

Original Research Article

Hyperthermotherapy in the rice emasculation process

ABSTRACT

SAMPLE ABSTRACT:

Aims: The objective of this work was to evaluate the emasculation by hyperthermotherapy method in irrigated rice genotypes, and to compare it with the emasculation by vacuum suction.

Study design: The experimental design used to compare the two methods was completely randomized, with two treatments (emasculation by hyperthermotherapy and vacuum suction) and six replications. To analyze the emasculation by hyperthermotherapy, this design was also used with three replications.

Place and Duration of Study: The study was carried out in the agricultural years of 2012/2013 (1st year) and 2013/2014 (2nd year), at the Terras Baixas Experimental Station of Embrapa Clima Temperado, in the municipality of Capão do Leão, RS (31°48'15.47"S and 52°24'47.11" W).

Methodology: In the emasculation by hyperthermotherapy, 48 treatments were analyzed, consisting of the combination of 6 water temperatures (40 °C, 42 °C, 44 °C, 46 °C, 48 °C and 50 °C), 4 panicle immersion times (2.5 min, 5.0 min, 7.5 min and 10 min) and two cultivars (BRS Pampa and IAS 12-9 Formosa).

Results: The progressive increase in the temperature and time decreases the formation of grains until a certain condition in which the total sterilization of rice flowers occurs, being possible execute the emasculation before this occurs. This condition is 46 °C for 2.5 minutes of panicle immersion. The genotype IAS 12-9 Formosa showed higher tolerance to high temperatures.

Conclusion: The condition that presented the best result to perform the hybridization was a temperature of 46 °C for a panicle immersion time of 2.5 minutes for both cultivars. The hyperthermotherapy produces a smaller amount of grains, but presents a lower percentage of self-fertilization, thus, being more effective in the artificial rice hybridization process.

Comment [AL1]: Methodology is the systematic, theoretical analysis of the methods applied to a field of study. And you use a few methods only.

Keywords: *Oryza sativa*; genetic enhancement; crossing; hybridization.

1. INTRODUCTION

Among the several stages of a rice-breeding program, hybridization is one of the most important and fundamental, since it allows associating characteristics manifested in other genotypes in a single genotype. Through this process, genes are transferred between plants, increasing the genetic variability and increasing the possibility of forming new genetic combinations, among these some can be highly favorable, leading to agronomically superior genotypes.

In rice, the emasculation technique normally used in breeding programs consists of cutting the top of the spikelets and removing the anthers by means of a vacuum pump. However, this method is laborious, has low operating efficiency, and needs skilled labor to remove the anthers in order to prevent contact with the suction tip that can cause mechanical damage to the stigma [1, 2].

An alternative method is hyperthermotherapy, which consists in the use of a particular source of heat, in this specific case hot water, to promote the increase of the temperature of the floral structure. This method is based on the difference in thermal sensitivity between the male and female part of the rice flower, where pollen grains are more sensitive to higher temperatures than stigma. The male gametophyte is particularly sensitive to high temperatures at all stages of development, whereas the pistil

28 and the female gametophyte are considered more tolerant [3]. Hyperthermotherapy is easy to perform,
29 less labor intensive, and does not necessarily require skilled labor [4].

30 As rice breeding programs perform numerous hybridizations in order to introduce new genes into their
31 working germplasm and/or hybridizations among their elite genotypes to develop their cultivars, there is a
32 need to refine emasculation methods to provide greater benefits at this stage of the program.

33 Analyzing the need to create new emasculation methodologies, which are practical, inexpensive and
34 have high yields to facilitate this step in breeding programs, the present study aims to evaluate the
35 method of emasculation by hyperthermotherapy in genotypes of irrigated rice (*Oryza sativa* L.), of the
36 Indica and Japonica subspecies, and to compare it with the vacuum suction method.

37 2. MATERIAL AND METHODS / EXPERIMENTAL DETAILS / METHODOLOGY

38 The study was carried out in the agricultural years of 2012/2013 (1st year) and 2013/2014 (2nd year), at
39 the Terras Baixas Experimental Station of Embrapa Clima Temperado, in the municipality of Capão do
40 Leão, RS (31°48'15.47"S and 52°24'47.11" W). In the first year of the experiment, only the emasculation
41 process was carried out, with all studied treatments, in order to determine the viability of the pollen grain
42 (Table 1). In the 2nd year, the emasculation was performed with the treatments that could provide the
43 sterility of the pollen grain without causing thermal damage in the female part of the flower. These were
44 treatments that presented results close to zero, and referred to treatments with the temperatures of 46 °C,
45 48 °C and 50 °C, in the four analyzed times. Later, artificial pollination was carried out.

46 Three rice genotypes (*Oryza sativa* L.) were used, two to evaluate the process of emasculation by
47 hyperthermotherapy, the BRS Pampa (Indica subspecies), IAS 12-9 Formosa (Japonica subspecies) and
48 the third was BRS Querência (Indica subspecies), being used as male parent in hybridization. The sowing
49 was done in a staggered way, to coincide with the flowering of the cultivars, in 10-liter buckets filled with
50 soil classified as Albaqualf soil.

51 **Table 1. Treatments performed in the hyperthermotherapy emasculation process in rice cultivars**
52 **BRS Pampa and IAS 12-9 Formosa.**

Treat.	Temp. (°C)	Time (min.)	Cultivar	Treat.	Temp. (°C)	Time (min.)	Cultivar
T1	40	2.5	BRS Pampa	T25	40	2.5	IAS 12-9 Formosa
T2	40	5.0	BRS Pampa	T26	40	5.0	IAS 12-9 Formosa
T3	40	7.5	BRS Pampa	T27	40	7.5	IAS 12-9 Formosa
T4	40	10.0	BRS Pampa	T28	40	10.0	IAS 12-9 Formosa
T5	42	2.5	BRS Pampa	T29	42	2.5	IAS 12-9 Formosa
T6	42	5.0	BRS Pampa	T30	42	5.0	IAS 12-9 Formosa
T7	42	7.5	BRS Pampa	T31	42	7.5	IAS 12-9 Formosa
T8	42	10.0	BRS Pampa	T32	42	10.0	IAS 12-9 Formosa
T9	44	2.5	BRS Pampa	T33	44	2.5	IAS 12-9 Formosa
T10	44	5.0	BRS Pampa	T34	44	5.0	IAS 12-9 Formosa
T11	44	7.5	BRS Pampa	T35	44	7.5	IAS 12-9 Formosa
T12	44	10.0	BRS Pampa	T36	44	10.0	IAS 12-9 Formosa
T13	46	2.5	BRS Pampa	T37	46	2.5	IAS 12-9 Formosa
T14	46	5.0	BRS Pampa	T38	46	5.0	IAS 12-9 Formosa
T15	46	7.5	BRS Pampa	T39	46	7.5	IAS 12-9 Formosa
T16	46	10.0	BRS Pampa	T40	46	10.0	IAS 12-9 Formosa
T17	48	2.5	BRS Pampa	T41	48	2.5	IAS 12-9 Formosa
T18	48	5.0	BRS Pampa	T42	48	5.0	IAS 12-9 Formosa
T19	48	7.5	BRS Pampa	T43	48	7.5	IAS 12-9 Formosa
T20	48	10.0	BRS Pampa	T44	48	10.0	IAS 12-9 Formosa
T21	50	2.5	BRS Pampa	T45	50	2.5	IAS 12-9 Formosa

Comment [AL2]: you should be arranged the head of Table 1 as Table 2 and remove 2 columns of Cultivar

T22	50	5.0	BRS Pampa	T46	50	5.0	IAS 12-9 Formosa
T23	50	7.5	BRS Pampa	T47	50	7.5	IAS 12-9 Formosa
T24	50	10.0	BRS Pampa	T48	50	10.0	IAS 12-9 Formosa

Treat. = Treatment, Temp. (°C) = Temperature in degrees Celsius and time (min.) = Time in minutes

The emasculaton process was performed when the panicle was in the reproductive stage R2 - R3, and the spikelets were removed from the upper third (self-fertilized) and lower third (immature), resulting between 50 and 60 spikelets per panicle, with each spikelet cut on top with scissors before being immersed in the "water bath". After, the panicles were identified and protected until the grain maturation.

The pollination stage performed in the 2nd year, was shortly after the emasculaton, placing in the envelope a panicle of the male parent along with one of the female parent and in the period from 12:00 to 13:30 h, when the spikelets had their the anthers and stigma exposed, by manually shaking the envelope so that the pollen "rain" of occurred.

Four weeks after emasculaton, the number of fertile and sterile spikelets was determined in order to determine the ideal emasculaton conditions. The spikelets that formed the grain indicate that the treatment was not able to carry out the sterilization of the pollen grains, leading to self-fertilization. In the 2nd year, after four weeks of pollination, the percentage of sterile and formed grains was calculated, thus observing the occurrence or not of artificial hybridization, and thus verifying the viability of the female structure.

To compare the emasculaton by hyperthermotherapy with vacuum suction methods, the experiment was carried out in two agricultural years. The first one in 2012/2013 in a greenhouse, to carry out the hybridizations with the two methods of emasculaton and in the second agricultural year in 2013/2014, the seeds from each method were seeded in the experimental field, in order to determine the number of self-fertilized plants and hybrids. Emasculaton by hyperthermotherapy was performed at a water temperature of 45 °C for a panicle immersion time of 5 minutes. In both emasculaton methods, the BRS Querência was used as the female parent and BRS Pampa as the male one.

In the 1st year, after 30 days of pollination, the number of grains formed was assessed by counting, and the percentage for the emasculaton methods analyzed was calculated. In the 2nd year, for each method, the number of self-fertilized and hybrid plants was determined through a morphological marker of hairiness, with glabrous plants resulting from self-pollination and pilose ones from artificial hybridization.

The experimental design used to compare the two methods was completely randomized, with two treatments (emasculaton by hyperthermotherapy and vacuum suction) and six replications. To analyze the emasculaton by hyperthermotherapy, this design was also used with three replications. Data were submitted to analysis of variance (ANOVA) through the statistical program Assistat, version 7.6 [5].

3. RESULTS AND DISCUSSION

With a time of 2.5 min and temperature of 40 °C, the cultivars IAS 12-9 Formosa and BRS Pampa presented a grain formation of 39.47% and 41.20%, respectively, being in group "d" and statistically differing from the other three panicle immersion times in the "e" group (Table 2). Thus, it can be inferred that at the temperature of 40 °C independently of the analyzed times, the percentage of grains formed was high for the process (Figure 1A), not being an efficient treatment for rice emasculaton.

At 42 °C (Figure 1B), BRS Pampa cultivar showed a gradual reduction in the percentage of grains formed as the panicle immersion time increased, where at the initial time the percentage of grains formed was 47.48% (group e) and at the final time, this was 16.63% (group b) according to Table 2. For IAS 12-9 Formosa, the grain formation was 39.02% (group d) at time 2.5 minutes, with an increase in self-fertilization (% of grains formed) at the time of 5 minutes (51.61%), remaining statistically the same at 7.5 minutes and 10 minutes, where the percentage of grains formed was 47.93% and 45.93%, respectively (Table 2). In this way, it can be inferred that the cultivar IAS 12-9 Formosa has a higher tolerance than

the BRS Pampa at this temperature during the flowering period, because with the increase of the panicle immersion time at that temperature, there was no reduction in the formation of grains.

At a temperature of 44 °C (Figure 1C), it was observed that the variation in the percentage of grains formed in the Japonica subspecies genotype was lower, with 37.02% (group d) at the time of 2.5 minutes and after 10 minutes, this was 16.65% (group b), presenting a high level of viability of pollen grain with increasing emasculatation time at this temperature (Table 2). The variation in the percentage of grains formed in the Indica subspecies genotype was higher, with an increase in the panicle immersion time from 2.5 to 5 minutes, with a variation from 48.69% to 4.56%, remaining statistically the same at all times, thus demonstrating that this genotype is less tolerant to high temperatures than the Japonica subspecies genotype.

Table 2. Percentage of grains formed after emasculatation by hyperthermotherapy in rice cultivars BRS Pampa and IAS 12-9 Formosa.

Temp. (°C)	BRS Pampa				IAS 12-9 Formosa			
	Time (min.)				Time (min.)			
	2.5	5	7.5	10	2.5	5	7.5	10
40	41.20dB	47.67eD	46.91eC	45.47eC	39.47dB	53.72eD	52.06eC	48.02eC
42	47.48eB	34.83dC	27.83cB	16.63bB	39.02dB	51.61eD	47.93eC	45.93eC
44	48.69eB	4.56aB	2.42aA	2.29aA	37.02dB	30.09cC	29.57cB	16.65bB
46	3.01aA	1.62aA	1.89aA	1.04aA	10.71bA	8.66bB	3.41aA	2.66aA
48	2.92aA	0aA	0aA	0aA	3.60aA	0aA	0aA	0aA
50	0aA	0aA	0aA	0aA	0aA	0aA	0aA	0aA

The averages followed by the same lowercase letter, in the same row, and upper case, in the same column, do not differ statistically by the Scott-Knott method at 5% probability. Temp. = Temperature. °C = degrees Celsius, min = minutes.

In Figure 1D, it is observed that during all the evaluated times, cultivar IAS 12-9 Formosa showed a higher percentage of grains formed than BRS Pampa, showing a reduction from 10.71% (group b) to 2.66% (group a) as the panicle immersion time increased (Table 2).

It can be seen in Figure 1E that the two cultivars presented some similarity, and the percentage of grains formed from IAS 12-9 Formosa (3.60%) was slightly higher than BRS Pampa (2.92%) at time 2.5 minutes, but not statistically different from each other nor from times 5, 7.5. and 10 minutes, where the genotypes had the same percentage of grains formed, showing a desired hyperthermotherapeutic emasculatation (Table 2).

At 50 °C (Figure 1F), it can be seen that for the two cultivars analyzed, the first panicle immersion time was able to provide a desired emasculatation, remaining statistically the same for the other analyzed times (Table 2).

According to the results, it is observed that the temperature is an important factor in the determination of grain formation in rice. The development stage in which the plant is exposed to high temperatures determines the severity of possible grain formation damage. Temperatures higher than the ideal in the reproductive phase induce the sterility of the spikelets and consequently decrease the productivity [6]. In rice, the period of microsporogenesis and flowering are considered the most sensitive stages at high temperatures [7].

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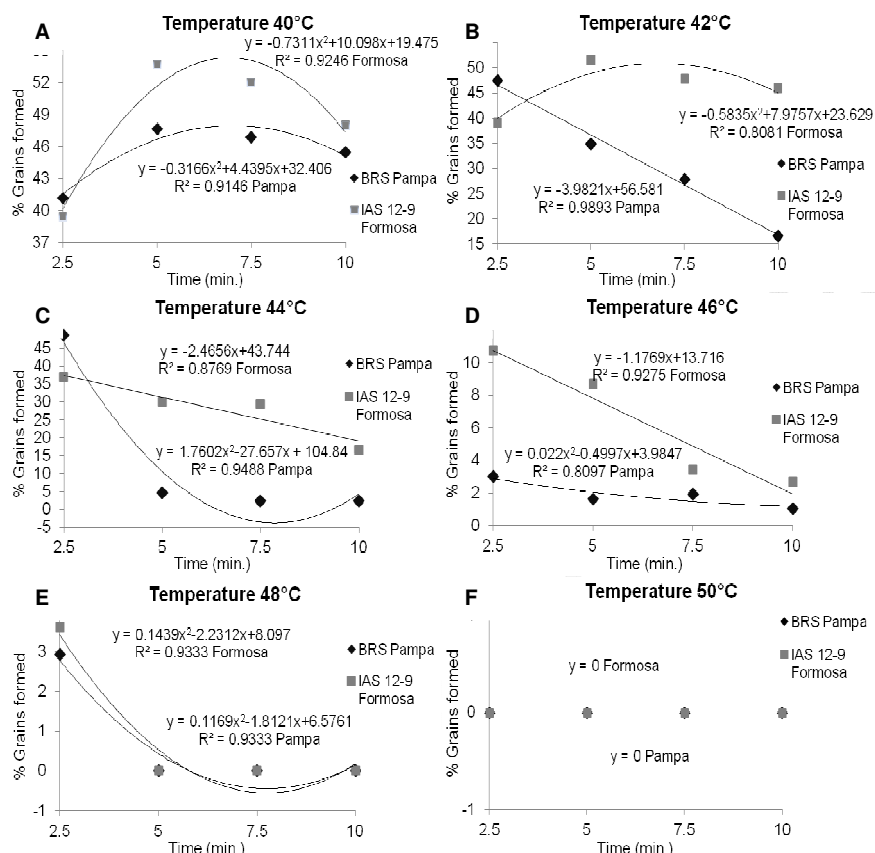


Figure 1. Percentage of grains formed in BRS Pampa and IAS 12-9 Formosa cultivars, setting the emasculat

Comment [AL4]: Did you tray 3D graph. Grains formed =f(Time, Temp.). You can find optimum?

There is a genotypic variability for partial tolerance to the sterility of rice spikelets at high temperatures in the Indica and Japonica subspecies of *Oryza sativa* [8]. Different characteristics are mentioned among tolerant or susceptible genotypes, the occurrence of well-developed locular cavities in the anthers and thick walls allow easy rupture of the septa in response to increased pollen grain volume resulting in better anther dehiscence and pollination in tolerant cultivars [9].

Some morphological characteristics may be related to the high temperature tolerance in the reproductive phase of rice. If the plant architecture presents itself in such a way that the panicle is surrounded by many leaves, it will be able to withstand the high temperatures, due to the increase in the cooling in the perspiration, preventing the evaporation in the anther, due to the shading provided by the leaves, thus guaranteeing pollen grains swelling and anther dehiscence [10]. Genotypes with greater anther length are more tolerant to high temperatures since they have a large number of pollen grains per anther, which compensates for their germination in the stigma [11].

According to the results obtained in the process of emasculat

In Figure 2A, it is observed that BRS Pampa and IAS 12-9 Formosa did not suffer damage in the viability of the pollen grain due to water temperature elevation from 40 °C to 44 °C since the percentage of grains formed did not differ statistically. This proves that at a maximum period of 2.5 minutes between these temperatures, the percentage of grains formed is not affected, and emasculation can thus occur. At the temperature of 46 °C, there was a considerable reduction in the percentage of grains formed in relation to the initial temperatures in both cultivars, from 48.69% (group b) to 3.01% (group a) for BRS Pampa and 37.02% (group b) to 10.71% (group a) for IAS 12-9 Formosa. In this sense, it can be inferred that the temperature of 46 °C during 2.5 minutes caused a significant decrease in the percentage of grains formed, remaining statistically the same with the temperatures of 48 °C and 50 °C (Table 2).

Figure 2B shows a significant reduction in the percentage of grains formed in BRS Pampa, with a difference in the analyzed variable between cultivars at temperatures of 42 °C, 44 °C and 46 °C, where IAS 12-9 Formosa presented a higher percentage of grains formed and did not differ statistically at temperatures of 48 °C and 50 °C (Table 2).

During the treatment time of 7.5 minutes (Figure 2C), an abrupt reduction in grain formation is observed in BRS Pampa, with an increase in temperature from 42 °C to 44 °C, different from IAS 12-9 Formosa, where this change occurred from 44 °C to 46 °C, demonstrating a higher tolerance of high temperatures. However, at temperatures of 40 °C, 48 °C and 50 °C there was no statistical difference between the cultivars (Table 2).

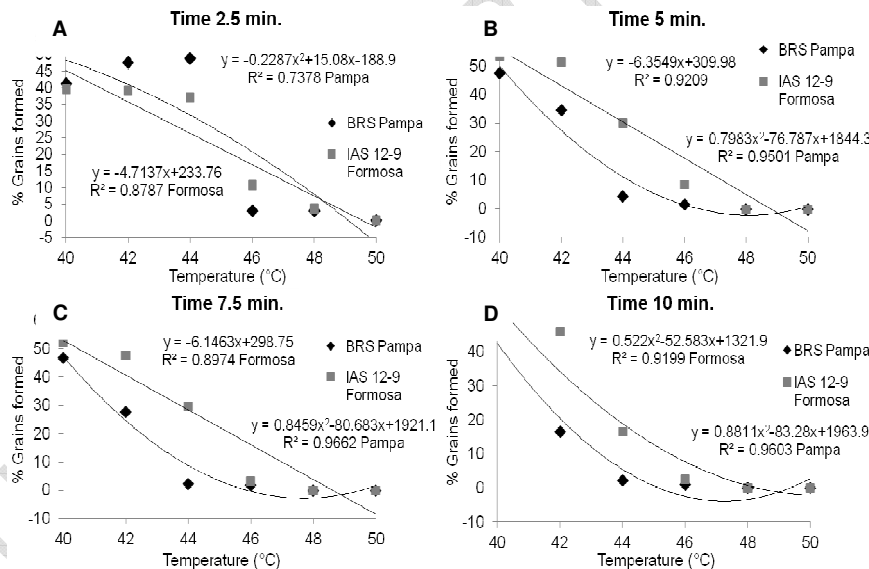


Figure 2. Percentage of grains formed in BRS Pampa and IAS 12-9 Formosa cultivars, setting the immersion times of the rice panicle in the emasculation by hyperthermotherapy.

In the treatment time of 10 minutes (Figure 2D), a greater reduction is observed in the percentage of grains formed in the BRS Pampa than in IAS 12-9 Formosa as the emasculation temperature increases, until the two are equal, as verified at the emasculation time of 7.5 minutes (Figure 2C). There was, nevertheless, a statistical difference between the cultivars at temperatures of 42 °C and 44 °C (Table 2).

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191 In emasculum by hyperthermotherapy, time is a relevant factor to determine the efficiency of the
 192 process. For example, if at a certain temperature one obtains ideal emasculum at different times, the
 193 shorter time must be used as this will result in a higher operating yield and cause less stress to the
 194 female parent.

195 In Cambodia rice cultivars, thermal emasculum can be applied for artificial hybridization between the
 196 Indica and Japonica genotype groups under the conditions of 43 °C for 7 minutes [4]. Even though the
 197 present work has similar temperatures and emasculum time to the experiments of these
 198 aforementioned authors, the results are different because a higher percentage of grains was obtained.

199 | The treatment of rice with hot water at 40 °C to 44 °C, for 10 min, at most, is enough to start the
 200 emasculum, and this variation depends on the genotype [12]. In the described results, there was a
 201 difference between the analyzed cultivars, with BRS Pampa presenting results that were closer to those
 202 | of the authors mentioned. According to Sha (2013), The ideal conditions for emasculum in rice are 45
 203 °C during 5 minutes so that the pollen grain loses viability and the stigma remains normal [13]. [4]
 204 reported similar efficacy in emasculum at temperatures of 45 °C and 46 °C. The emasculum with hot
 205 water at 47 °C is lethal to the female part of the rice flower, affecting the hybridization process [14].
 206 Although there was no such temperature, two higher temperatures (48 °C and 50 °C) were analyzed,
 207 where this finding was confirmed in the second year of the experiment after emasculum followed by
 208 pollination.

209 The BRS Pampa cultivar presented 23.71% of grains formed, after the emasculum by
 210 hyperthermotherapy at the temperature of 46 °C and time of 2.5 minutes, whereas the IAS 12-9 Formosa
 211 in this same condition presented 14.96% of grains formed (Table 3). Comparing these results with those
 212 of the first year of evaluation (Table 2), the two cultivars showed a higher percentage of grains formed in
 213 the second year, meaning that there was a percentage of artificial hybridization, being more expressive in
 214 BRS Pampa. This difference is explained by the lower percentage of hybridization between rice
 215 genotypes of the Indica x Japonica subspecies due to genetic causes, or because of the higher tolerance
 216 presented in the high emasculum temperatures in IAS 12-9 Formosa.

217
 218 **Table 3. Percentage of grains formed in BRS Pampa and IAS 12-9 Formosa cultivars after**
 219 **emasculum by hyperthermotherapy followed by pollination.**

Treatments (T °C / Time min.min)	% of Grains Formed	
	BRS Pampa	IAS 12-9 Formosa
46°C / 2.5 min.min	23.71 a	14.96 b
46°C / 5 min.min	8.25 c	7.83 c
46°C / 7.5 min.min	0.00 d	2.27 d
46°C / 10 min.min	0.00 d	0.00 d
48°C / 2.5 min.min	0.00 d	0.00 d
48°C / 5 min.min	0.00 d	0.00 d
48°C / 7.5 min.min	0.00 d	0.00 d
48°C / 10 min.min	0.00 d	0.00 d
50°C / 2.5 min.min	0.00 d	0.00 d
50°C / 5 min.min	0.00 d	0.00 d
50°C / 7.5 min.min	0.00 d	0.00 d
50°C / 10 min.min	0.00 d	0.00 d

220 The averages followed by the same letter do not differ statistically from each other by the Scott-Knott method at a 5%
 221 probability level. T: temperature in degrees Celsius, min.: minutes.

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222
223 In the emasculum condition of 46 °C for 5 minutes, both cultivars presented similarity in the percentage
224 of grains formed, and lower than in the previous condition, when comparing Table 3 data to that from
225 Table 2 in emasculum by 46 °C for 5 minutes. It is observed that the BRS Pampa showed a higher
226 percentage of grains formed in the second year of the experiment, thus occurring artificial hybridization. In
227 this condition, this cultivar had a reduction in the percentage of grains formed (8.25%) compared to the
228 emasculum by 46 °C for 2.5 minutes (23.71%), due to the longer emasculum time. However, IAS 12-9
229 Formosa presented a similar percentage of grains formed in the two years. This is due to the greater
230 tolerance presented by this genotype at high emasculum temperatures.

231 With the pollination process carried out in the second year, it can be seen that from the temperature of 46
232 °C and time of 7.5 minutes until the temperature of 50 °C and 10 minutes, the female structure of the rice
233 flower was damaged by the high temperatures. This caused infertility of the female gamete, except for
234 IAS 12-9 Formosa at the temperature of 46 °C for 7.5 minutes. (Table 3), which presented a similar
235 percentage of formed grains during the two evaluation years. The occurrence of a possible self-pollination
236 before the emasculum process in the first year of evaluation resulted in a small percentage of grains
237 formed at temperatures of 46 °C for 10 minutes and 48 °C for 2.5 minutes in both cultivars, as well as for
238 BRS Pampa at a temperature of 46 °C for 7.5 minutes (Table 2), which made the hyperthermotherapeutic
239 emasculum impossible. In the second year, it can be seen that these temperatures cause thermal
240 damage to the female structure, that is, sterility.

241 The effect of high temperature can cause death of cells and tissues, occurring within minutes or even
242 seconds [15]. With the results of high temperature being a complex function of intensity, duration and
243 temperature variation [16], as well as the stage of development of the plant, with the reproductive phase
244 being the most sensitive [17].

245 This thermal stress can reduce the number, decrease size and deform the flower organs [18], impair cell
246 division and decrease pollen production [8], promote poor dehiscence of the anthers by the closure of the
247 locules, reducing dispersion of rice pollen grains [11], and cause the deposition of carbohydrates in the
248 pollen grains [19], which may be due to disturbances in sugar metabolism on the tapetum [20]. It also
249 induces early abortion of tapetal cells [21], reducing energy for pollen tube growth, causing sterility of the
250 spikelet. Cell death due to high temperatures is attributed to a catastrophic collapse in its organization
251 due to changes in its structures [22].

252 High temperatures induce the production of reactive oxygen species, which in high concentrations will
253 result in oxidative damage and, potentially, cell death [23]. With the increase of reactive oxygen species
254 levels, plant growth regulator production and alteration of membrane fluidity can act as factors to trigger
255 transcriptional changes due to high temperatures [24], resulting in the expression of genes coding for the
256 heat shock proteins.

257 These proteins are known to be an important strategy for adaptation and repair under high temperature
258 stress conditions, helping to maintain the integrity and properties of cell membranes, protecting
259 intracellular proteins from being denatured and preserving their stability [25].

260 Genotypes of rice tolerant to high temperatures present a greater accumulation of heat shock proteins in
261 the anthers [26]. Quantitative Trait Loci (QTLs) associated with high levels of heat shock proteins in the
262 anthers, spikelets and rice leaf, provide maintenance of grain formation under high temperatures [27, 28].

263 When the results of Table 3 are related to the described discussions, it can be inferred that the conditions
264 of emasculum by hyperthermotherapy that resulted in zero percent of grains formed are due to the
265 stress suffered by the cells, causing their death. On the other hand, in the cases where grains were
266 formed, hybridization or tolerance to stress by the genotype occurred. To verify the occurrence of
267 hybridization, the plants resulting from the F1 seeds were evaluated in the field by means of a
268 morphological marker (pilosity).

In the comparison between the two methods of emasculation (Table 4), a difference in the percentage and quantity of grains formed is observed. The vacuum suction method presented the best results for these two variables, because the method promotes the removal of the anthers without causing damage to the female structure of the flower. In the other method, the temperature of the emasculation water physically affects the whole rice flower. The amount of grains formed in rice, through emasculation by hyperthermotherapy and vacuum suction, obtaining 16.5% and 31.5%, respectively [14]. Indicating that vacuum suction provides greater amount of grains formed. Since the emasculation by hyperthermotherapy presents a higher operating efficiency, that is, a greater amount of emasculated panicles at a given time, this difference in grains formed in the hybridization can be easily compensated.

Table 4. Percentage and quantity of grains formed in rice using the methods of emasculation by hyperthermotherapy and vacuum suction, and percentage of F1 hybrids.

Emasculation method	Grains formed (%)	Quantity of grains formed	% F1 Hybrids
Hyperthermotherapy	23.62 b	92 b	97.33 a
Vacuum suction	38.56 a	127 a	88.12 b

The averages followed by the same letter do not differ statistically from each other by the Tukey test at the 5% probability level.

Emasculation by hyperthermotherapy showed higher efficiency, due to the higher percentage of hybrid plants than vacuum suction, being 97.33% and 88.12%, respectively (Table 4). Emasculation by hyperthermotherapy results in a higher percentage of F1 hybrid plants, with a suitable temperature for each cultivar [14]. This method provides a higher percentage of hybrid F1 plants, since it is more stable because it has controlled temperature and time, which promotes greater sterility of the pollen grain. While the suction method has a greater susceptibility to error because there maybe failure in removing all rice flower anthers, leaving some behind and causing self-pollination.

Hyperthermotherapy can be applied in rice breeding programs, since it facilitates the execution, improves the operational performance and allows an increase in the quantity of F1 hybrid seeds obtained, facilitating the selection of genetically superior genotypes.

4. CONCLUSION

1. Among all the emasculation by hyperthermotherapy conditions analyzed, the condition that presented the best result to perform the hybridization was a temperature of 46 °C for a panicle immersion time of 2.5 minutes for both cultivars.

2. The progressive increase in temperature and time decreases the formation of grains to a certain condition in which the total sterilization of rice flowers occurs. The genotypes of the Japonica subspecies have a greater tolerance to this stress.

3. The emasculation by vacuum suction method results in a higher quantity of grains formed, but with a higher percentage of self-fertilization. However, hyperthermotherapy produces a smaller amount of grains, but presents a lower percentage of self-fertilization, thus, being more effective in the artificial rice hybridization process.

REFERENCES

1. Coffman, W. R.; Herrera, R. M. Rice: hybridization of crop plants. Madison, Wisconsin (USA): American Society of Agronomy. 1980, 511-521.

2. CORDEIRO, A. C. C. In: Genetic improvement methods of irrigated rice. Boa Vista: Embrapa Roraima, 2008: 46.
3. Hedhly, A. Sensitivity of flowering plant gametophytes to temperature fluctuations. Environmental and Experimental Botany, Bornova-Izmir. 2011, 74:9-16.
4. Tong, L.; Yoshida T. Can hot-water emasculation be applied to artificial hybridization of indica - Type Cambodian Rice? Plant Production Science, Nagoya. 2008, 11:132-133.
5. Silva, F. de A. S.; Azevedo, C. A. V. de. Principal Components Analysis in the Software Assistat-Statistical Attendance. In: WORLD CONGRESS ON COMPUTERS IN AGRICULTURE, 7, USA: American Society of Agricultural and Biological Engineers. 2013
6. Nakagawa, H.; Horie, T.; Matsui, T. Effects of climate change on rice production and adaptive technologies. In Rice Science: Innovations and Impact for Livelihood. Proceedings of the International Rice Research Conference, Beijing, China, 16–19 September 2002 (Eds T.W. Mew, D. S. Brar, S. Peng, D. Dawe & B. Hardy). 2003, 635-658.
7. Farrell, T. C. et al. Genotypic variation for cold tolerance during reproductive development in rice: screening with cold air and cold water. Field Crops Research, Aberdeenshire. 2006, 98:178-194.
8. Prasad, P. V. V. et al. Species, ecotype and cultivar differences in spikelet fertility and harvest index of rice in response to high temperature stress. Field Crops Research, Aberdeenshire. 2006, 95:398-411.
9. Matsui, T.; Omasa, K.; Horie, T. The difference in sterility due to high temperatures during the flowering period among japonica-rice varieties. Plant Production Science, Nagoya. 2001, 4:90–93.
10. Shah, F. et al. Impact of high-temperature stress on rice plant and its traits related to tolerance. Journal of Agricultural Science, Belihuloya. 2011, 149:545-556.
11. Matsui, T.; Omasa, K. Rice (*Oryza sativa* L.) cultivars tolerant to high temperature at flowering: anther characteristics. Annals of Botany, Oxford. 2002, 89:683–687.
12. Chhabra, A. K. Emasculation and pollination techniques. Department of Plant Breeding, CCSHAU, Hisar, Haryana, India 2010.
13. Sha, X. Rice Artificial Hybridization for Genetic Analysis. Rice Protocols, Methods in Molecular Biology, vol. 956, Springer Science Business Media, Chapter 1. 2013. 1-12.
14. Yzaguirre, A. G.; Carreres, R. Efficiency of different hybridization methods in single crosses of rice for pure line breeding. Spanish Journal of Agricultural Research, Madrid, 2008, 6(3):395-400.
15. Hasanuzzaman, M.; Hossain, M. A.; Fujita, M. Physiological and biochemical mechanisms of nitric oxide induced abiotic stress tolerance in plants. American Journal of Plant Physiology, Nova Iorque. 2010, 5:295–324.
16. Thakur, P. et al. Cold stress effects on reproductive development in grain crops: an overview. Environmental and Experimental Botany, Bornova-Izmir. 2010, 67:429–443.
17. Prasad, P. V. V. et al. Sensitivity of grain sorghum to high temperature stress during reproductive development. Crop Science, Madison. 2008, 48(5):1911-1917.
18. Morrison, M. J.; Stewart, D. W. Heat stress during flowering in summer Brassica. Crop Science, Madison. 2002, 42:797-803.

- 369
370 19. Jain, M. et al. Effects of season-long high temperature growth conditions on sugar-to-starch
371 metabolism in developing microspores of grain sorghum (*Sorghum bicolor* L. Moench). *Planta*, Berlin.
372 2007, 227:67–79.
373
374 20. Oliver, S. N. et al. Cold-induced repression of the rice anther-specific cell wall invertase gene OSINV4
375 is correlated with sucrose accumulation and pollen sterility. *Plant, Cell and Environment*, Malden.
376 2005, 28:1534–1551.
377
378 21. Parish, R. W.; Phan, H. A.; Iacuone, S.; Li, S. F. Tapetal development and abiotic stress: a centre of
379 vulnerability. *Functional Plant Biology*, Hobart. 2012, 39:553–559.
380
381 22. Howarth, C. J. Genetic improvements of tolerance to high temperature. In: Ashraf, M., Harris, P.J.C.
382 (Eds.), *Abiotic Stresses: Plant Resistance Through Breeding and Molecular Approaches*. Howarth
383 Press Inc., New York, 2005.
384
385 23. Apel, K.; Hirt, H. Reactive oxygen species: metabolism, oxidative stress, and signal transduction.
386 *Annual Review of Plant Biology*, Palo Alto. 2004, 55:373–399.
387
388 24. Kotak, S. et al. Complexity of the heat stress response in plants. *Current Opinion in Plant Biology*,
389 Hertfordshire. 2007, 10:310–316.
390
391 25. Baniwal, S. K. et al. Heat stress response in plants: a complex game with chaperones and more than
392 twenty heat stress transcription factors. *Journal of Biosciences*, Bangalore. 2004, 29:471–487.
393
394 26. Jagadish, S. V. K. et al. Physiological and proteomic approaches to address heat tolerance during
395 anthesis in rice (*Oryza sativa* L.). *Journal of Experimental Botany*, Eynsham. 2010, 61:143–156.
396
397 27. Ye, C. et al. Mapping QTL for heat tolerance at flowering stage in rice using SNP markers. *Plant*
398 *Breeding*, Malden. 2012, 131:33–41.
399
400 28. SHI, W. et al. Source-sink dynamics and proteomic reprogramming under elevated night temperature
401 and their impact on rice yield and grain quality. *New Phytologist*, Lancaster. 2013, 197:825–837.