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Cultivation of safflower flower stems with seeds treated by thermotherapy

Janine Farias Menegaes*, Ubirajara Russi Nunes, Rogério Antônio Bellé, Fernanda Alice Antonello Londero Backes, Juçara Terezinha Paranhos, Sidinei José Lopes

Federal University of Santa Maria, Santa Maria, Brazil
*Corresponding author, e-mail: janine_rs@hotmail.com

Abstract

The floral stems of safflower (*Carthamus tinctorius* L.) present an ornamental character due to their rusticity and versatility of use. The propagation via seeds shows high incidence of pathogens, negatively affecting the establishment of plants in the field, requiring treatments. Thus, the objective of this study was to evaluate the cultivation of safflower flower stems from seeds treated by thermotherapy and sown at different seasons in the year. The experiment was carried out in a completely randomized, 4 x 3 factorial design (sowing dates and thermotherapy treatments), with four replications. Sowings took place in the first seasonal fortnights (spring and summer of 2016, and autumn and winter of 2017), after undergoing thermotherapy treatment or not: control (without treatment), moist heat thermotherapy (45° C 15 min^{-1}) and heat dry thermotherapy (45° C 24 h^{-1}). It was evaluated the emergence of seedlings for plant stand formation, the phenological stages until flowering, the duration of the cultivation cycle, phyllochron, anthochron, the biometry of flower stems and inflorescences. It was observed that the seed treatments via thermotherapy were beneficial for the initial establishment of seedlings in the field. The development and duration of the cultivation cycle of the flower stems were different for all sowing dates, with the maintenance of the ornamental characteristics and the quality of the flower stems.

Keywords: *Carthamus tinctorius* L., sowing dates, cut flower

Introduction

The inflorescences of safflower (*Carthamus tinctorius* L.), a plant that belongs to the Asteraceae botanical family and is originally from Asia, present an ornamental character due to their beauty, rusticity and versatility of use, with flower stems used fresh or dry, with a 15-day up to two-month postharvest durability, respectively. They are marketed as cut flowers and must have a minimum length of 60 cm and three inflorescences (Cooperativa Veiling Holambra, 2016; Menegaes et al., 2019).

It is an annual and herbaceous plant, up to 1.5 m high, its branches produce one to five solitary inflorescences (capitulum) at the apex of the branches in the colors yellow, orange or red, having its propagation only via seeds, without the need to overcome dormancy (Coronado, 2010; Emongor & Oagile, 2017).

The cultivation cycle for flower stems varies from 80 days in the summer to 140 days in the winter, with good adaptation to the climatic conditions of southern Brazil, and can be cultivated all year round (Bellé et al., 2012). However, sowing season is the key point to optimizing productivity and quality of flower stems, and studies have shown that this cultivation is responsive to the sowing season in regions with mild temperatures and with precipitations above 400 mm (Golzarfar et al., 2012; Omidi et al., 2012).

Introduced in the south of Brazil in the 90s as an ornamental plant, currently the production of safflower flower stems has been gradually reduced due to the high incidence of phytopathogens in the entire production cycle (Emongor & Oagile, 2017; Sampaio et al., 2017). With this, economic and scientific investments are necessary to obtain seeds with phytosanitary quality.

Although in Brazil there is a high number of products registered for seed treatment in agricultural

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species, in ornamental species, such as safflower, there is no registration in MAPA (Ministry of Agriculture, Livestock and Supply). In this context, and seeking agricultural practices with low environmental impact, the use of thermotherapy as seed treatment becomes a promising alternative for crops (Coutinho et al., 2007) such as safflower, which provides a wide range of raw materials, especially oil, medicinal and ornamental materials.

Thus, the objective of this study was to evaluate the cultivation of safflower flower stems with seeds treated by thermotherapy and planted in different seasons of the year.

Material and Methods

This study was carried out from October 2016 to November 2017, in the experimental area of the Floriculture Sector in the Phytotechnics Department of the Federal University of Santa Maria (UFSM), located in Santa Maria, RS (29°43 'S; 53°43' W and altitude of 95 m). The climate in the region is humid subtropical (Cfa), according to the Köppen-Geiger classification, with accumulated average annual rainfall of 1,769 mm, average annual temperature close to 19.2° C and air humidity around 78.4 %.

The experiment had a completely randomized design, organized in a 4 x 3 factorial scheme (sowing dates and thermotherapy treatments), with four replications. Each replication consisted of a plot with dimensions of 1 m x 2 m. The planting of safflower, from the Lasting Orange cultivar, took place in sowing dates in the first seasonal fortnights: S1: spring 2016 (October 6th, 2016); S2: summer 2016 (December 22nd, 2016); S3: autumn 2017 (April 5th, 2017) and S4: winter 2017 (July 5th, 2017).

The thermotherapy treatments were: control (TEST; no treatment); moist heat thermotherapy (MHT); and dry heat thermotherapy (DHT). For MHT: seeds were placed in a 500 mL Becker glass containing distilled water and kept in a thermo-digital water bath with water heated for 45° C 15 min^{-1}. The seeds were previously soaked in unheated distilled water for one hour to eliminate air pockets between the dead surface tissues, facilitating the conduction of heat in the seed tissues (Coutinho et al., 2007), and then placed to dry on paper towels at room temperature for a period of 24 h. For DHT: the seeds were placed in Kraft paper bags (1.0 kg brown type) and submitted to temperature 45° C 24 h^{-1}, in a forced circulation oven.

Before sowing, the beds were prepared (1.2 m x 9.0 m) with soil correction according to the result of the soil physical-chemical analysis. Considering that there is no information on fertilization and liming for the cultivation of safflower for the states of RS and SC, it was used the proposed recommendation for the cultivation of sunflower (*Helianthus annuus* L.) (SBCS, 2016), as it belongs to the same botanical family. A drip tape irrigation system spaced at 20 cm (with drippers spaced at 20 cm and a flow rate of 7.5 L h^{-1} m^{-1}) was installed over the beds, with the woven meshes (12.5 cm x 10 cm) forming the density of 80 plants m^{-2} recommended by Bellé et al. (2012).

Sowing took place directly in the beds with three seeds per cell in the tutoring woven mesh, with the objective of observing the emergence rate and, also, guaranteeing the formation of the initial plant stand. The thinning of the seedlings was carried out, forming a density of 80 plants per m^{-2} recommended by Bellé et al. (2012).

The evaluation of seedling emergence in the field was done using as criterion the development of cotyledons and epicotyl, for 14 days after sowing (DAS), and the results were expressed as percentage of emergence (Brasil, 2009). The parameters of emergence speed index (ESI), mean emergence time (MET) and mean emergence speed (MES) were determined by daily evaluations according to the methodologies described by Maguire (1962) and Furbeck et al. (1993).

The periods (days) of each phenological stage (Figure 1) were evaluated according to the safflower phenological scale until flowering, adapted from the proposal of Rivas & Matarazzo (2009) and Flemmer et al. (2015). The biometric parameters of the crop (Figure 2A): floral stem length (cm) from the neck of the plant to the central inflorescence; length of branches of the floral stem (cm) from ramification to inflorescence; root length (a block of soil 30 cm-deep was removed and then the soil was removed and washed for the removal of roots; cm); number of leaves on the stem, considering from the neck to the ramification and, average number of leaves per branch; diameter (mm) of the floral stem measured below the first pair of leaves above the ramification; diameter (mm) of the stem-branch obtained in the pair of leaves below the inflorescence; diameter and length of inflorescences with the use of a digital pachymeter (accuracy of 0.001); fresh and dry mass of the floral stem with the use of a digital scale (accuracy of 0.001g).

Total leaf area (AF) was calculated using the methodology described by Hallaire et al. (1970), expressed in the Equation [AF $=\sum_1^n$ (L*C) *k], where L: leaf width; C: leaf length; n: number of leaves; k: correction factor calculated from the angular coefficient of the linear equation between leaf width and length, according to Moraes et al. (2013), k=0.42.

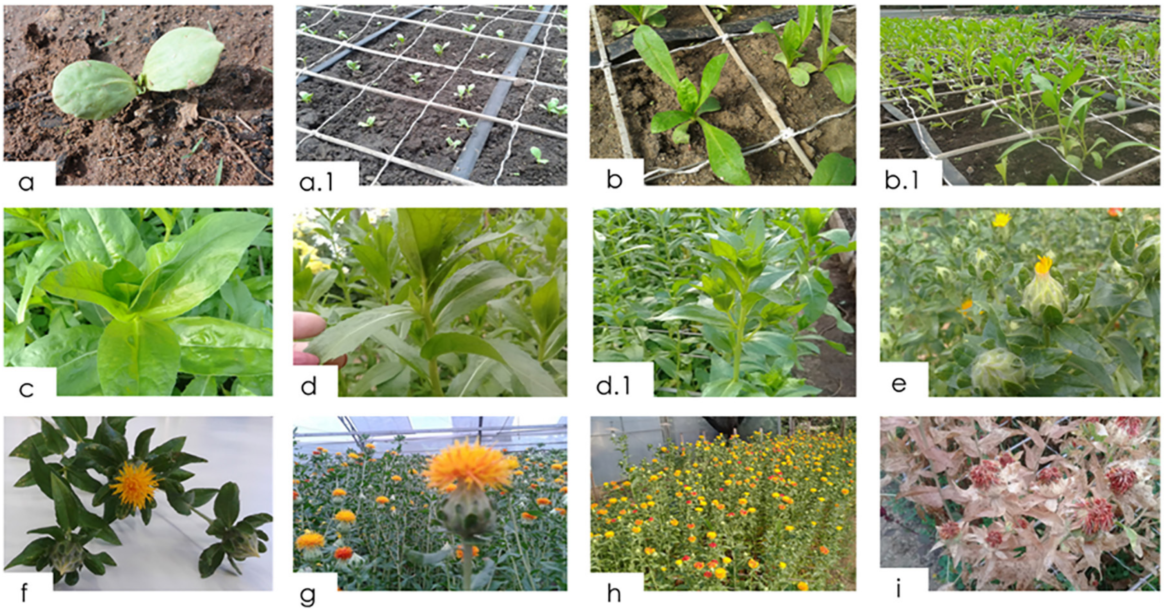

Figure 1. Phenological stages of *Carthamus tinctorius* L. adapted from Rivas & Matarazzo (2009) and Flemmer et al. (2015) until flowering. a-a.1: emergence; b-b.1: elongation; c: differentiation of central inflorescence; d: beginning of ramification; d.1: ramification of lateral inflorescences; e: flowering; f: stem collection point; g: full flowering; h: end of harvest flowering, i: dry flower stems. Photos: The Authors (2016).

The accumulated thermal sum (STa, ° C day) from emergence to full flowering, followed the methodology of Arnold (1960), expressed in Equation [$STa=\sum_{1}^{n}((T_{max}+T_{min})/2)-T_b$], where n: days between emergence and full flowering; T_{max}: maximum daily air temperature (° C); T_{min}: minimum daily air temperature (° C); T_b: base temperature (°C). It was used Tb = 5° C, according to Streck et al. (2005).

The phyllochron of each sowing date was estimated by the inverse of the angular coefficient of the linear regression between the number of leaves and the thermal sum, between the phenological stages of emergence to the beginning of ramification (Figure 1) (Streck et al., 2005).

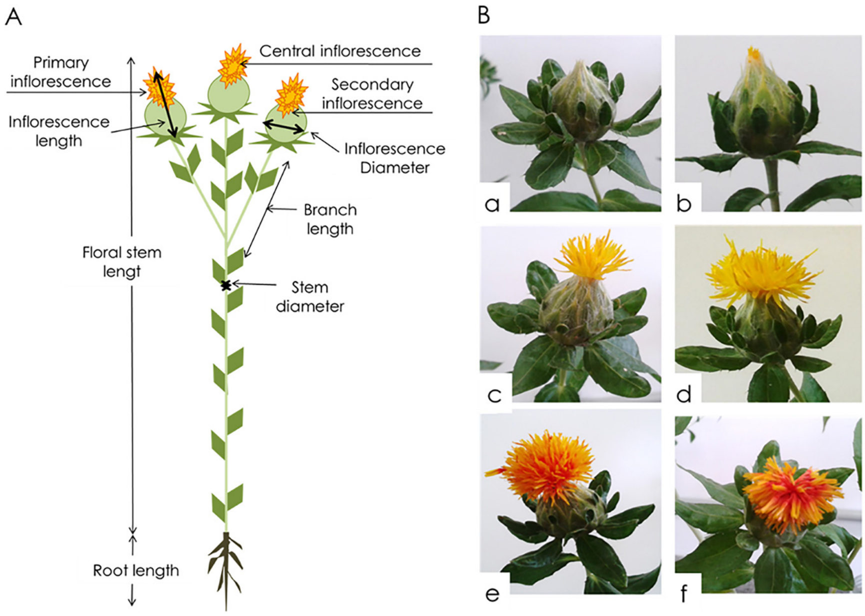

Figure 2. *Carthamus tinctorius* L. A - Illustration for the evaluation of the biometric parameters of the floral stem. B - Flowering stages: appearance of color in the ligules on the bud (a), appearance of the visible stamens (b), stamens and ligules partially exposed (c), full flowering (d), end of flowering (e) and senescence of the inflorescence (f). Source/Photos: adapted from Menegaes et al. (2019).

The anthochron of each sowing date was estimated by the inverse of the angular coefficient of the linear regression of the beginning of flowering and the thermal sum, based on the methodology used to estimate the phyllochron, between the flowering stages (Figure 2Ba to 2Bd) (Streck et al., 2005; Schwab et al., 2014). During the study, the following meteorological variables were monitored: maximum and minimum temperatures, wind speed, precipitation and solar radiation, obtained from the meteorological station of the National Institute of Meteorology (INMET), located in the UFSM *Campus*.

The data expressed as percentage were transformed into arc sine √ (x/100). The analysis of variance of the data and the comparison of qualitative means by the Scott-Knott test ($p < 0.05$) were performed with the aid of the SISVAR software (Ferreira, 2014).

Results and Discussion

The average air thermal amplitudes were 20.6; 24.6; 17.5 and 17.9° C maximum and, 19.5; 23.4; 17.5 and 16.7° C minimum for the sowing seasons in spring, summer, autumn and winter, respectively (Figure 3a). The region where the study took place is within the thermal range suggested by Rivas & Matarazzo (2009), in which the sowing and cultivation of safflower are recommended for regions with temperatures between 20 and 35° C.

The accumulated rainfall was of 2,274.7; 2,212.0; 2,973.8 and 1,856.2 mm (Figure 3b), with average solar radiation of 923.9; 883.7; 583.3 and 639.0 MJ m^{-2} day^{-1} for sowing dates in spring, summer, autumn and winter, respectively (Figure 3c). The average wind speed was 2.1 m s^{-1} for all sowing dates (Figure 3d), without damage to the plants. In all sowing dates, no lodging of the plants was verified.

Golzarfar et al. (2012) and Omidi et al. (2012) report that the safflower culture thrives well in environments with average annual rainfall between 600 and 1,000 mm, being resistant to water stress. However, the accumulated rainfall during the execution of this study favored the early senescence of the quality of the flower stems, due to the exposure for long periods to leaf wetness.

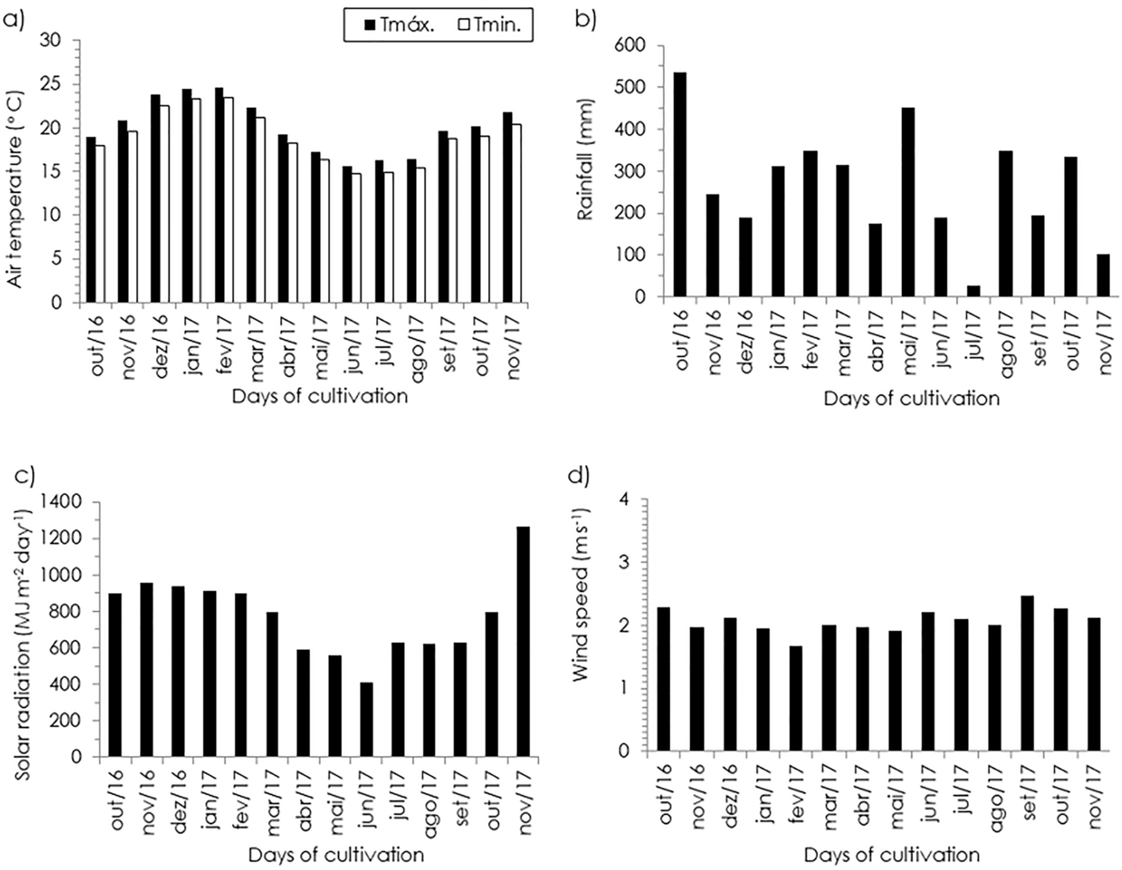

Figure 3. Meteorological variables during the cultivation of *Carthamus tinctorius* L. at different sowing dates in spring, summer, autumn and winter 2016/2017, in Santa Maria. Monthly averages of maximum and minimum air temperature (° C; a), rainfall (mm; b); solar radiation (MJ m^{-2} day^{-1}; c) and wind speed (m s^{-1}; d).

It was observed that the sowing dates did not influence the emergence of seedlings either for seeds that received thermotherapy treatments or not (Table 1). The average seedling emergence was 84% (202 plants m^{-2}) and 83% (199 plants m^{-2}) for seeds treated with moist heat (MHT) and dry heat (DHT) thermotherapy treatments, respectively, differing statistically from untreated seeds, with 73% of emergence (175 plants m^{-2}). This emergence directly reflects in the initial establishment of seedlings in the bed, providing a stand of uniform plants, in which the thermotherapy treatments provided a gain of 15.1 and 13.7% in the emergence for thermotherapy via moist and dry heat, respectively, in comparison to untreated seeds.

Table 1. Seedling emergence, emergence speed index (ESI), mean emergence time (MET) and mean emergence speed (MES) of *Carthamus tinctorius* L. in the flowerbeds to form the initial plant stand.

TREAT.	Sowing dates									
	Spring	Summer	Autumn	Winter	MD	Spring	Summer	Autumn	Winter	MD
	Initial emergence (%)					ESI				
TEST	72 ns	71	76	75	73 B	23.3 Bb *	26.6 Bb	30.0 Ba	30.4 Ba	27.6
MHT	84	81	88	84	84 A	37.8 Ab	32.3 Bc	40.5 Aa	36.9 Bb	36.9
DHT	80	83	83	87	83 A	39.3 Ab	38.7 Ab	40.1 Ab	43.7 Aa	40.5
MV	79 b	78 b	82 a	82 a		33.5	32.5	36.9	37.0	
CV (%)		2.53					11.19			
	MET (days)					MES ($days^{-1}$)				
TEST	5.9 Ab *	5.7 Ab	9.4 Aa	8.9 Aa	7.5	0.185 Ba *	0.188 Ba	0.107 Ab	0.112 Ab	0.148
MHT	5.0 Ab	5.2 Ab	9.4 Aa	9.4 Aa	7.2	0.199 Aa	0.195 Aa	0.107 Ab	0.107 Bb	0.152
DHT	4.9 Ab	5.0 Ab	9.2 Aa	9.1 Aa	7.1	0.204 Aa	0.205 Aa	0.108 Ab	0.110 Ab	0.157
MV	5.3	5.3	9.3	9.1		0.196	0.196	0.107	0.110	
CV (%)			2.75					2.78		

* significant interaction and ns non significant interaction of factors. Test of means not followed by the same letter, uppercase in the column and lowercase in the row, differ by the Scott-Knott test ($p < 0.05$). MV: mean value. CV: coefficient of variation. TREAT: seed treatments: control (TEST), moist heat thermotherapy (MHT) and dry heat thermotherapy (DHT)

The mean emergence speed index (ESI) for the sowing dates was 36.9 for the MHT treatment and 40.5 for the DHT, compared with 27.6 from seeds without treatment. It was observed by the ESI that both thermotherapy treatments on the seeds provided a faster emergence, thus positively influencing the emergence of seedlings and, consequently, the formation of the initial stand.

The mean emergence time (MET) was on average 5.3; 5.3; 9.3 and 9.1 days (Table 1 and Figure 4a) and the mean emergence speed (MES) was of 0.196; 0.196; 0.107 and 0.100 $days^{-1}$ for the sowing seasons in spring, summer, autumn and winter, respectively. These parameters indicate that the emergence of plants requires a longer period of time to occur when they are exposed to low temperatures, which is characteristic of colder seasons (autumn and winter). According to Paiva & Almeida (2014), the emergence of safflower seedlings varies from 10 to 14 days in temperatures between 20 and 23º C.

Both thermotherapy treatments were found to provide safflower seeds with a greater expression of their physiological potential. Kaya (2014), researching the physiological quality of seeds of different safflower cultivars submitted to controlled deterioration with moist heat at 45º C, verified that up to 24 h of exposure to this temperature there was an increase in germination and emergence potential.

The use of thermotherapy allowed a percentual gain in the emergence, verified as seed treatment for the safflower crop, allowing for a better use of solar radiation, water and nutrients, besides promoting the uniformity of plants in the area, factors that are decisive for decision making in the scaling of production, especially in floriculture. Marcos-Filho (2015) reports that the physiological potential of seeds is expressed by emergence and, it is related to the interaction of climatic conditions to which they were exposed, which may benefit the initial development of plants and the quality of seedlings, especially those that represent commercial products, for example, vegetables and flowers.

It was found that the thinning of the seedlings at the phenological stage of starting elongation (Figures 1 and 4) provided better development of flower stems with uniform density and spacing. Sampaio et al. (2017) found that sowing date and spacing are the main factors that affect the safflower crop, compromising plant quality and seed productivity. For cut flowers, Bellé et al. (2012) recommend 80 plants m^{-2} to obtain homogeneous plants with little branching, which is desired for the commercialization and classification of safflower cut flowers as seen by Cooperativa Veiling Holambra (2016).

In general, the growth and development of safflower plants observed in their phenological stages (Figure 4) showed a small variation due to the different seed treatments by thermotherapy, however, it is pointed out a variation among sowing dates (Table 2).

It was observed that safflower plants are responsive to the thermal sum resulting in flower stems suitable for harvest, with an average cultivation cycle of 68; 57; 106 and 92 DAS for sowing dates in spring, summer, autumn and winter, respectively (Table 2). It was found that the sowings in the autumn and winter seasons result in floral stems of greater length, diameter, fresh weight and number of leaves, in relation to the spring and summer seasons (Table 3).

In this experiment, it was observed that for the flowering of safflower, the plant needs an accumulated thermal sum of at least 964.8° C day, obtained in the summer sowing and a maximum of 1,375.5° C day in autumn (Table 2). Mendonça et al. (2012) report that there is a direct relationship between the thermal sum and the days in the civil calendar, for the biological time in plant species, showing the adaptation of the plant to the cultivation environment.

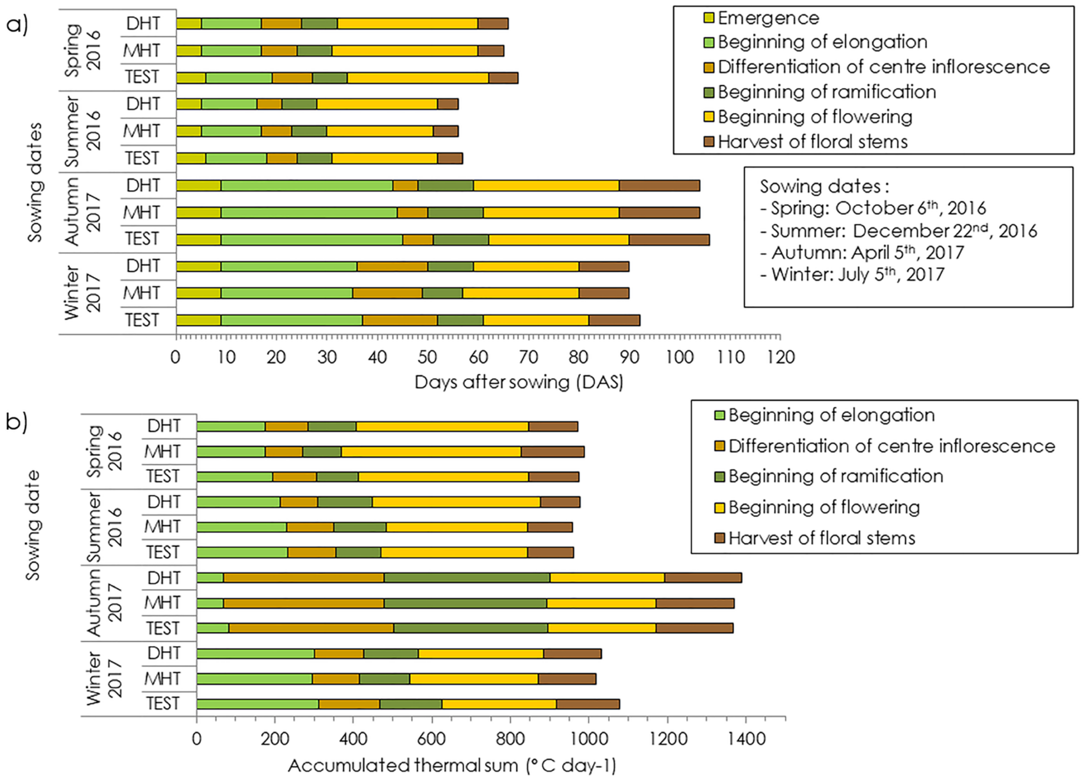

Figure 4. Days after sowing (DAS; a) and accumulated thermal sum (° C day; b) in function of seed treatments and sowing dates for each phenological stage of *Carthamus tinctorius* L., adapted from the scale of Rivas & Matarazzo (2009) and Flemmer et al. (2015), grown in Santa Maria, RS.

Table 2. Total thermal sum, phyllochron, antochronum and harvest of the floral stems of *Carthamus tinctorius* L. according to the different sowing dates.

Sowing dates	Total thermal sum (° C day)	Philochron (° C day^{-1} leaf^{-1})	Antochron (inflorescence days^{-1})	Harvest of flower stems (DAS)
Spring	978.4 c *	26.8 c *	0.563 b *	68
Summer	964.8 c	35.5 a	0.510 b	57
Autumn	1,375.5 a	31.7 b	0.790 a	106
Winter	1,043.0 b	18.3 d	0.720 a	92
Average	1,090.4	28.1	0.646	81
CV (%)	2.87	2.06	31.05	-

* Test of means not followed by the same letter differ by the Scott-Knott test ($p < 0.05$). CV: coefficient of variation. DAS: days after sowing.

Emongor & Oagile (2017) point out that safflower plants are responsive to thermal sum, which directly influences the duration of the cultivation cycle. Bellé et al. (2012) observed that the cultivation cycle for safflower flower stems in Santa Maria, RS, varies from 80 days in summer to 140 days in winter. FAOSTAT (2017) indicates that the average safflower cultivation cycle, worldwide, for seed production, varies from 160, 120, 200 and 230 days in the spring, summer, autumn and winter seasons, respectively, counting from the periods of emergence to the harvest of seeds.

It was observed that the phyllochron for the different seasons of safflower sowing showed an overall average of 28.1° C day leaf^{-1}, the sowing in winter having the lowest thermal accumulation for the emission of leaves with 18.3° C day leaf^{-1} (Table 2). Streck et al. (2005) verified the emission of safflower leaves with a phyllochron of 25.5°C day leaf^{-1}, for the sowing in spring. Fagundes et al. (2007) observed differences of phyllochron between 22.0 to 25.4° C leaf^{-1} day for sunflower due to the different nitrogen fertilizations.

Table 3. Biometry of the flower stem and inflorescences of *Carthamus tinctorius* L. in function of seed treatments and sowing dates.

TREAT.	Sowing dates									
	Spring	Summer	Autumn	Winter	MV	Spring	Summer	Autumn	Winter	MV
	Floral stem length (cm)					Root length (cm)				
TEST	78.8 Bc *	76.8 Bc	122.5 Bb	148.9 Ba	106.7	20.8 ^{ns}	18.3	20.6	24.6	21.1 A
MHT	78.5 Bc	80.3 BC	130.7 Ab	151.0 Aa	110.2	19.5	19.3	21.8	24.9	21.4 A
DHT	80.8 BC	81.5 BC	132.0 Ab	150.3 Aa	111.1	20.0	20.8	22.1	24.8	21.9 A
MV	79.3	79.5	128.4	150.1		20.1 c	19.4 c	21.5 b	24.8 a	
CV (%)	4.99					6.93				
	Flower stem branch length (cm)					Diameter of floral stem (mm)				
TEST	14.9 ^{ns}	12.4	21.9	24.5	18.4	4.6 Aa *	4.0 Aa	3.7 Ab	3.9 Bb	4.0
MHT	17.2	13.5	21.5	25	19.3 A	4.2 Aa	3.8 Ba	3.6 Ab	4.0 Ba	3.9
DHT	16.4	14.5	24.5	26.7	20.5 A	4.2 Aa	4.3 Aa	3.3 Bb	4.5 Aa	4.1
MV	16.1 c	13.5 d	22.6 b	25.4 a		4.3	4.0	3.5	4.1	
CV (%)	17.52					7.54				
	Number of leaves on the floral stem (units)					Average number of leaves on the branch (units)				
TEST	24.5 Bc *	19.5 Bc	36.6 Bb	52.2 Ba	33.2	6.3 ^{ns}	5.0	7.2	8.4	6.8 A
MHT	24.5 Bc	19.5 Bc	38.4 Bb	60.6 Aa	35.7	4.8	4.5	6.6	6.8	5.7 B
DHT	26.0 BC	25.0 BC	44.2 Ab	61.4 Aa	39.1	5.8	6.0	7.6	8.2	6.9 A
MV	25.0	21.3	39.7	58.1		5.6 b	5.2 b	7.1 a	7.8 a	
CV (%)	10.56					15.91				
	Fresh mass of floral stem (g)					Dry mass of floral stem (g)				
TEST	34.9 Bb *	27.5 Bc	38.4 Bb	47.5 Ba	37.1	7.2 ^{ns}	4.9	7.1	8.0	6.8 B
MHT	37.3 Ab	18.8 CDs	30.1 Cc	49.5 Aa	33.9	7.3	6.0	7.2	8.2	7.2 A
DHT	38.5 Ab	31.8 BC	40.2 Aa	48.0 Ba	39.6	8.0	3.7	6.8	8.1	6.7 B
MV	36.9	26.0	36.3	48.3		7.5 b	4.8 c	7.0 b	8.1 a	
CV (%)	24.66					22.68				
	Leaf area (cm2)					Central inflorescence diameter (mm)				
TEST	340.2 Ac *	339.6 Bc	499.3 Bb	574.2 Ba	438.3	19.4 ^{ns}	19.6	20.7	21.6	20.3 A
MHT	326.9 Bc	327.5 Cc	500.3 Bb	653.7 Aa	452.1	19.7	21.7	19.3	22	20.7 A
DHT	339.2 BC	385.4 BC	530.3 Ab	660.8 Aa	478.9	17.7	20.5	19.9	21.9	20.0 A
MV	335.5	350.8	510.0	629.6		18.9 c	20.6 b	20.0 b	21.9 a	
CV (%)	4.86					8.79				
	Primary inflorescence diameter (mm)					Secondary inflorescence diameter (mm)				
TEST	23.0 Aa *	18.2 Bc	19.7 Ab	20.5 Ab	20.3	20.5 Aa *	18.0 Bb	16.2 Ab	16.9 Ab	17.9
MHT	15.0 Bc	22.2 Aa	18.4 Bb	20.9 Ab	19.2	14.8 Bc	21.2 Aa	15.1 Bc	17.2 Ab	17.1
DHT	20.9 Aa	15.9 Bc	18.9 Ab	20.8 Aa	19.2	21.5 Aa	15.3 Cc	15.5 Bc	17.1 Ab	17.3
MV	20.0	18.8	19.0	20.8		18.9	18.2	15.6	17.0	
CV (%)	13.98					17.81				
	Central branch diameter (mm)					Primary branch diameter (mm)				
TEST	1.7 Ab *	1.3 Bc	1.7 Ab	1.9 Aa	1.7	1.3 Ab *	1.6 Aa	1.4 Ab	1.5 Ba	1.4
MHT	1.3 Bb	1.9 Aa	1.6 Ab	2.0 Ba	1.7	1.3 Ab	1.4 Bb	1.2 Bb	1.6 Ba	1.4
DHT	1.5 Bb	1.3 Bb	1.3 Bb	2.5 Aa	1.7	1.3 Ab	1.4 Bb	1.0 Bc	2.0 Aa	1.4
MV	1.5	1.6	1.6	1.9		1.3	1.5	1.2	1.7	
CV (%)	17.62					18.01				
	Secondary branch diameter (mm)					Central inflorescence length (mm)				
TEST	1.3 Aa *	1.3 Aa	1.1 Aa	1.2 Ba	1.3	17.1 ^{ns}	18.6	19.6	19.4	18.7
MHT	1.1 Bb	1.4 Aa	1.0 Ab	1.3 Ba	1.2	17.8	19.4	16.9	19	18.3
DHT	1.4 Aa	1.2 Ab	0.8 Bc	1.6 Aa	1.3	17.2	17.7	18.5	19.5	18.2 A
MV	1.3	1.3	1	1.4		17.3 c	18.5 b	18.3 b	19.3 a	
CV (%)	17.96					11.66				
	Primary inflorescence length (mm)					Secondary inflorescence length (mm)				
TEST	16.6 ^{ns}	18.1	14.7	14.5	15.9 A	17.1 ^{ns}	14.9	12.3	12.2	14.1 A
MHT	17	18.6	12.7	14.3	15.7 A	14.7	19.3	10.7	12	14.2 A
DHT	15.4	17.4	13.9	14.6	15.3 A	15.5	15.2	11.7	12.3	13.7 B
MV	16.3 a	18.0 a	13.8 c	14.5 b		15.8 a	16.5 a	11.6 b	12.2 b	
CV (%)	11.25					19.19				

* significant interaction and ^{ns} non-significant interaction of the factors. Test of means not followed by the same letter, uppercase in the column and lowercase in the row, differ by the Scott-Knott test (p <0.05). MV: mean value. CV: coefficient of variation. TREAT: seed treatments: control (TEST), moist heat thermotherapy (MHT) and dry heat thermotherapy (DHT).

There was an average value of 0.646 days inflorescence^{-1} (Table 2), for floral opening in safflower flowering stages (Figure 2Ba to 2Bd). In visual observation, it was found that the increase in air temperature accelerates the opening of safflower flowers, and consequently the chapter, confirming the anthochron values for the seasons spring (0.563 days inflorescence^{-1}) and summer (0.510 days inflorescence^{-1}), in relation to the cultivations in autumn and winter. Schwab et al. (2014) point the anthochron as a parameter that represents the time interval for the opening of the inflorescences, ideal for scaling the post-harvest period.

The biometric parameters of the floral stem and inflorescences for the different sowing dates and seed treatments by thermotherapy (Table 3). It was observed that the average length of flower stems was of 79.3; 79.5; 128.4 and 150.1 cm for sowing dates in spring, summer, autumn and winter, respectively. This difference in the length of the stems may be attributed to the prolongation of the cultivation cycle (Table 2), thus favoring the development of flower stems in terms of length, mass and leaf area.

It was verified that, at all sowing dates, the lengths of the stems were consistent with the marketing standards and classification criteria for safflower cut flowers determined by the Cooperativa Veiling Holambra (2016). Shahbazi et al. (2011), studying the characteristics of safflower stems in Iran, observed length averages ranging from 60 to 120 cm, depending on the cultivar and sowing date, which is a genetic characteristic of the plant. Bellé et al. (2012) found an average length of 96 cm of safflower flower stems grown in a protected environment for the sowing dates in spring/summer and 130 cm in autumn/winter, respectively. Sampaio et al. (2017) found an average length of 79 and 122 cm of safflower stems sown in the field in the winter and autumn seasons, in the municipality of Cascavel, PR.

The average root length of safflower plants was 20.1; 19.4; 21.5 and 24.8 cm for sowing dates in spring, summer, autumn and winter, respectively. Rivas & Matarazzo (2009) report that the development of the root system of safflower plants varies according to the water availability of the soil, as this crop is resistant to water stress. Beyyavas et al. (2011) concluded that both the length of stems and roots of safflower are highly dependent on the climatic conditions of the growing region, especially on the temperature and humidity of the soils.

The branching of safflower flower stems is an unwanted characteristic for cut flower due to its irregular opening and floral senescence, requiring the standardization of three branches/inflorescences per stem (Figure 2A). However, when safflower cultivation is intended for the production of seeds/grains, the greater the number of branches, the greater the productivity per area, since each branch produces an inflorescence with an average of 15-30 seeds/grains (Beyyavas et al., 2011; Golzarfar et al., 2012).

It was found that the average length of the stem branch was 16.1; 13.5; 22.6 and 25.4 cm, and an average leaf number of 5.6; 5.2; 7.1 and 7.8 per branch, for sowing dates in spring, summer, autumn and winter, respectively (Table 3). The length of the stem branches, as well as the diameter, the number of leaves and branches are important characteristics for the aesthetics of safflower floral stems, forming a homogeneous and uniform bundle/bouquet (Figure 2A), several authors attribute these characteristics of the stems to cultivation conditions, such as sowing date, plant density, soil type, nutrient and water availability, among others (Rivas & Matarazzo, 2009; Beyyavas et al., 2011; Shahbazi et al., 2011; Golzarfar et al., 2012; Omidi et al., 2012; Moghaddas & Omidi, 2015; Sampaio et al., 2017).

In this study (Table 3) it was found that the average diameters of the stems were 4.3; 4.0; 3.5 and 4.1 mm and, the average number of leaves was 25.0; 21.3; 39.7 and 58.1 per stem, for sowing dates in spring, summer, autumn and winter, respectively. According to Menegaes et al. (2017), the stem diameter is directly related to the architecture of the plant, obtaining the necessary rigidity to support the inflorescence mass. Streck et al. (2005) attributed the emission of the number of safflower leaves as a variable dependent on the thermal sum and the interception of solar radiation by the plant, corroborating the results of this study.

The fresh mass of the average stem was 36.9; 26.0; 36.3 and 48.3 g stem^{-1}, with humidity of 79.6; 79.4; 80.7 and 83.2% for sowing dates in spring, summer, autumn and winter, respectively (Table 3). The Cooperativa Veiling Holambra (2016) classifies the amount of safflower flower stems by bundle and per season, in which the stems grown in summer are thin forming bundles with 9 to 10 stems and those grown in winter are thick forming bundles with 5 to 8 stems. However, the Cooperativa does not establish a specific mass value per floral bundle of safflower stems, as it is the case for chrysanthemum (*Dendranthema grandiflora* Tzevelev.), with 1.4 kg. Menegaes et al. (2017), studying the quality of different cultivars of cut chrysanthemums, found that floral stems that are too heavy generate bundles with few floral units, which is not feasible for commerce.

It was observed that there was an increase in the average leaf area of the safflower flower stems according to the performed sowing dates, with values of 335.5; 350.8; 510.0 and 629.6 cm^2 in spring, summer, autumn and winter, respectively. This increase in leaf area was also verified by Lucas et al. (2015), when studying the relationship between thermal sum and sowing dates for sunflower cultivation. Menegaes et al. (2016) attributed the leaf area of chrysanthemum cv. Snowdon to the period of exposure to long days (in weeks) favoring the emission of leaves and, consequently, the number of leaves.

The floral opening of safflower inflorescences starts in the central bud and then the buds according to the arrangement of the branches (Figure 2A). Regarding the biometry of its flower stems, it was observed that the central inflorescences develop more than the others in the first and second branches, sequentially, due to the accumulation of photoassimilates.

The diameter of the safflower central inflorescence and the lengths of the inflorescences (central, primary and secondary) showed no significant difference between the sowing dates and seed treatments by thermotherapy, indicating that the development of the plant in relation to the ornamental characteristics is maintained throughout the year, guaranteeing aesthetic quality, a key item for the flower trade. However, the diameters of the primary and secondary inflorescences and the diameters of the branches (central, primary and secondary) showed significance between the sowing dates and seed treatments, but the aesthetic variation was minimal, not negatively affecting the ornamental quality of the stems in general aspects.

Conclusions

The treatment of safflower seeds (*Carthamus tinctorius* L.) by thermotherapy, either via moist or dry heat, is efficient for the initial establishment of seedlings in the field, regardless of the sowing date. It was obtained an average seedling emergence time of five and nine days for sowings performed in the spring/summer and autumn/winter seasons, respectively.

The development and the cultivation cycle of safflower flower stems from different sowing dates respond to the accumulation of thermal sum, with an average cycle of 68; 57; 106 and 92 days after sowing, for spring, summer, autumn and winter, respectively, and can be grown throughout the year. The ornamental characteristics and the quality of the safflower flower stems were maintained at all dates of sowing.

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