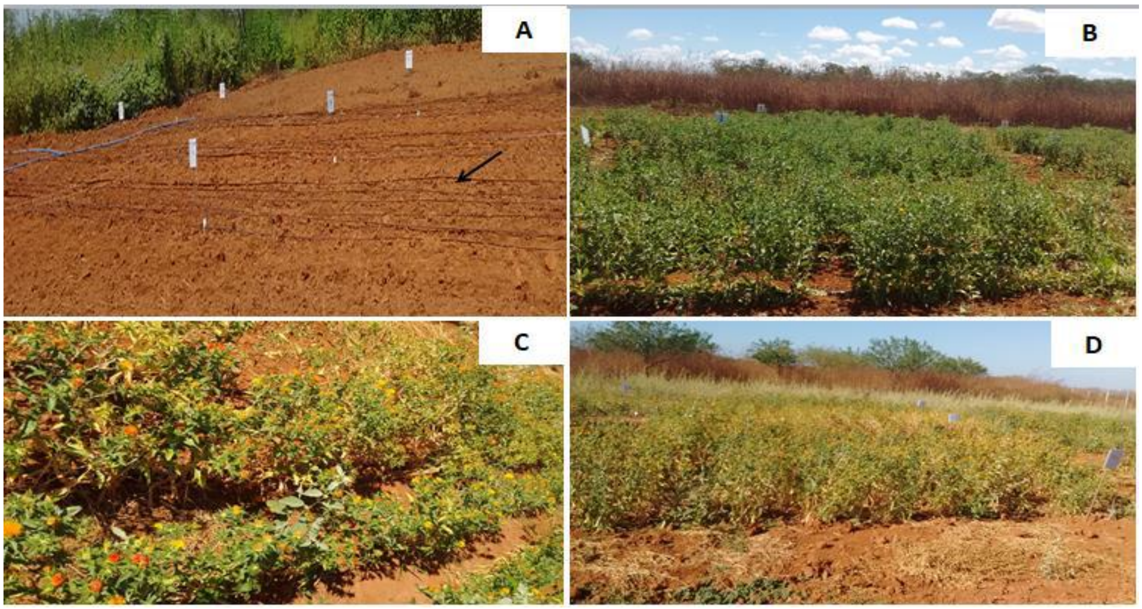
2.3 Field study and cultivation área

Cultivation was carried out in an experimental field of the Federal Institute of Education, Science and Technology of Rio Grande do Norte (IFRN), Apodi campus, located in the municipality of Apodi, Rio Grande do Norte, Brazil (5º37´34´´S 37º 48´27ºW). According to fertility analysis, the soil contained calcium (4.40 cmolc/dm^3), aluminum (0.033 cmolc/dm^3), phosphorus (16.3 mg/dm^3), potassium (187 mg/dm^3), sodium (76.3 mg/dm^3), and pH of 7.78. The climate of the region is semiarid according to the Koopen classification (Köppen 1900), with an annual average temperature around 28.1ºC, which can reach maximums of 36°C and minimums of 21°C; 68% relative humidity; 2,700 annual hours of sunshine, rainy season from March to May, with sparse and irregular rains. The field experiment was conducted from June to September 2018, minimum temperature of 20,8°C and maximum 35°C, relative humidity 54,8%, average day length 12 h, total rainy days: one, and rainfall accumulate 65 mm during the crop growth period, National Institute of Meteorology (INMET). A year in which rainfall was 857.8 mm according to the Agricultural Research Company of Rio Grande do Norte (EMPARN).

Figure 1 – Safflower cultivation in the field: (A) Map of Rio Grande do Norte, (B) Federal Institute of Education, Science and Technology of Rio Grande do Norte, IFRN - Apodi campus: Highlighted area: Experimental plot.

The achenes were planted directly in the soil manually, which was fertilized according to the EMPARN recommendations for sunflower cultivation, including 50 kg/ha of simple superphosphate (20% P_2O_5), 20 kg/ha of urea (45% N) and 20 kg/ha of potassium chloride (58% K_2O) (Castro et al. 1996), due to the absence of a specific protocol for safflower cultivation. The experiment was carried out in a randomized block design with an area of 18 m² each and three replicates per cultivar, totaling nine blocks. The blocks with the sown cultivars were interspersed, so that the same cultivar was not in neighboring blocks, with a distance of 1.5 m² between them, 0.5 m² between rows, 0.2 m² between holes, totaling six rows of six meters and 30 holes with thee plants each.

Figure 2 – Safflower Cultivation under field Conditions: (A) sowing; (B) Pre-flowering Stage; (C) Flowering Stage; (D) Onset of Senescence. Arrow: Irrigation system.



For physiological measurements, data collection of capitulum number per plant and dry mass, four useful lines, disregarding one line on each side, considered as border. The irrigation system was drip type, watering occurred daily in the morning, lasting one hour, flow rate of 1.5L, from planting until the third day of seedling emergence and, subsequently, on alternate days.

2.4 Gas Exchange

Net CO_2 assimilation rate – photosynthesis (A_N), and transpiration rate (E) were measured at the vegetative (30 days after germination), flowering (45 days after germination) and senescence (60 days after germination) stages on the third leaf expanded from apex to base using an infrared gas analyzer (model LCpro-SD System ADC, Bioscientific Ltd.) of 15 plants for each cultivar, five plants per plot. The instantaneous water use efficiency (WUE) was estimated by the A/E ratio. As safflower is a C3 plant, assessments were performed at 7:30 to 10:30 am, according to Ferraz et al. (2012) and Lichston et al. (2016).

2.5 Stem and leaf anatomy

Handmade histological cross-sections of the stem and leaf of 15 plants for each cultivar, five plants per plot, in the vegetative stage were carried out, stained with Safranin and Alcian Blue for the preparation of semi-permanent slides with 50% glycerin (Kraus and Arduin 1997). ImageJ 1.44 software was used to measure the total xylem area in the stems and the thickness of the palisade parenchyma in the leaves.

2.6 Production and Yield

At the end of the experiment, 75 days of seeding, plants were sectioned at ground level and the shoot dry weight (DW) was determined according to Brasil (2009) and Abud et al. (2010), with values expressed in grams. In addition, the number of capitulum per plant (NCP), the number of seeds per capitulum (NSC) and the yield, expressed by the weight of seeds per area (kg m²), were measured.

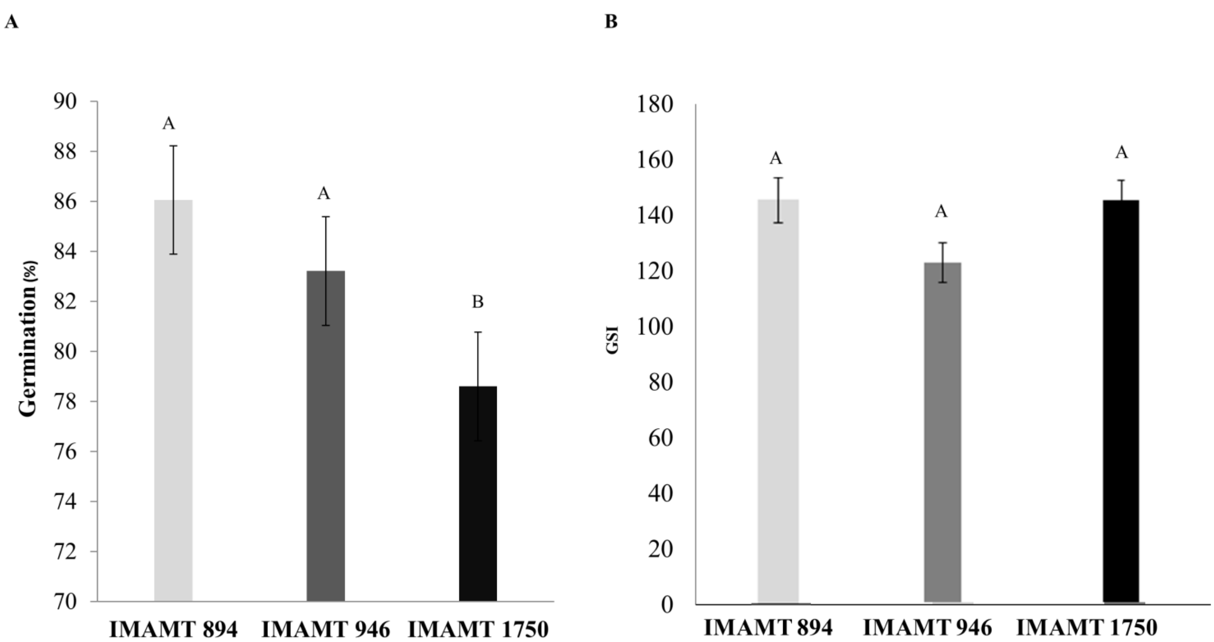
2.7 Statistical analysis

The results obtained were submitted to analysis of variance (ANOVA) and the means were compared by the Tukey HSD test ($p<0.05$) using the JMP software (SW-SAS) version 13.0.

3. Results and Discussion

The germination of IMAMT 894, IMAMT 946 and IMAMT 1750 cultivars started 24 h after sowing and was completed after 96 h, when maximum germination was observed. Cultivars IMAMT 894 and IMAMT 946 showed 86.0 and 83.2% germination, respectively, with no significant differences. The IMAMT 1750 cultivar differed from the others, presenting 78.6% germination (Figura 3A). The germination speed index did not vary among cultivars (Figure 3B).

Figure 3: Germination percentage (A) and germination speed index (GSI) (B) in seeds of three safflower cultivars (IMAMT 894, IMAMT 946 and IMAMT 1750). Seeds were disinfected, sown between sheets of paper and incubated for 7 days under controlled conditions. Columns represent the mean and bars correspond to the standard deviation.



The germination is the first stage of spermatophyte development (Thu et al. 2020) and germination percentage has been used as a marker of seed viability and quality (Elouaer and Hannachi, 2012). For the differentiation of more viable cultivars, values between 76% (Toscano et al., 2017) and 91% (Silva et al. 2017 b) in Asteraceae are considered The IMAMT 894 and IMAMT 946 cultivars have greater viability than IMAMT 1750 cultivar (Fig. 3A), due to the high germination percentage. Gama et al. (2019), De-Melo et al.

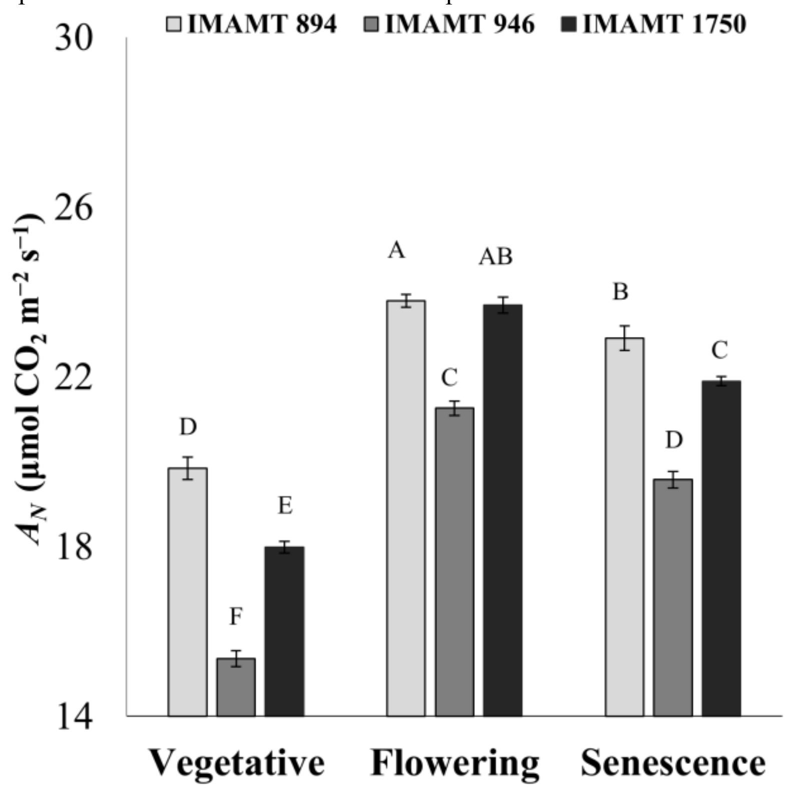
(2019) and Isik and Leblebici (2016) obtained germination percentages between 80% and 97% for safflower cultivars ICA 193, ICA 173 and RemziBey values indicating cultivars of high viability.

The germination percentages found in our research for the IMAMT 894 cultivar were close to those observed for the safflower cultivars Dinçer (96.7%), Balci (95%), Yenice (93.3%), Means (93.3%) and Remzibey (88.3%) (Arslan and Culpan 2019), which surpassed those observed for other oilseeds, such as *Sesamum indicum* L. (60%) (Harfi et al. 2016) and *Glycine max* L. (67%) (Pellizzari et al. 2020).

In parameters physiological, of CO_2 assimilation rate - photosynthesis (A_N; µmol CO_2 m^{-2} s^{-1}), in general, the highest (A_N), were obtained during the flowering stage, followed by those recorded in the senescence stage (Figure 4).

The IMAMT 894 cultivar exhibited the highest values of A_N in relation to the other cultivars in the vegetative and senescence stages, being 9.4% and 22.6% higher during vegetative growth and 4.4% and 14.5% higher during senescence, compared with cultivars IMAMT 1750 (A_N: 23,68 µmol CO_2 m^{-2} s^{-1}) and IMAMT 946 (A_N 21,25 µmol CO_2 m^{-2} s^{-1}), respectively. During flowering, A*n* was 10.7% higher in cultivar IMAMT 894 (A_N: 23, 79 µmol CO_2 m^{-2} s^{-1}) compared with cultivar IMAMT 946 (Figure 4).

Figure 4: Parameter physiological of CO_2 assimilation rate - photosynthesis (A_N; µmol CO_2 m^{-2} s^{-1}) in safflower cultivars IMAMT 894, IMAMT 946 and IMAMT 1750, during the vegetative, flowering and senescence stages. Columns represent the mean and bars correspond to the standard deviation of five replicates.

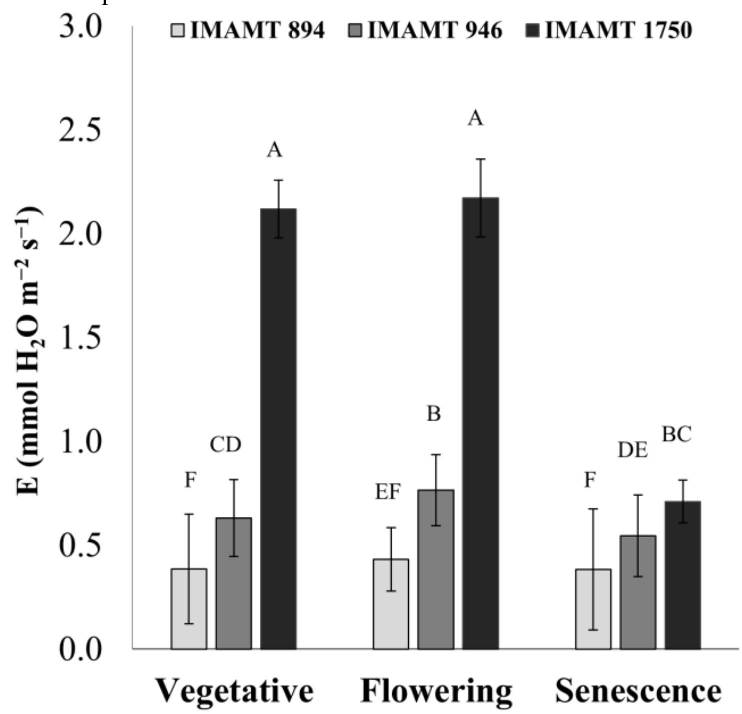


Photosynthetic rate is linked to production efficiency (Oliveira-Freire et al., 2014) and can be considered a marker of tolerance to environmental conditions in safflower and other oilseed crops (Salem et al. 2014; Wei et al. 2020). Probably, the IMAMT 894 cultivar (FIG. 3A) is the one with the greatest tolerance to the semiarid environment among the other cultivars. Environmental tolerance is related to the photosynthetic rate, which can be affected by reduced concentrations of chlorophyll a, b, total, and carotenoids, induced by the environment (Bortolheiro and Silva 2017).

The reduction of A acts as a strategy to reduce the amount of reactive oxygen species generated during photosynthesis (Najafabadi and Ehsanzadeh 2017), aiding in plant survival, a fact that may explain the lower A rates in the IMAMT 1750 and IMAMT 946 cultivars compared with IMAMT 894. High photosynthetic rates are related to the efficiency of the carboxylation process (Mohammadi et al. 2017). In this sense, the IMAMT 894 cultivar can be highlighted in terms of productive efficiency. Values of A lower than those observed in this study were reported for the safflower cultivar Isfahan (7.91 µmol CO_2 m^{-2} s^{-1}) (Kazemeini et al. 2015), for the *Nouelia insignis* Franch (Asteraceae), (13.00 µmol CO_2 m^{-2} s^{-1}) (Liu et al. 2020) and for soybeans (9.15 µmol CO_2 m^{-2} s^{-1}) (Ulguim et al. 2017).

High transpiration rate (E), in combination with other physiological parameters, can negatively affect A rates (Khan et al. 2020), harming crop development and productivity. The highest values of transpiration rate (E) were obtained in the vegetative development and flowering stages, followed by those recorded in the senescence stage (Figure 5).

Figure 5: Parameter of transpiration rate (E; mmol H_2O m^{-2} s^{-1}) in safflower cultivars IMAMT 894, IMAMT 946 and IMAMT 1750, during the vegetative, flowering and senescence stages. Columns represent the mean and bars correspond to the standard deviation of five replicates.



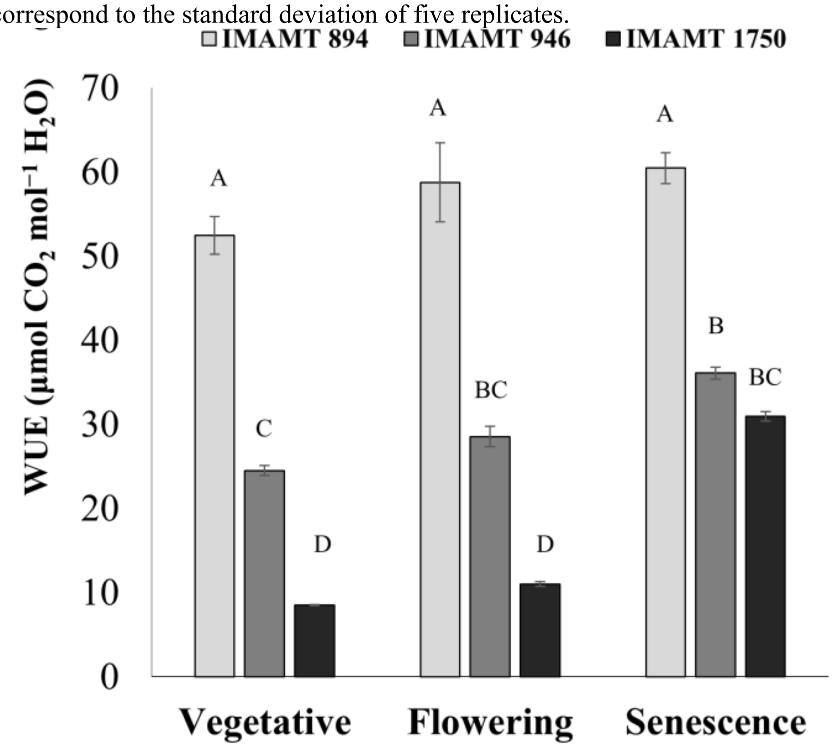
The IMAMT 1750 cultivar presented the highest values of E in relation to the other cultivars at all developmental stages. In the cultivar IMAMT 1750, E was 82% and 70% higher in the vegetative stage (E: 2,12 mmol H_2O m^{-2} s^{-1}), 80% and 64% higher during flowering (E: 2,17 mmol H_2O m^{-2} s^{-1}) 46% and 24% higher in the senescence (E: 0,71 mmol H_2O m^{-2} s^{-1}) than that found for the cultivars IMAMT 894 and IMAMT 946, respectively. The IMAMT 894 cultivar demonstrated the lowest E values at all development stages vegetative (E: 0, 39 mmol H_2O m^{-2} s^{-1}), flowering (E: 0, 43 mmol H_2O m^{-2} s^{-1}), senescence (E: 0, 38 mmol H_2O m^{-2} s^{-1}).

In our study, the cultivar with the lowest water loss by transpiration was IMAMT 894, which was also more efficient in A (Figure 4, 5). This fact may be related to the climatic conditions of the semiarid region, with high temperatures and solar radiation, in which the closing of stomata reduces transpiration (Barboza and Teixeira-Filho 2017), ensuring water availability (Ulguim et al. 2017) and plant performance (Menegaes et al. 2020).

Higher values of E than those verified in this study are reported for the safflower cultivars PI8311 (4.6 mmol H_2O m^{-2} s^{-1}) and S333 (5.7 mmol H_2O m^{-2} s^{-1}) by Singh et al. (2016 a) and similar ones are reported for other crops such as *Eremanthus crotonoides* by Aguiar et al. (2020) and *N. insignis* (E above 2.5 mmol H_2O m^{-2} s^{-1}) (Liu et al. 2020). The variations of E, between 1 and 3 mmol H_2O m^{-2} s^{-1}, obtained from our study in the cultivars IMAMT 946 and IMAMT 1750 are in agreement with Siddiqi et al. (2009) for Safflower-31, Safflower-33, Safflower-34, Safflower-35, Safflower-36, Safflower-3, which were superior to those obtained for the cultivar IMAMT 894 (Figure 5).

The water use efficiency (WUE) is measured by the ratio of the amount of evaporated water to the amount of plant production. Regarding instantaneous water use efficiency (WUE), the cultivar IMAMT 894 presented superior values of 53.3 and 83.8% in the vegetative state (52,44 µmol CO_2 mol^{-1} H_2O), 51% and 81.3% in the flowering stage (58, 74 µmol CO_2 mol^{-1} H_2O), and 40.3 and 48.8% in the senescence stage (60,43 µmol CO_2 mol^{-1} H_2O), when compared with the cultivars IMAMT 946 and IMAMT 1750, respectively (Figure 6).

Figure 6: Parameter physiological of water use efficiency (WUE; µmol CO_2 mol^{-1} H_2O) (C) in safflower cultivars IMAMT 894, IMAMT 946 and IMAMT 1750, during the vegetative, flowering and senescence stages. Columns represent the mean, and bars correspond to the standard deviation of five replicates.



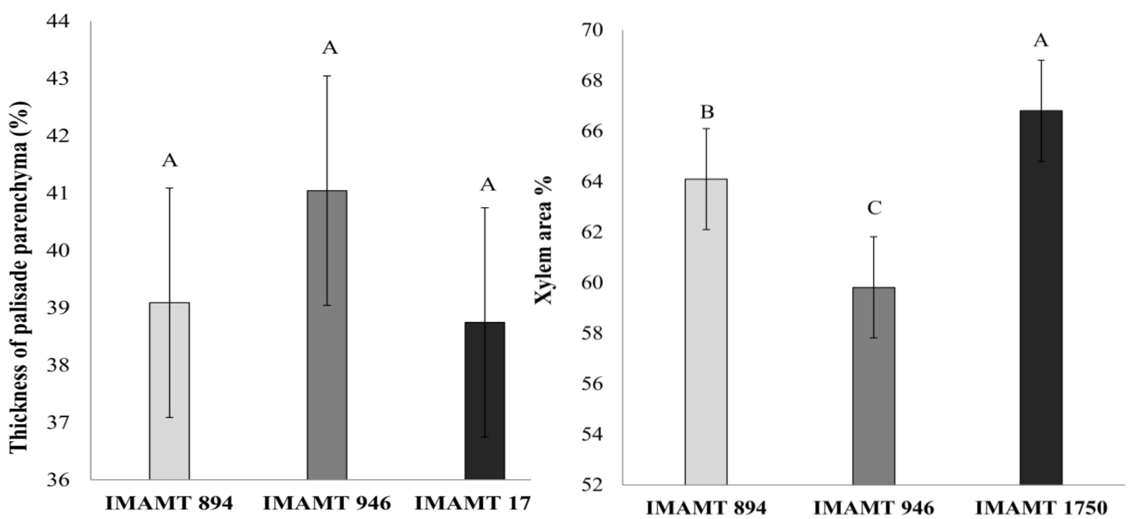
Thus, higher WUE may be related to higher productivity in oilseeds (Hossain et al. 2019) as found for IMAMT 894 cultivar. Changes in WUE values are related to plant response to unfavorable environmental conditions (Farooq et al. 2019; Bhattarai et al. 2020), which may explain the variations in WUE values among cultivars as reported in this study. Bortolheiro and Silva (2017) and Singh et al. (2016) indicated the WUE as a marker of tolerance and productivity in safflower cultivars. Therefore, it is possible to suggest that the

IMAMT 894 cultivar seems to be the most tolerant and the most productive.

Other water supply strategies to carry out photosynthesis are anatomical changes such as increased parenchyma thickness and reduced xylem area (Kulkarni and Phalke 2009). Anatomical analyses of the leaf showed that the thickness of the palisade parenchyma did not differ among safflower cultivars (Figure 7A). For stem xylem area, however, the IMAMT 1750 with average values of 1360μm cultivar differed from the others, showing a value 2.7% higher than IMAMT 894 with 830 μm and 7% higher than IMAMT 946 with 60 μm (Figure 7B).

Figure 7: Thickness of palisade parenchyma in leaves (%) (A) and xylem area in stem (%) (B) of safflower cultivars IMAMT 894, IMAMT 946 and IMAMT 1750 in vegetative stage. Columns represent the mean, and bars correspond to the standard deviation of five repetitions.

A **B**



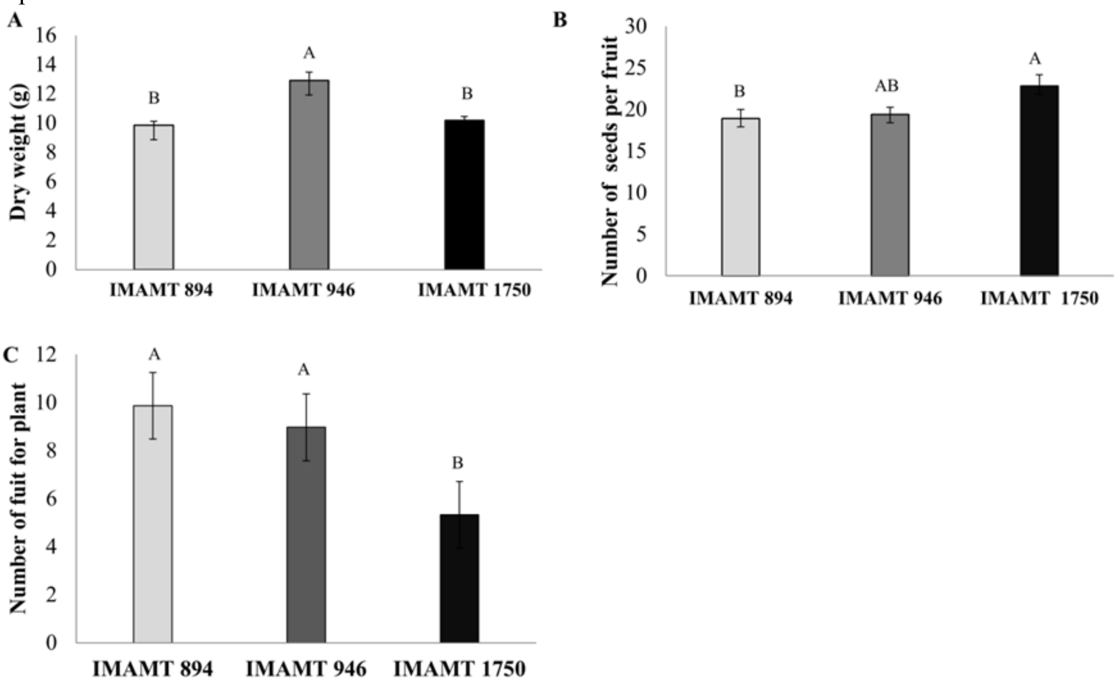
Changes in the xylem area may be more related to survival (Condé et al. 2020), preventing embolism in conductive vessels (Lovisolo and Schubert, 1998) also related to efficiency in water use (Farooq et al. 2019). The tissue can decrease or increasing its diameter depending on the edaphoclimatic conditions (Farooq et al. 2019) and in combination with other tissues for exemple the phloem ensuring efficient water availability for plant growth and survival (Secchi et al. 2017). The cultivar that presented the smallest xylem area was IMAMT 946, however this cultivar did not show more expressive physiological rates. The most outstanding cultivar in terms of physiological parameters, IMAMT 894, showed intermediate xylem development as a survival strategy.

Another strategy related to crop survival is the reduction of the phenological cycle. When annual plants are subjected to environments with reduced water availability, such as semi-arid regions, they tend to accelerate the flowering stage (Silva et al. 2021a). In complementary studies to this one Silva et al. (2021) observed a 75-day maturation period for safflower cultivated in the semi-arid region. Phenological responses in relation to soil and climate conditions tend to be transferred to other generations, even though the crop has a higher or lower density of individuals (Silva et al. 2021).

The IMAMT 946 cultivar stood out with the highest value of dry weight (DW) of the aerial part (Fiure 7A). Considering the number of seeds per capitulum (NSC), the cultivar IMAMT 1750 had the highest NSF compared with the other cultivars, about 17% and 14% higher than IMAMT 894 and IMAMT 946, respectively

(Figure 8B). The IMAMT 894 cultivar presented the highest value for the number of capitulum per plant (NCP), being 46% and 12.2% higher than that found for IMAMT 1750 and IMAMT 946 cultivars, respectively (Figure 8C).

Figure 8: Dry weight (A), number of seeds per fruit (B) and number of fruits per plant (C) of safflower cultivars IMAMT 894, IMAMT 946 and IMAMT 1750. The columns represent the mean, and the bars correspond to the standard deviation of five repetitions.



Dry matter accumulation, grain production (Ye et al. 2017) and capitulum quality result from the efficiency of a set of physiological parameters, including photosynthesis, WUE and E (Oliveira-Freire et al. 2014). In the of selection of cultivar cultivars for production the analysis of parameters such as number of capitula since productivity is also influenced by branching (Neto et al. 2020; Zanetti et al. 2022), as it is at their ends where the capitula are formed and the number of seeds per capitulum indicate high productivity are the main criteria for selection of *C. tinctorius* germplasm (Hussain et al. 2016; Neto et al. 2020; Ebrahimian et al. 2019).

Values close, but still lower, of the number of seeds per capitulum (NSC) to those obtained for the IMAMT 1750 cultivar (Figure 8B) were reported by Omidi et al. (2012) for the cultivar Goldasht (NSC 19.4) this variation is influenced by the cultivar (Koutroubas et al. 2021). The number of capitula per plant (NCP) is a marker of final productivity for safflower (Paludo et al. 2017; Ramonda et al. 2019), as verified in our study for the IMAMT 894 cultivar with values similar to those observed to Zanetti et al. (2022) to safflower about 8,6 capitulum per plant. The main explanation for what was observed for safflower it is due to the high number of branches, where the capitula are formed and the higher number of these reflects in the high number of capitula per plant and final productivity (Neto et al. 2020).

This was also reported for the safflower cultivars FARAMIN (Zafari et al. 2020) and K.w.2 (Omidi et al. 2012). The better yield performance is one of the factors that can indicate the most tolerant safflower genotypes, as found in the study by Yeloojeh et al. (2020) for the cultivars Kouseh C116, C128, C4110, E2417, E2427, E2428, K12, K21, M420, S122, S149 and S3110. Similar NFP values to those of IMAMT 946 cultivar

(Figure 8C) were reported for safflower cultivars Goldasht and Padideh, with 7.53 and 7.47 capitula per plant, respectively (Omidi et al. 2012).

According to Siddiqi et al. (2009), the greatest biomass accumulation is found in cultivars with higher A. However, this characteristic was not observed in the cultivars investigated in the present study. The higher A_N is more related to the final yield, in number of seeds, than to biomass accumulation for the cultivars analyzed here. Farhat et al. (2013) obtained 9.16 DW for safflower, a value lower than that verified in our study for safflower cultivars. The cultivars show yield of 1.07 $kg.m^{-2}$ to IMAMT 894, 0.53 $kg.m^{-2}$ to IMAMT 946 and 0.48 $kg.m^{-2}$ to IMAMT 1750. In general, the IMAMT 894 cultivar, under semiarid conditions, has viability and emphasis on physiological performance (A, E, WUE), with productivity standing out, being about 50% higher in yield compared with the other cultivars. Such criteria are essential for choosing oilseed crops for field production (Silva et al., 2017).

The IMAMT 1750 and IMAMT 946 cultivars can be used as plant cover, a potential already elucidated by Spiassi et al. (2011). Thus, the production of safflower in other regions of Northeast Brazil, with similar edaphoclimatic conditions, contributes to the diversification of potential energy plant matrices for biofuel production. Here we show for the first time data on the phenological and productive development of the IMAMT 894, IMAMT 946 and IMAMT 1750 safflower cultivars in the semi-arid region of Rio Grande do Norte. Further research focusing on other characteristics, such as productive, physiological and morphological, is desirable to map the development of safflower cultivars in semiarid environments.

4. Conclusion(s)

Here we show for the first time data on the phenological and productive development of the IMAMT 894, IMAMT 946 and IMAMT 1750 safflower cultivars in the semi-arid region of Rio Grande do Norte. There is diversification of physiological and productive patterns among the evaluated safflower cultivars. The IMAMT 894 cultivar showed the best germinative (86.0%), anatomical, physiological (A N: 23, 79 μmol $CO2$ $m-2$ $s-1$) performance being considerably more productive (10.0 capitulum per plant), surpassing the other two cultivars together, it is the most suitable among the three cultivars evaluated for production in Brazilian semiarid conditions.

It is evident the need to expand studies to map the physiological mechanisms of different safflower cultivars, in search of combining the greatest number of characteristics, focusing on cultivation efficiency and higher yields in semiarid regions, to improve the socio-economic development of regions with similar edaphoclimatic conditions.

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