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Thermotherapy via dry heat for the treatment of safflower seeds

Termoterapia via calor seco para o tratamento de sementes de cártamo

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ABSTRACT

The objectives of this work were to evaluate the method of thermotherapy via dry heat for the treatment of safflower (Carthamus tinctorius L.) seeds and, to verify its effect on the physiological and sanitary quality of seeds. The experiment was conducted in entirely randomized design, arranged in 5x6+1 factorial scheme, with six levels of temperature: 35, 45, 55, 65, 75 and 85 ºC and with five time periods: 24, 48, 72, 96 and 120 h, plus the additional treatment (control), with eight repetitions. The seeds were packaged in Kraft paper bags and submitted to the forced circulation greenhouse according to the factorial mentioned above. We evaluated the physiological and sanitary qualities by the standard tests of germination, length and mass of seedlings, emergence at field and sanity. We observed that the thermotherapy can be used as treatment of safflower seeds, and it is efficient in the control of phytopathogens, without damage to the physiological quality up to 45 ºC, and the combination of 45 ºC 24 h-1 provided better phytosanitary quality for these seeds, increasing their germinative potential and emergence at field.

Keywords: Carthamus tinctorius L.; Germination; Heat treatment; Phytosanitary quality

RESUMO

Os objetivos deste trabalho foram avaliar o método de termoterapia via calor seco para o tratamento de sementes de cártamo (Carthamus tinctorius L.) e verificar seu efeito na qualidade fisiológica e sanitária das sementes. O experimento foi conduzido em delineamento inteiramente casualizado, arranjado em esquema fatorial 5x6+1, com seis níveis de temperatura: 35, 45, 55, 65, 75 e 85 ºC e com cinco períodos: 24, 48, 72, 96 e 120 h, mais o tratamento adicional (controle), com oito repetições. As sementes foram acondicionadas em sacos de papel Kraft e submetidas à estufa de circulação forçada, conforme o fatorial mencionado acima. Avaliamos as qualidades fisiológicas e sanitárias pelos testes padrão de germinação, comprimento e massa de plântulas, emergência em campo e sanidade. Observamos que a termoterapia pode ser utilizada como tratamento de sementes de cártamo e é eficiente no controle de fitopatógenos, sem prejuízo da qualidade fisiológica até 45 ºC, e a combinação de 45 ºC 24 h-1 proporcionou melhor qualidade fitossanitária para sementes, aumentando seu potencial germinativo e emergência no campo.

Palavras-chave: Carthamus tinctorius L.; Germinação; Tratamento térmico; Qualidade fitossanitária

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1 INTRODUCTION

The seed is one of the agricultural inputs of high cost, whose production is subject to a series of biotic and abiotic adversities, in which according to the severity of them, compromises, directly, its physiological and sanitary qualities. In this sense, the sanity of seed is extremely important, because the same constitutes itself as a vehicle of dissemination of inoculum in the beginning of the natural cycle, and its necessary its treatment (MARCOS-FILHO, 2015; MEDEIROS et al., 2015).

Among the methods of seed treatment described in literature, the thermotherapy uses the binomial temperature-time for the control of phytopathogens associated to seeds, by two sources of heat, humid or dry. The thermotherapic treatment via dry heat requires a greater period of seed exposure to the heat source, due to its low thermal capacity, when compared to the treatment via humid heat. However, the levels of temperature and the periods of exposure to dry heat, in which the seeds are submitted, vary according to the phytopathogens incident to the same, as well as their sensitivity to heat (GAMA et al., 2014; PEREIRA et al., 2015).

The thermotherapy via dry heat for the control of phytopathogens has showed efficient for several species, such as carrot (Daucus carota L.) (TRIGO et al., 1998), tomato (Solanum lycopersicum L.) (LOPES; ROSSETTO, 2004), castor bean (Ricinus communis L.) (MARRONI et al., 2009), rice (Oryza sativa L.) (MARINI et al., 2012), fennel (Foeniculum vulgare Mill.) (GAMA et al., 2014), soybean (Glycine max L.) (SANTOS et al., 2016), among others, without damage to its physiological quality, offering an alternative to the use of chemical products, commonly, used in the seed treatment. However, for the success of this method, it is necessary to know the adequate combination between the levels of temperature and the periods of heat exposure to which the seeds are submitted, which is variable according to species, batch, initial vigor, among other factors (BRAGA et al., 2010; PEREIRA et al., 2015).

Among the species of economic interest, the safflower (Carthamus tinctorius L.) presents a wide aptitude of use, feed, oil and ornamental (Figure 1). Introduced in the south of the country in the 1990s, as an ornamental plant, the production of safflower

flower stems has been gradually reduced, due to the high incidence of phytopathogens throughout the productive cycle (SANTOS; SILVA, 2015; SAMPAIO et al., 2017). With this, economic-scientific investments are necessary to obtain seeds with phytosanitary quality.

In this context, the objectives of this work were to evaluate the method of thermotherapy via dry heat for the treatment of seeds of safflower and, verify its effect on the physiological and sanitary quality of seeds.

Figure 1 – *Carthamus tinctorius* L. bouquet of inflorescences (a), floral stem (b), detail of the inflorescence (c), number of inflorescences per stem (d) and seeds (e)

Source: authors (2016)

2 MATERIAL AND METHODS

The experiment was conducted in the period from September to November, 2016 and from May to July, 2017, in the Didactic and Seed Research Laboratory, Department of Plant Science, Federal University of Santa Maria (29º43' S; 53º43' W and altitude of 95 m). The safflower seeds used were from Yellow Saffron cultivar, harvested in the crop 2015/2016, and stored in cold chamber (15ºC and 40% UR) in Kraft paper bags (brown type of 1.0 kg), with degree of average humidity of 9.0% until the execution of this experiment.

The design used was completely randomized, in 6x5+1 factorial scheme, with six levels of temperatures: 35, 45, 55, 65, 75 and 85 ºC and, with five periods of time: 24, 48, 72, 96 and 120 h, plus the additional treatment (control: without treatment), with eight repetitions. The seeds were packaged in Kraft paper bags (brown type of 1.0 kg) and submitted to the temperatures and time according the factorial above mentioned, in forced circulation greenhouse.

In the sequence, we evaluated the qualities by the following tests:

Degree of humidity of seeds after thermotherapy: determined by the method of greenhouse 105±3 ºC for 24 h, using four repetitions of 5 g (BRASIL, 2009a).

Germination Standard Test (GST) and germination speed index (GSI): the seeds, with eight repetitions of 50 units, were distributed in paper roll of germination, moistened with distilled water in the proportion of 2.5 times the mass of dry paper. The rolls were maintained in germinator BOD (Box Organism Development) type, with photoperiod of 24 h and temperature of 25±2 ºC (BRASIL, 2009a). The evaluations of germination were at the four and 14 DAS (days after sowing), and the results expressed in percentage of normal seedlings. The SGI was carried out with daily evaluations according to the methodology by Maguire (1962), using as criteria the elongation of the primary root and emergence of cotyledons (ABUD et al., 2010).

Length and dry mass of seedling: the seeds, with eight repetitions of 20 units, were maintained in the same condition of GST, at four DAS, it was measured the length of aerial part and root part of ten normal seedlings of each repetition. In the sequence, we determined the total dry mass by drying of the material in forced ventilation greenhouse at 65±5 ºC for 48 h (NAKAGAWA, 1999).

Emergence at field and emergence speed index (ESI): the seeds, with eight repetitions of 50 units, were distributed in lines of 1 m, spaced at 0.2 m and with deepness of 0.03 m, final evaluation at 14 DAS, with results expressed in percentage of emergence of seedlings. The ESI was carried out with daily evaluations according to the methodology by Maguire (1962), we used as criteria the complete development of cotyledons and epycotil (ABUD et al., 2010).

For the variables of germination and emergence of seedlings at field, we used as reference the Normative Instruction n.45/2013 from MAPA (Ministry of Agriculture, Livestock and Supply) for cultivation of sunflower (*Helianthus annuus* L.), because it belongs to the same botanical family of safflower (Asteraceae), and it is demanded values 65-70% (BRASIL, 2013).

Sanity test: the seeds, with eight repetitions of 25 units, were distributed in transparent plastic boxes for germination in paper substrate (Blotter Test) moistened in distilled water corresponding to 2.5 times the mass of dry paper. We inhibited the germination of seeds by freezing of 24 h at temperature of 06±1 ºC, in the sequence the boxes were maintained in BOD, for five days with photoperiod of 12 h of light at temperature of 20±2 ºC (BRASIL, 2009b). They were evaluated on magnifying glass (stereoscopic microscope) with the identification of phytopathogens in level of genus, and the results expressed in percentage of infested seeds.

The expressed data in percentage were transformed in arcsine $\sqrt{x/100}$. The analysis of variance of data were carried out with the help of SISVAR program ($p<0.05$) (FERREIRA, 2014). We used the contrast test of additional treatment (control) versus factorial (levels of temperature and period of time) and, also the comparison of averages of the deployment of factorial by Scott-Knott test ($p<0.05$). Pearson correlation was carried out among the total infested seeds and germination (four and 14 DAS), emergence of seedlings and dead seeds in germination test.

3 RESULTS AND DISCUSSION

The comparison of quality of safflower seeds by contrast of additional treatment (control) with the thermotherapic factorial (levels of temperature and periods of time) were significant ($p<0.05$), as well as the interaction of the tested factors. In general, the control presented superior average to the combinations of temperature and time, except for the variable of humidity degree (Table 1). We observed that for the most stringent levels of temperature and periods of time, they

end promoting acceleration of seed deterioration, thus, collaborating for the positive result of the estimate of control treatment in relation to the physiological quality of these seeds.

Braga et al. (2010) and Pereira et al. (2015) point out that the ideal adjustment of temperature-time binomial provides the efficiency of thermotherapy as treatment of seeds, being necessary the knowledge of lethal points of seed and of pathogens. Initially, the batch of safflower seeds presented 8.9% of humidity degree (without thermotherapy). We observed a gradual reduction according to the increase of the levels of temperature and the exposure period interfering negatively in the physiological quality of these seeds. This interference is confirmed by the contrast that presented negative estimate for the control treatment with the thermotherapic factorial (Table 1). Gama et al. (2014) observed gradual reduction of the percentage in the humidity degree of fennel seeds according to the increase of the exposure period, until 15 days, to the dry heat at 70 ºC.

For the germination at four DAS (days after sowing), we observed that the temperature of 45 ºC promoted improvement in the expression of germinative potential until the period of 96 h. Silva et al. (2002) verified that the thermotherapy (70 ºC 96 h^{-1}) reduced the initial germination potential of tomato seeds, however, this reduction was compensated in the seedling development due to the absence of phytopathogens eradicated through this treatment.

The initial physiological quality of the batch of safflower seeds used in this work presented 66% of germination at 14 DAS and in conditions of field presented 73% of emergence, characterizing itself as a commercial batch according to the standard of MAPA (Brasil, 2013). In the evaluation of germination (14 DAS), we verified that the seeds of this batch maintain themselves commercial in the temperatures of 35 and 45ºC until 48 h, obtaining the same performance in the emergence test at field (Table 1). Lopes and Rossetto (2004) observed that the tomato seeds submitted to thermotherapy via dry heat maintain the germination above 75% in the treatments of 70; 72.5 and 75 ºC for 48 h, with efficiency in the control of phytopathogens associated to the seeds.

Among the thermotherapic treatments, we verified that the safflower seeds submitted to the treatment of 45 ºC 24 h^{-1} obtained better performance than the others, with 71% of germination (14 DAS) and 75% of emergence at field. Gama et al. (2014) observed improvement in the germinative percentage of fennel seeds that were treated by thermotherapy at 70 ºC for 72 and 144 h. Nevertheless, Trigo et al. (1998) concluded that the reduction of the humidity degree of different batch of carrot seeds after treatment by thermotherapy at 70 ºC 72 h^{-1}, affected negatively the germination of the same.

Table 1 – Estimate of contrast between the control and the combination of temperature and time, and comparison of averages of the combinations for the physical and physiological quality of seeds and seedlings of *Carthamus tinctorius* L. submitted to thermotherapy via dry heat

Additional Treatment		**Factorial (levels of temperature x periods of time) [B]**					
		Temperature (ºC)	**Periods of time (h)**				
			24	**48**	**72**	**96**	**120**
Degree of humidity of seeds (%)							
Control	8.9	35	8.5 Aa**	7.3 Ab	5.6 Bb	5.6 Ac	5.1 Ac
Estimate [A]	-95.4 *	45	7.7 Bb	5.9 Cc	5.8 Ac	5.3 Ac	5.1 Ac
		55	6.9 Cb	5.3 Cc	5.3 Bc	4.8 Bc	4.8 Bc
		65	8.2 Ab	5.2 Ac	5.2 Bc	4.8 Bc	4.8 Bc
		75	6.2 Cb	5.1 Cb	5.1 Bb	4.8 Bb	4.8 Bb
CV (%)	2.43	85	6.5 Cb	6.2 Bb	6.1 Ab	4.8 Bb	4.8 Bb
Germination at four DAS (%)							

Control	38	35	40 Ba **	38 Ab	38 Bb	37 Ab	32 Ac
Estimate	284 *	45	42 Aa	40 Aa	40 Aa	39 Aa	34 Ac
		55	37 Ca	31 Bb	30 Cb	30 Cb	27 Bb
		65	39 Ba	38 Aa	36 Bb	35 Bb	34 Ab
		75	27 Db	26 Cb	25 Dc	24 Dc	24 Cc
CV (%)	4.93	85	00 Eb	00 Db	00 Eb	00 Eb	00 Db
Germination at 14 DAS (%)							
Control	66	35	67 Ba **	66 Aa	51 Ab	50 Ab	49 Bb
Estimate	616 *	45	71 Aa	67 Ab	54 Ac	53 Ac	52 Ac
		55	56 Cb	53 Bc	51 Ad	51 Ad	51 Cd
		65	58 Cb	57 Bb	44 Bc	43 Bc	41 Ac
		75	41 Db	40 Cb	37 Cc	37 Dc	37 Dc
CV (%)	4.21	85	32 Eb	20 Dc	13 Dd	12 Ed	6 Ee
Emergence at field (%)							
Control	73	35	66 Bb **	68 Aa	61 Bb	63 Aa	52 Ac
Estimate	781 *	45	75 Aa	68 Aa	64 Aa	58 Ab	57 Ab
		55	60 Cb	54 Bc	46 Bb	46 Bc	45 Bc
		65	64 Bb	62 Ab	58 Bb	48 Bc	46 Bc
		75	45 Db	43 Db	40 Cb	33 Cc	32 Cc
CV (%)	9.86	85	15 Eb	4 Ec	4 Dc	4	3 Dc

						Dc	
Germination Speed Index at four DAS (GSI)							
Control	47.3	35	59.9 Ba **	49.8 Ab	46.0 Bc	45.8 Bc	43.1 Bc
Estimate	214 *	45	66.5 Aa	55.4 Ab	51.1 Ab	50.9 Ab	47.9 Ac
		55	57.9 Bd	53.2 Aa	40.9 Bd	40.9 Dc	40.7 Bd
		65	44.4 Ca	43.6 Ba	44.0 Ba	45.2 Ba	44.8 Aa
		75	38.1 Db	37.5 Cb	37.8 Cb	38.6 Db	38.4 Cb
CV (%)	8.53	85	5.2 Eb	2.0 Dc	0.6 Dc	2.9 Db	0.0 Dc
Emergence speed index at 14 DAS (ESI)							
Control	26.4	35	23.5 Bc **	29.4 Aa	25.5 Bb	26.8 Ab	21.7 Ac
Estimate	218 *	45	32.8 Aa	28.3 Ab	29.7 Ab	24.2 Bd	23.4 Ad
		55	26.1 Ba	22.6 Bb	19.3 Bc	19.3 Cc	18.6 Bc
		65	25.0 Ba	21.9 Bb	24.0 Ba	19.6 Cb	21.6Ab
		75	17.5 Cb	15.3 Cc	16.8 Cb	13.7 Dc	15.1 Cc
CV (%)	11.54	85	3.8 Db	0.8 Dc	1.0 Dc	0.8 Ec	0.5 Dc

[A] Estimate of contrast by the coefficients (+30, -1,-1,-1,-1,-1,-1,-1,-1,-1,-1,-1,-1,-1,-1,-1,-1,-1,-1,-1,-1,-1,-1,-1,-1,-1,-1,-1,-1,-1 e -1), and values of the positive and negative coefficients divided by 30 (Ferreira, 2014). *significant effect by the contrast test ($p<0.05$) of additional treatment (control) versus the factorial (levels of temperature x periods of time). CV (%): coefficient of variation.

[B] Deployment of factorial with ** significant interaction. Tests of averages, not followed by the same letter, upper case in the column and lower case in the line, differ Scott-Knott test ($p<0.05$). DAS: days after the sowing.
Source: authors

In the emergence test at field, the safflower seeds demonstrated sensitivity to this way of heat, in all the tested temperatures, except for the treatment of 45 ºC 24 h^{-1}. We observed that the seeds treated by thermotherapy presented similar performance in the germination standard tests (14 DAS) and in the emergence at field, except for the temperature of 85 ºC for the last test.

Taiz and Zeiger (2009) and Marcos-Filho (2015) pointed that the submission of seeds to any form of stress, mainly, in the form of heat accelerates their deterioration. Once that the physiological alterations resulting of this stress are directly related to hydrolysis of their reservations, such as the degradation of starch and synthesis of sugars in the endosperm or to biosynthesis of new tissues, essential processes for the germination and emergence under favorable environmental conditions.

The GSI and ESI (germination and emergence speed index), confirmed the physiological quality (germination and emergence) of safflower seeds submitted to thermotherapy, with values that were greater than the control treatment, since that in the temperatures above 45 ºC, there was a greater deterioration of the same (Table 1). Results similar to the ones obtained in the present study were verified by Marini et al. (2012), who observed low indexes of SGI for rice seeds exposed to 30 and 35 ºC for 24 h in comparison to the control treatment.

In Table 2, the development of safflower seedlings verified by the length and dry mass of seedlings test was negatively affected according to the levels of temperature and period of exposure to dry heat. The seeds submitted to thermotherapy at 85 ºC accelerated their deterioration by thermal stress, in a way that prevented their plant development.

We verified that the reservations of the seeds germinated were mobilized for the length of seedlings in 81.5 and 18.5% for the root and aerial parts, respectively. We observed that the safflower seedlings, which developed themselves, presented greater

root expansion, corroborating with the observed by Abud et al. (2010), when they studied the development of safflower seedlings. Marcos-Filho (2015) reports that the root expansion facilitates the performance and establishment of the stand of plants at field.

Yet, the partition of dry mass of seedlings, in general, was of 15 and 85% for the root and aerial parts, respectively. Taiz and Zeiger (2009) mention that the growth and development of seedlings are compromised by the decrease in the enzymatic activities caused when the seed is submitted to stress conditions, like thermal.

Table 2 – Estimate of contrast between the control and the combination of temperature and time, and comparison of averages of the combinations for the physiological quality of seedlings of *Carthamus tinctorius* L. submitted to thermotherapy via dry heat

Additional Treatment		**Factorial (levels of temperature x periods of time) [B]**					
		Temperature	**Periods of time (h)**				
		(ºC)	**24**	**48**	**72**	**96**	**120**
Root length of seedling (cm)							
Control	6	35	6.8Aa **	6.8 Aa	6.8 Aa	6.6 Aa	5.5 Ab
Estimate [A]	53 *	45	6.2 Aa	6.2 Aa	6.0 Aa	5.0 Ab	5.0 Ab
		55	5.0 Aa	4.9 Aa	4.8 Ba	4.0 Bb	4.0 Ab
		65	4.6 Aa	3.7 Bb	4.2 Ba	5.8 Aa	5.3 Aa
		75	4.2 Aa	3.4 Bb	3.8 Bb	5.2 Aa	4.8 Aa
CV (%)	11.95	85	0.0 B	0.0 C	0.0 C	0.0 C	0.0 B
Length of aerial part of seedling (cm)							
Control	1.4	35	1.8 Aa **	1.9 Aa	1.9 Aa	1.8 Aa	1.7 Aa
Estimate	13 *	45	1.7	1.6	1.6	1.4	1.4

			Aa	Aa	Aa	Aa	Aa
		55	1.1 Aa	1.1 Aa	1.0 Aa	0.9 Aa	0.9 Aa
		65	1.0 Aa	0.8 Ba	0.7 Ba	0.9 Aa	1.0 Aa
		75	0.8 Aa	0.6 Ba	0.6 Ba	0.7 Ba	0.8 Aa
CV (%)	15.55	85	0.0 Ba	0.0 Ca	0.0 Ca	0.0 Ca	0.0 Ba
Dry mass of root part (mg pl^{-1})							
Control	2.4	35	2.3 Aa **	2.3 Aa	2.4 Aa	2.4 Aa	1.5 Ab
Estimate	31 *	45	2.5 Aa	2.5 Aa	2.5 Aa	2.4 Aa	1.8 Ab
		55	2.0 Aa	2.0 Aa	1.4 Ba	1.3 Bb	1.2 Ab
		65	1.2 Ba	1.2 Ba	1.4 Ba	1.3 Ba	1.2 Aa
		75	1.3 Ba	1.1 Ba	0.8 Ba	0.8 Ba	0.5 Bb
CV (%)	14.77	85	0.0 Ca	0.0 Ca	0.0 Ca	0.0 Ca	0.0 Ba
Dry mass of aerial part (mg pl^{-1})							
Control	13.6	35	13.0 Aa **	13.2 Aa	13.7 Aa	13.4 Aa	8.8 Ab
Estimate	176 *	45	13.9 Aa	14.4 Aa	14.1 Aa	13.6 Aa	10.1 Aa
		55	11.1 Aa	11.5 Aa	8.0 Bb	7.2 Bb	6.6 Bb
		65	7.0 B	6.9 Ba	7.9 Ba	7.2 Ba	6.7 Ba
		75	7.2 Ba	6.2 Ba	4.5 Ba	4.3 Ba	2.7 Cb
CV (%)	14.81	85	0.0 Ca	0.0 Ca	0.0 Ca	0.0 Ca	0.0 Ca

[A] Estimate of contrast by the coefficients (+30, -1,-1,-1,-1,-1,-1,-1,-1,-1,-1,-1,-1,-1,-1,-1,-1,-1,-1,-1,-1,-1,-1,-1,-1,-1,-1,-1,-1,-1 e -1), and values of the positive and negative coefficients divided by 30 (Ferreira, 2014).

*significant effect by the contrast test (p<0.05) of additional treatment (control) versus the factorial (levels of temperature x periods of time). CV (%): coefficient of variation.
[B] Deployment of factorial with ** significant interaction. Tests of averages, not followed by the same letter, upper case in the column and lower case in the line, differ Scott-Knott test (p<0.05). DAS: days after the sowing.
Source: authors

In the sanity test, we verified elevated incidence of phytopathogens with 40% of seeds infested in the control treatment (Table 3). We observed that the thermotherapic treatments tested were efficient in the control of phytopathogens with reduction of incidence of the same under the treated seeds, except for 35 ºC 24 h^{-1}. We highlight the treatments of 45 and 55 ºC 120 h^{-1} and 65 ºC 96 h^{-1}, with only 9; 8 and 8% of infestation percentage, in relation to the control treatment. Pereira et al. (2015) highlight that this method of seed treatment is efficient, safe and of low cost in the control of pathogens associated to seeds.

Table 3 – Estimate of contrast between the control and the combinations of temperature and time, and comparison of averages of combinations for sanity test of seeds of *Carthamus tinctorius* L. submitted to thermotherapy via dry heat

Additional Treatment		**Factorial (levels of temperature x periods of time) [B]**					
		Temperature (ºC)	**Periods of time (h)**				
			24	**48**	**72**	**96**	**120**
		Total infested seed (%)					
Control	40	35	48 Aa **	28 Ab	23 Ab	18 Ac	13 Bc
Estimate [A]	174 *	45	23 Bb	19 Ab	15 Ac	11 Bc	9 Bc
		55	21 Bb	17 Ab	10 Ac	10 Bc	8 Bc
		65	17 Bb	18 Ab	19 Ab	8 Bc	16 Bb
		75	17 Bb	18 Ab	19 Ab	10 Bb	16 Bb
CV (%)	26.02	85	13 Bb	14 Ab	16 Ab	19 Ab	21 Ab
		Aspergillius spp. (%)					
Control	18	35	18 Ab **	13 Ab	11 Ab	7 Bc	27 Aa
Estimate	42 *	45	13 Ab	11 Ab	7 Bb	27 Aa	0 Cc

		55	13 Ab	11 Ab	27 Aa	27 Aa	0 Cb
		65	0 Bb	6 Aa	0 Cb	0 Cb	0 Cb
		75	0 Bb	6 Aa	0 Cb	0 Cb	0 Cb
CV (%)	17.67	85	8 Aa	0 Bb	6 Ba	5 Ba	5 Ba
			Botrytis spp. (%)				
Control	17	35	18 Bb **	9 Bb	32 Ba	33 Aa	27 Ba
Estimate	17 *	45	9 Bc	32 Ab	33 Bb	27 Ab	56 Aa
		55	9 Bc	32 Ab	27 Bb	27 Ab	56 Aa
		65	41 Aa	44 Aa	32 Ba	13 Bb	31 Ba
		75	41 Aa	44 Aa	32 Ba	10 Bb	31 Ba
CV (%)	75.00	85	38 Aa	29 Ab	50 Aa	42 Aa	24 Bb
			Fusarium spp. (%)				
Control	28	35	28 Ab **	39 Ab	37 Ab	40 Aa	18 Ba
Estimate	45 *	45	39 Aa	37 Aa	40 Aa	18 Bb	11 Bb
		55	39 Aa	37 Aa	18 Bb	18 Bb	11 Bb
		65	24 Ab	39 Aa	21 Ab	50 Aa	19 Bb
		75	24 Ab	39 Ab	21 Ab	40 Aa	19 Bb
CV (%)	58.58	85	31 Ab	43 Aa	6 Bc	16 Bc	33 Ab
			Penicillium spp. (%)				
Control	22	35	23 Aa **	35 Aa	11 Bb	7 Bb	27 Aa
Estimate [A]	35 *	45	35 Aa	11 Aa	7 Bb	27 Aa	33 Aa
		55	35 Aa	11 Bb	27 Aa	27 Aa	33 Aa
		65	35 Aa	6 Bb	37 Aa	38 Aa	31 Aa
		75	35 Aa	6 Bb	37 Aa	50 Aa	31 Aa
CV (%)	62.45	85	8 Bb	29 Aa	38 Aa	37 Aa	33 Aa
			Sclerotinia spp. (%)				
Control	15	35	15 Aa **	4 Bb	11 Aa	13 Aa	0 Bb
Estimate [A]	35 *	45	4 Aa	11 Aa	13 Aa	0 Bb	0 Bb
		55	4 Aa	11 Aa	0 Bb	0 Bb	0 Bb
		65	0 Bb	6 Aa	11 Aa	0 Bb	19 Aa
		75	0 Bb	6 Aa	11 Aa	0 Bb	19 Aa
CV (%)	155.7	85	15 Aa	0 Bb	0 Bb	0 Bb	5 Aa

[A] Estimate of contrast by the coefficients (+30, -1,-1,-1,-1,-1,-1,-1,-1,-1,-1,-1,-1,-1,-1,-1,-1,-1,-1,-1,-1,-1,-1,-1,-1,-1,-1,-1,-1,-1 e -1), and values of positive and negative coefficients divided by 30 (Ferreira, 2014). *significant effect and [ns] non-significant effect by contrast test ($p<0.05$) of the additional treatment (control) versus the factorial (levels of temperature x periods of time). CV (%): coefficient of variation.
[B] Deployment of factorial having ** significant interaction. Tests of averages not followed by the same letter, upper case in the column and lower case in the line, differ Scott-Knott test ($p<0.05$).
Source: authors

The identification of the pathogens on the safflower seeds occurred in genus level (Aspergillius spp., Botrytis spp., Fusarium spp., Penicillium spp. and Sclerotinia spp.), and the incidence of them in the control treatment was of 18; 17; 28; 22 and 15%, respectively (Table 3). Girardi et al. (2013) verified high incidence of Aspergillus spp., Fusarium spp. and Penicillium spp. in the percentages of 62; 42 and 56%, respectively, in safflower seeds harvested in different periods of maturation.

We observed a great variation in the control of all the pathogens identified on the safflower seeds. Nevertheless, we verified a total eradication (0%) of the pathogen Aspergillius spp. in the treatments of 85 ºC for 48 h, 65 and 75 ºC for 24; 72 and 96 h and 35 to 75 ºC for 120 h and, of pathogen Sclerotinia spp. in the treatments of 65 and 75 ºC for 24h, 85 ºC for 48 h, 55 and 85 ºC for 72 h, 45 to 85 ºC for 96 h and 35 to 55 ºC for 120 h.

Lopes and Rossetto (2004) verified reduction in the incidence of phytopathogens on the tomato seeds treated with dry heat, and the most significant reduction was on the genus Aspergillus sp.. Besides that, Marroni et al. (2009) concluded that the thermotherapy by dry heat was not enough in the control of pathogens Fusarium spp. and Penicillium spp., incident on the castor bean seeds.

Garcia (1999) reports that the main creators of harm to the safflower culture are the pathogens of the genus Botrytis spp., because the presence of these pathogens in the safflower flowering stage attack the ligules and host themselves inside the buds (inflorescences), impair the seed germination, by emptying the locule. And, the pathogens of the genus Fusarium spp. are responsible for substantial losses,

more than 40% of the safflower productivity, and the seeds can provoke stains, rotting and moulds, anticipating their deterioration.

We observed that the thermotherapy was beneficial for the sanitary quality of safflower seeds submitted to this treatment in relation to the control treatment, verified by the index of control of infested seeds. However, the more increased the phytopathogenic control, the lower the expression of the potential of germinability of the seeds. Result of this work are opposed to the ones pointed out by Medeiros et al. (2015), who verified efficiency of fungi control on the seeds enhanced the expression of physiological quality of the same, especially, germination.

In Table 4, the coefficient of linear correlation between the total infested seeds in the sanity test and germination at four and 14 DAS, emergence at field and dead seeds in germination test were presented. We observed that there was significant positive correlation between the total infested diaspores and the germination at four DAS, highlighting the thermotherapic treatments at 45 and 55º C for 48 h.

The positive correlation of greater highlight for germination at 14 DAS was in the thermotherapic treatment of 65º C 96 h-1, in this treatment there are 8% of infested seeds. Yet, the positive correlations for the emergence at field were in the treatments of 65 and 75º C 96 h-1, in Table 1, these treatments presented total infested seeds of 8 and 10% respectively.

The positive correlations of dead seeds were different in virtue of the high variation of infested seeds, and the positive correlation was more significant (0.98) in the control treatment in greenhouse of air circulation in all the tested temperatures, in these treatments, there are 40% of infested seeds. This indicates that the sanity of infested seeds is indispensable for maintaining their physiological quality, reducing the future damages.

Table 4 – Coefficients of Pearson linear correlation between the total infested seeds in sanity test and germination at four and 14 DAS (days after sowing), emergence at field and dead seeds in the germination test of Carthamus tinctorius L. submitted to thermotherapy via dry heat

Additional Treatment		**Factorial (levels of temperature x periods of time)**					
		Temperature (º C)	**Periods of time (h)**				
			24	**48**	**72**	**96**	**120**
Germination at four DAS							
Control	0,55**	35	-0,42	0,71**	-0,97	-0,13	0,25**
		45	-0,87	0,89**	0,10*	-0,64	-0,94
		55	-0,69	0,89**	0,10*	-0,64	-0,94
		65	0,24**	0,41**	0,65**	0,47**	0,50**
		75	0,24**	0,41**	0,74**	0,58**	0,50**
		85	0	0	0	0	0
Germination at 14 DAS							
Control	-0,82	35	-0,1	-0,8	-0,51	0,0	0,45**

			3	8		6	
		45	0,57**	-0,25	-0,7	-0,55	0,48**
		55	0,57**	-0,25	-0,7	-0,55	0,48**
		65	0,13*	0,75**	-0,35	0,87**	-0,5
		75	0,13*	0,75**	-0,81	0,69**	-0,5
		85	-0,82	-0,78	-0,5	0,56**	0,45
Emergence at field							
Control	-0,2	35	-0,67	-0,61	0,72**	-0,91	0,24**
		45	0,72**	-0,91	0,24**	-0,13	-0,2
		55	-0,61	0,72**	-0,91	0,24**	-0,13
		65	0,76**	0	-0,93	0,8	-0,71

		75	0,76**	0	-0,22	0,98**
		85	0,58**	-0,55	0	-0,82
						0,48**
Dead seeds in germination test						
Control	0,98**	35	-0,18	0,75**	-0,37	0,47**
		45	-0,1	0,60**	0,82**	0,73**
		55	-0,1	0,60**	0,82**	0,73**
		65	-0,15	0,94**	-0,04	-0,65
		75	-0,15	0,94**	0,87	-0,3
		85	0,76**	0,79**	0,41**	-0,43
						-0,98

** and * are significant by the *t* test in 0.01 and 0.05 of probability of error, respectively.
Source: authors

Gama *et al*. (2014) and Marini *et al*. (2012) report that the thermotherapy applied to seeds aiming at sanitary control if not adequate to species, can be highly damaging to its physiological quality, compromising, mainly, the initial germination. Medeiros *et al*. (2015) observed efficiency on this method as a seed treatment, besides controlling the incidence of several phytopathogens, environmentally it is not pollutant and it has no residual.

In relation to the safflower seeds sanity after submission to thermotherapy via dry heat, we observed efficiency in percentage control of phytopathogens in all the temperatures and periods of time tested. Nevertheless, this thermotherapic technique preserves the physiological quality of safflower seeds until the temperature of 45 ºC. Among the variation of thermotherapic treatments via dry heat tested on the safflower seeds, we highlight the combination of 45 ºC 24 h^{-1}, for promoting improvement in physiological expression of the same for germination at four DAS (42%), germination at 14 DAS (71%) and emergence at field (75%), besides the control under the total infested seeds (23%).

Despite the highlight and international investment, the safflower cultivation in Brazil is incipient. Initial research of improvement and adaptability of the culture indicates the species as alternative of off-season cultivation, especially for seed production. Results of the present work suggest good perspectives of thermotherapy use for treatment of safflower seeds, offering an option to the use of chemical products. In virtue of the low environmental impact, without residual effect and efficient in phytosanitary control, besides the easy manipulation of the method, appropriated to familiar or agroecological agriculture.

5 CONCLUSIONS

The treatment of seeds by means of thermotherapy via dry heat was efficient for the control of phytopathogens incident in the safflower seeds, without damage to their physiological quality until 45 ºC. Among the thermotherapic treatment of seeds,

the combination of 45 ºC 24 h^{-1} provided better phytosanitary quality for the safflower seeds, increasing still their potential of germination and emergence at field.

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