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Initial growth and agronomic performance of some important North American safflower cultivars

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Abstract

North American safflower cultivars can be considered as alternatives for cultivation in light of the limited improvement in the commercially grown and registered cultivars in Brazil. This study aimed to evaluate the initial growth and agronomic performance of North American safflower cultivars in Brazil. The experimental design for North American cultivars included random blocks with six cultivars (S-351, 3307, 8311, 0260, 0210 and S-323) and six replicates. The emergence percentage, emergence speed index, average emergence time, and average emergence speed were determined at 15 days after emergence (DAE). Plant height, stem diameter, number of leaves per plant, fresh plant mass, and dry plant mass were determined at 30 DAE. Plant height, stem diameter, number of branches, number of chapters, number of leaves, fresh plant mass, dry plant mass, fresh root mass, and dry root mass were determined at the flowering stage. The final plant density, number of chapters per plant, 100-grain weight, grain yield, oil content, and protein content were determined at the harvest stage. Cultivar S-351 had the greatest initial growth and exhibited greater emergence and emergence speed index. At 30 DAE, the cultivars did not differ with respect to the accumulation of dry mass and number of leaves. During flowering, cultivars S-323 and 8311 had greater accumulation of plant and root dry mass, as well as a greater number of leaves, branches, and chapters. Cultivars 210 and 260 had higher grain yield, whereas cultivars 3307 and S-323 had higher oil content, and cultivar S-351 had higher protein content.

Keywords: *Carthamus tinctorius* L., oilseed, winter.
Abbreviations: DAE_days after emergence; ESI_emergence speed index; AET_average emergence time; AGS_average germination speed; PH_plant height; SD_stem diameter; NL_number of leaves; FPM_fresh plant mass; DPM_dry plant mass; NB_number of branches; NC_number of chapters; FRM_fresh root mass; DRM_dry root mass.

Introduction

Safflower (*Carthamus tinctorius* L.) is an annual oilseed of the Asteraceae family, which can be used as an alternative crop in autumn-winter crop rotation systems because of its tolerance to drought (Santos et al., 2017) and soil compaction (Sarto et al., 2018). The crop shows productive potential, easy adaptability, and good resource use in clay and sandy soils (Santos et al., 2015). Thus, safflower could be used as an energy-producing plant because it is a species with high oil content and can therefore be amenable for biodiesel production (Dordas and Sioulas, 2008).
The species has high cultivation potential, even under adverse environmental conditions (Dantas et al., 2011). However, the planted safflower area is limited globally owing to lack of information on its management. The cultivation cycle of this crop in its center of origin can reach 240 days, which limits its use in tropical agricultural regions such as Brazil. Cultivated safflower should be tested to ascertain its adaptability, seed yield, and oil quality. Safflower has low economic expression in the country, which may be related to the lack of technical knowledge regarding its management and the lack of available cultivars (Galant et al., 2015). Safflower cultivation has recently attracted attention from researchers and industries because it is an oilseed with special characteristics, promising with respect to the quantity and quality of its oil (Silveira et al., 2017). Although this plant has already been studied in southern Brazil for more than a decade, especially for the production of ornamental flowers (Bellé et al., 2012), few safflower cultivars are registered in the National System of Protection of Cultivars (SNPC).
In the current production system in the South, the main summer crop is soybean, which is planted shortly after the beginning of the second harvest or winter crop, called "safrinha", between January and April. In addition to the safflower being an alternative for the winter crop, the resistance of the species to frost renders safflower useful for the late winter crop, between March and April, when the risk of frost makes it difficult to grow maize.
Yields of over 2000 kg ha^{-1} have been recorded for national safflower cultivars under winter cultivation (IAPAR and

IMAmt) in the Southwest region of Brazil (Santos et al., 2017; Santos et al., 2018) and South Brazil (Sampaio et al., 2016; Sampaio et al., 2017; Zanão Júnior et al., 2017). Brazil has promising climatic conditions for safflower cultivation in the winter; however, there is still a need to select species and cultivars in order to increase the yield in Brazil.

The low potential of grain yield and oil content is related to the environmental conditions and the cultivar studied (Çamas et al., 2007; Omid et al., 2012). Ghamarnia and Sepehri (2010) observed significant differences between cultivars for the number of floral chapters per plant, number of seeds per chapter, and the 100-grain weight. In studies to evaluate the genetic and environmental variation for seed production and oil content, Omidi et al. (2012) found that the success of introducing and developing the safflower in a particular country or region depends to a large extent on the seed yield and oil content. In a study carried out in Iran, the authors found a seed yield of 1,500 to 2,000 kg ha^{-1} and an oil content of 24 to 29%.

Commercial cultivars of safflower are not cultivated under tropical conditions. Our hypothesis is that commercial safflower cultivars could be productive in Brazil. Thus, this work aimed to evaluate the initial growth and agronomic performance of North American safflower cultivars in Brazil as the winter crop.

Results and discussion

Traits measured at 15 DAE

The cultivar S-351 stood out with respect to emergence and the emergence speed index, despite the lower average speed of emergence. The average germination speed of cultivar 8311 was 0.33 days; however, this cultivar had a low emergence percentage (35.5%) (Table 1). Maziero et al. (2018) observed variation in the emergence of national safflower genotypes.

Traits measured at 30 DAE

Cultivars 210 and S-323 presented higher plant height at 30 DAE (12 and 13.3 cm, respectively). The other cultivars had similar heights in the range of 10.5 and 11.1 cm (Table 2). Santos et al. (2015) observed a height of 13.5–16.5 cm, which was greater that the height recorded in this study at 30 DAE, for cultivars of IMAmt upon dryland cultivation in the Southwest. The higher initial growth of the IMAmt cultivars may be due to greater adaptation of the cultivars to the environment in Brazil, in addition to the favorable characteristics of the soil and climate. For stem diameter, cultivars S-351 and 3307, which presented lower initial growth, were also grouped with the smaller stem diameters of 2.13 and 2.16 mm, respectively. The best-performing cultivars (210 and S-323) had a larger stem diameter of 2.56 and 2.60 mm, respectively, similar to cultivars 260 and 8311. The other variables evaluated at 30 DAE (number of leaves and fresh and dry mass of plant) did not vary among the cultivars. On an average, the cultivars presented 5.6 leaves, a fresh mass of 0.7 g, and a dry mass of 0.07 g (Table 2). Despite the variation in height and stem diameter, the accumulation of dry mass at the initial phase did not differ significantly among the cultivars assessed in the present study.

Traits measured at flowering

At flowering, the plant heights of cultivar S-323 and 260 were greater than those of the others (100 and 105 cm, respectively). Plant height ranged from 73 to 105 cm (Table 3). Plant height is an important characteristic for mechanized harvest as it varies with cultivar and edaphoclimatic conditions. Santos et al. (2017) verified the presence of variation from 0.69 to 0.93 cm for safflower cultivars in the Southwest. Bellé et al. (2012) observed a height of 112 cm upon cultivation in the South. The variation in height observed in previous studies is due to the characteristics of the cultivar studied; however, North American cultivars have similar stature to the cultivars improved in Brazil.

Cultivars S-323 and 8311 stood out with respect to the stem diameter, number of branches, and number of chapters. The stem diameter ranged from 11.8 to 7.7 mm, whereas the number of branches ranged from 6.8 to 17.1 branches per plant. Owing to the large number of branches, cultivars S-323 and 8311 presented 27.3 and 32.6 chapters per plant, respectively (Table 3). Cultivars S-323 and 8311 showed higher accumulation of plant and root dry matter, as well as a higher number of leaves (Table 4). Selecting cultivars with a potential for dry mass production enables their use in the form of pasture, forage, hay, and silage, and contributes to the maintenance of straw in a no-till system.

Traits measured at harvest

As noted for initial growth, cultivar S-351 also showed the best performance in terms of a greater number of plants per meter in the harvest (24 plants per meter). Cultivar 8311 had a final population of only 9 plants per meter, similar to cultivar 3307 and S-323 with 12 plants per meter each. Cultivars 210 and 260 had similar populations at harvest, with 16 and 15 plants, respectively (Table 5). The safflower can compensate for spatial variation, producing secondary and tertiary chapters. Sampaio et al. (2017) observed that in the fall (April) in southern Brazil, 16 plants per meter are sufficient, whereas for winter crops (July), more than 20 plants per meter are needed. Despite differences in population, owing to the semi-determined growth habit, safflower can counterbalance this variation with better development with respect to the number of stems and/or loss of some chapters, producing more grains in the remaining chapters (Mündel et al., 1994). The cultivars did not differ in relation to the number of chapters per plant, with a variation from 17 to 27 chapters (Table 5). This fact can be explained by the greater swelling and consequent compensation of the smaller populations of cultivars. Santos et al. (2017) observed variation between 10 and 34 chapters for four cultivars in two types of soils. Sampaio et al. (2016) observed 12 chapters in winter and 9 chapters in the autumn. The number of chapters per plant is affected by the spatial arrangement of plants, as evidenced by the fact that the number of chapters per area decreased with the increase in plant density, as reported by Vaghar et al. (2014) and Sampaio et al. (2017). The 100-grain weight of cultivars 3307, 8311, 260, and 210 was similar, varying from 2.3 to 2.4 g, although it was higher in cultivars S-351 (1.9 g) and S-323 (1.6 g) (Table 5). Santos et al. (2017) observed a variation of 2.6–4.3 g in the Southwest of Brazil. Sampaio et al. (2016)

observed the 100-grain weight to be 6.8 g in winter and 4.8 g in autumn when cultivating IAPAR. The 100-grain weight observed for the North American cultivars in the present study was lower than that in the registered Brazilian national cultivars, because the 100-grain weight is affected by the characteristics and genetic background of the plant (Braileanu et al., 2013). The cultivars 260 and 210 showed higher grain yield in relation to the others. The grain yield was 1,607 and 1,198 kg ha^{-1} for cultivars 260 and 210, respectively. The other cultivars showed similar grain yield with a variation of 628 to 953 kg ha^{-1} (Table 5). Santos et al. (2017) observed variation

Table 1. Emergence, emergence speed index (ESI), average emergence time (AET) and average germination speed (AGS) of safflower cultivars at 15 DAE.

Cultivars	Emergence (%)	ESI	AET	AGS
S-351	79.8 a	2.91 a	7.13 a	0.14 d
3307	50.0 b	1.99 b	4.22 c	0.25 b
8311	35.5 c	1.30 c	3.19 c	0.33 a
260	39.5 c	1.32 c	3.94 c	0.26 b
210	58.3 b	2.35 b	4.81 b	0.22 c
S-323	57.0 b	2.18 b	4.97 b	0.20 d
CV (%)	14.1	13.8	16.6	20.8

Same letters belong to the same group by the Scott and Knott grouping test, at 5% probability (p ≤ 0.05).

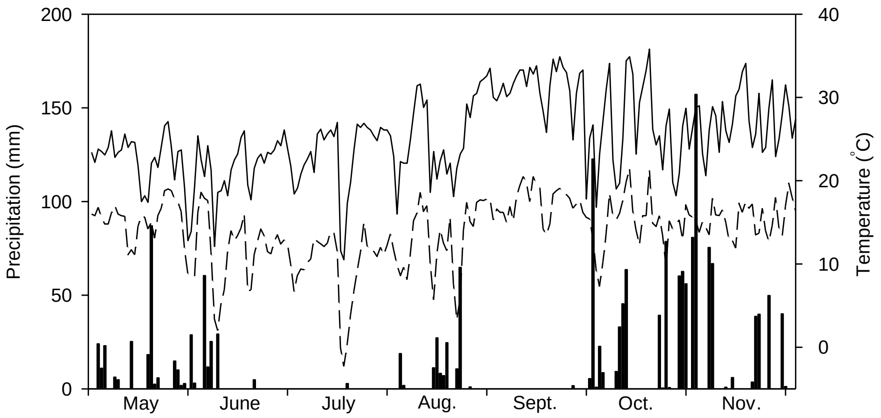

Fig 1. Behavior of meteorological variables of precipitation and mean temperature during safflower cultivation Cascavel, PR, Brazil, in 2017.

Table 2. Plant height (PH), stem diameter (SD), number of leaves (NL), fresh plant mass (FPM), and dry plant mass (DPM) of safflower cultivars at 30 DAE.

Cultivars	PH (cm)	SD (mm)	NL	FPM (g)	DPM (g)
S-351	10.8 b	2.13 b	5.67	0.70	0.07
3307	11.1 b	2.16 b	5.83	0.66	0.07
8311	10.5 b	2.39 a	5.67	0.62	0.06
260	10.5 b	2.48 a	5.33	0.75	0.07
210	13.3 a	2.56 a	5.83	0.90	0.08
S-323	12.0 a	2.60 a	5.83	0.96	0.09
CV (%)	11.9	8.2	14.9	33.8	32.1

Same letters belong to the same group by the Scott and Knott grouping test, at 5% probability (p ≤ 0.05).

Table 3. Plant height (PH), stem diameter (ST), number of branches (NB) and number of chapters (NC) of safflower cultivars at flowering.

Cultivars	PH (cm)	ST	NB	NC
S-351	96 b	7.7 c	6.8 c	14.3 c
3307	73 d	9.6 b	9.6 b	23.6 b
8311	84 c	10.8 a	17.1 a	27.3 a
260	105 a	10.0 b	12.0 b	21.1 b
210	91 b	8.0 c	9.8 b	22.1 b
S-323	100 a	11.8 a	15.0 a	32.6 a
CV (%)	4.8	11.0	18.4	22.5

Same letters belong to the same group by the Scott and Knott grouping test, at 5% probability (p ≤ 0.05).

Table 4. Number of leaves (NL), fresh plant mass (FPM), dry plant mass (DPM), fresh root mass (FRM) and dry root mass (DRM) of safflower cultivars at flowering.

Cultivars	NL	FPM (g)	DPM (g)	DPM (g)	RDM (g)
S-351	124 b	143.1 c	45.8 c	14.0 b	6.2 b
3307	141 b	218.7 b	72.0 c	15.9 b	7.0 b
8311	220 a	310.2 a	109.8 a	35.1 a	12.1 a
260	215 a	236.4 b	80.7 c	31.2 a	11.0 a
210	106 c	172.4 c	65.3 c	9.8 b	4.6 b
S-323	200 a	337.0 a	119.3 a	27.6 a	14.2 a
CV (%)	11.7	21.0	21.9	22.3	42.2

Same letters belong to the same group by the Scott and Knott grouping test, at 5% probability ($p \leq 0.05$).

Table 5. Plant density, chapters per plant, 100-grain weight, grain yield, oil content and protein of safflower grains at harvest.

Cultivars	Plant density	Chapters per plant	100-grain weight (g)	Grain yield (kg ha^{-1})	Oil content (%)	Protein (%)
S-351	24 a	25	1.9 b	914 b	12.2 c	16.6 a
3307	12 c	17	2.4 a	931 b	22.7 a	13.2 b
8311	9 c	19	2.4 a	953 b	19.3 b	13.1 b
260	15 b	27	2.2 a	1198 a	18.7 b	11.1 d
210	16 b	27	2.3 a	1607 a	18.4 b	7.7 e
S-323	12 c	25	1.6 b	628 b	23.4 a	12.4 c
CV (%)	23.4	37.5	17.1	44.3	6.2	3.6

Same letters belong to the same group by the Scott and Knott grouping test, at 5% probability ($p \leq 0.05$).

from 900 to 2,600 kg ha^{-1} for winter cultivation in Southwest Brazil. Sampaio et al. (2016) and Zanão Júnior et al. (2017) observed an average of 3,820 and 4,532 kg ha^{-1} for national cultivars, respectively, cultivated in the South of Brazil. The grain yield of the North American cultivars tested in the South was lower than that reported previously, which may be due to the non-adaptation of the cultivars to subtropical conditions. The oil content of the North American safflower cultivars was between 12.2 and 23.4%, particularly for cultivars 3307 and S-323 (Table 5). Sampaio et al. (2016) observed similar content in winter (23.5% for IAPAR). Zanão Júnior et al. (2017) observed a variation from 23.1 to 29.4%, with an average of 26% for national cultivars. Santos et al. (2018) observed a variation from 23.9 to 30.0% for the IAPAR national cultivar. Santos et al. (2017) recorded a maximum of 45.8% for cultivar 2103 IMAmt in the Southwest. El-Lattief (2013) reported that the oil content of safflower can reach 50%, and oil content is strongly dependent on the genotype (Hang and Evans, 1985). Omid et al. (2012) reported that the potential for grain production and safflower oil content is related to the environmental conditions and the cultivar studied and also largely determines the success of safflower introduction in a given country or region. Safflower can be used for medicinal purposes, in bird feeding, as an ornamental plant, and in feeding ruminants with the use of hay and pie (Bem Moumen et al., 2015). The protein content ranged from 7.7 to 16.6% and was the highest for cultivar S-351. Owing to the wide variation, the results revealed five groups of significance, where cultivar 210, which was the most productive (1,607 kg ha^{-1}) had the lowest protein content (7.7%). El-Lattief (2013) reported that the protein content in grains can reach 20%, as the seed cake contains 35–45% protein and can be used in ruminant and monogastric feed because it has no anti-nutrient factors (Ebrahimian and Soleymani, 2013).

Materials and methods

Study site description

The experiment was conducted at the Foundation for Scientific and Technological Development in the Municipality of Cascavel, Paraná, Brazil (latitude 25°00′24″S, longitude 53°17′09″W and altitude of 802 m). The climate is considered Cfa (subtropical climate), with an average annual rainfall above 1800 mm, but with no defined dry season and with the possibility of frost during the winter. The meteorological conditions during the experiment are presented in Fig. 1. The soil of the experimental area was classified as Rhodic Acrudox (Soil Survey Staff, 2010). The results of the chemical analysis were as follows: pH 4.47 in $CaCl_2$ (0.01 mol L^{-1}); 50 g dm^{-3} organic matter; 2.8 mg dm^{-3} P (Mehlich 1); 0.37 cmol$_c$ dm^{-3} of K^+; 4.1 cmol$_c$ dm^{-3} of Ca^{2+}; 1.5 cmol$_c$ dm^{-3} of Mg^{2+}; 14.8 cmol$_c$ dm^{-3} of cation exchange capacity (CEC); and 40% saturation basis.

Treatments

Six North American safflower cultivars (S-351, S-323, 3307, 8311, 260, and 210) were planted on a no-till system on May 12, 2017. The experimental units consisted of seven 40-m rows with a spacing between rows of 0.45 m and seed spacing of 0.05 m.

Field management

To implement the experiment, the area was cleaned with 950 g i.a. ha^{-1} of glyphosate. The sowing was performed mechanically, using a seeder-fertilizer machine, regulated to 32 seeds per meter. Fertilization was carried out at 130 kg ha^{-1} of the 8-20-20 formulation. The pre-emergent herbicide Metolachlor was applied at a dosage of 960 g i.a. ha^{-1}.
On August 1, 2017, nitrogen fertilization was performed with 170 kg ha^{-1} of encapsulated urea (45% N).

Traits measured

To evaluate initial growth, data were collected at 15 days after emergence (DAE) to determine the emergence percentage, emergence speed index, average germination time, and average emergence speed. The percentage of emergence, average emergence time, and average emergence speed were calculated as described by Labouriau and Valadares (1976). The emergence speed index was determined by the sum of the number of normal seedlings that emerged daily divided by the number of days elapsed between the sowing and emergence, according to the formula proposed by Maguire (1962).

At 30 DAE, plant height and stem diameter were determined using a pachymeter; the number of leaves per plant and the plant fresh and dry mass were measured. To determine the dry mass, seedlings were placed in a forced circulation oven at 65°C for 72 hours.

On September 30, 2017, at flowering, plant height, stem diameter, number of branches, number of chapters, number of leaves, fresh plant mass, dry plant mass, fresh root mass, and dry root mass were determined.

At the time of harvest, between October 23 and November 1, 2017, the plant density, number of chapters per plant, 100-grain weight, grain yield, oil content, and protein content were determined. Oil content was determined using the Soxhlet method (IAL, 1985) and protein content was determined using the Kjeldahl method (AOAC, 1995).

Statistical analysis and experimental design

Data were subjected to analysis of variance in a randomized block design with six replicates. The averages were grouped by a clustering test proposed by Scott and Knott, at a level of 5% ($p \leq 0.05$) probability using the software SISVAR® (Ferreira, 2011).

Conclusion

The cultivar S-351 had the best performance with respect to initial growth, with a greater emergence and index of emergence speed. At 30 DAE, the cultivars did not differ in the accumulation of dry mass and leaves. With respect to flowering, cultivars S-323 and 8311 had greater accumulation of plant and root mass, as well as higher numbers of leaves, branches, and chapters. Cultivars 210 and 260 had the highest grain yield, whereas cultivars 3307 and S-323 had higher oil content.

References

Abud HF, Reis RGE, Innecco R, Bezerra AME (2010) Emergência e desenvolvimento de plântulas de cártamo em função do tamanho das sementes. Rev Ciên Agron. 41:95–99.

AOAC - Association Of Official Analytical Chemists (1995) Official methods of analysis. 16th ed. Arlington, USA: AOAC.

Bellé RA, Rocha EK, Backes FAAL, Neuhaus M, Schwab NT (2012) Cártamo cultivado em diferentes épocas de semeadura e densidades de plantas. Ciênc Rural. 42:2145–2152.

Ben Moumen A, Mansouri F, Richard G, Abid M, Fauconnier ML, Sindic M, Serghini CH (2015) Biochemical characterisation of the seed oils of four safflower (*Carthamus tinctorius*) varieties grown in north–eastern of Morocco. Int J Food Sci Technol. 50:804–810.

Braileanu SI, Kadar RR, Duda MM, Gocan TM, Moldovan C (2013) The Influence of technological elements on some production components for the spring wheat. Pro Environment. 6:379–383.

Çamaş N, Çirak C, Esendal E (2012) Seed yield, oil content and fatty acids composition of safflower (*Carthamus tinctorius* L.) grown in northern Turkey conditions. J Facul Agric (Turkey). 22:98–104

Dantas S, Vanúcia C, Silva IB, Pereira G, Maia JM, Lima S, Macedo CEC (2011) Influência da sanidade e déficit hídrico na germinação de sementes de *Carthamus tinctorius* L. Rev Bras Sementes. 33:574–382.

Dordas CA, Siolas C (2008) Safflower yield, chlorophyll content, photosynthesis, and water use efficiency response to nitrogen fertilization under rainfed conditions. Ind Crops Prod. 27:75–85.

Ebrahimian A, Soleymani A (2013) Response of yield components, seed and oil yields of safflower to nitrogen, phosphorus and potassium fertilizers. Int J Agron Plant Product. 4:1029–1032.

El–Lattief EAA (2013) Safflower yields and water use efficiency as affected by irrigation at different soil moisture depletion levels and plant population density under arid conditions. Arch Agron Soil Sci. 59:1545–1557.

Ferreira DF (2011) Sisvar: a computer statistical analysis system. Ciênc Agrotec. 35:1039–1042.

Galant NB, Santos RF, Silva MA (2015) Melhoramento de cártamo (*Carthamus tinctorius* L.). Acta Iguazu. 4:14–25.

Ghamarnia H, Sepehri S (2010) Different irrigation regimes affected water use, yield and other yield components of safflower (*Carthamus tinctorius* L.) crop in a semi–arid region of Iran. J Food Agri Environ. 8:590–593.

Hang AN, Evans DW (1985) Deficit sprinkler irrigation of sunflower and safflower. Agron J. 77:588–592.

IAL (Instituto Adolpho Lutz) (1985) Chemical and physical methods for food analysis. Analytical Standards, São Paulo, 317.

Zanão Júnior LA, Paschoal TS, Pereira N, Araújo PM, Secco D, Santos RF, Prior M (2017) Seed productivity, oil content and accumulation of macronutrients in safflower (*Carthamus tinctorius* L.) genotypes in subtropical region. Aust J Crop Sci. 11:1254–1260.

Labouriau LG, Valadares MB (1976) On the germination of seeds of *Calotropis procera*. An Acad Bras Ciên. 48:174–186.

Maguire JD (1962) Speed of germination and in selection and evaluation for seedlings emergence and vigor. Crop Sci. 2:176–177.

Maziero CL, Santos RF, Leite LAB, Nascimento LFJ, Masiero MA (2017) Emergência e desenvolvimento inicial de plântulas de Cártamo (*Carthamus tinctorius* L.) inoculadas com Azospirillum Brasilense. Acta Iguazu 6:104–113.

Mündel HH, Morrison RJ, Blackshaw RE, Entz T, Roth BT, Gaudiel R, Kiehn F (1994) Seeding–date effects on yield, quality and maturity of safflower. Can J Plant Sci. 74:261–266.

Omidi AH, Khazaei H, Monneveux P, Stoddard F (2012) Effect of cultivar and water regime on yield and yield components in safflower (*Carthamus tinctorius* L.). Turk J. Field Crops 17:10–15.

Sampaio MC, Santos RF, Bassegio D, Vasconselos ES, Silveira L, Lenz NBG, Tokuro LK (2017) Effect of plant density on oil yield of safflower. Afr J Agric Res. 12:2147–2152.

Sampaio MC, Santos RF, Bassegio D, Vasconcelos ES, Silva MA, Secco D, Silva TRB (2016) Fertilizer improves seed and oil yield of safflower under tropical conditions. Ind Crop Prod. 94: 589–595.

Santos RF, Silva MA, Klar AE, Zanotto MD, Bassegio D (2015) Comportamento morfológico no período de crescimento de genótipos de *Carthamus tinctorius* L. em cultivo sob sequeiro e irrigado. Rev Bras Energ Ren. 4:146–167

Santos RF, Bassegio D, Silva MA (2017) Productivity and production components of safflower genotypes affected by irrigation at phenological stages. Agric Water Manag. 186:66–74.

Santos RF, Bassegio D, Sartori MMP, Zanotto MD, Silva MA (2018) Safflower (*Carthamus tinctorius* L.) yield as affected by nitrogen fertilization and different water regimes. Acta Agron. 67:264–269.

Sarto, MVM, Bassegio D, Rosolem CA, Sarto JRW (2018) Safflower root and shoot growth affected by soil compaction. Bragantia. 77:348–355.

Silveira L, Júnior ES, Dal Pozzo DM, Santos RF, Tokura LK, Secco D (2017) Influência alelopática do extrato aquoso de folhas de Citronela (*Cymbopogon*) sobre a germinação e desenvolvimento inicial de quatro genótipos conhecidos de Cártamo (*Carthamus tinctorius* L.). Acta Iguazu. 6: 197-206.

Soil Survey Staff (2010) Keys to soil taxonomy. 11.ed. Washingthon, USDA–Natural Resources Conservation Service. 338.

Vaghar MS, Shamsi K, Kobraee S, Behrooz R (2014) The effect of planting row interval and plant density on the phonological traits of safflower (*Carthamus tinctorius* L.) under dry land condition. Int J Bios. 4:202–208.