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INTRASPECIFIC COMPETITION OF HYBRIDS USING MIXTURES OF POLLINATOR LINES FOR HYBRID RICE PRODUCTION

Paulo Eduardo Rocha Eberhardt[1]*, Luis Osmar Braga Schuch[1], Vitor Vaz Mondo[2], Daniel Fernandez Franco[3], Letícia Ramon de Medeiros[1] & Aline Klug Radke[1]

1 - Federal University of Pelotas, Eliseu Maciel Agronomy College (FAEM), Capão do Leão, Rio Grande do Sul, Brazil

2 - Secretary of Innovation and Business, Brasília, Distrito Federal, Brazil

3 - Embrapa Temperate Climate, Lowlands Station, Pelotas, Rio Grande do Sul, Brazil

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ABSTRACT

The aim of this study was to evaluate the use of pollinator seed mixture to obtain hybrid rice seeds. The study was performed at Embrapa Clima Temperado, in the harvests of 2015/2016 and 2016/2017. Seeds of hybrids H7 and BRS AH 703 CL and the pollinator, Puitá INTA-CL cultivar were used in the proportions of 0.00%, 0.75%, 1.50%, 3.00%, 6.00%, 12.00% and 24.00% in the first year and 0.00%, 0.75%, 1.50%, 3.00%, 6.00%, 12.00% and 24.00%, 50.00% and 100.00% for the second year. The experimental design was a randomized complete block design with four repetitions and the data was submitted to analysis of variance. Seeding was performed in November and October. The plots were 5 meters long with 4 meters of plot area, being evaluated: Number of plants.m^{-2}, Number of culms.m^{-2}, Number of panicles.m^{-2}, Panicle length, Productivity of grain, plot uniformity, plant height, percentage of whole grains, broken grains. Plants from hybrid rice seeds in the mix had no effect on yield components. Plants from hybrid seeds showed plot uniformity like plants from self-fertilization. The industrial quality of the grains was like grains of self-fertilized plants but differing in the intermediate mixtures used.

Palavras-chave:
Oriza sativa
Contaminação parental
Vigor híbrido

COMPETIÇÃO INTRAESPECÍFICA DE HÍBRIDOS UTILIZANDO MISTURAS DE LINHAS POLINIZADORAS PARA A PRODUÇÃO DE ARROZ HÍBRIDO

RESUMO

Objetivou-se com este trabalho avaliar o uso de mistura de sementes polinizadoras na obtenção de sementes de arroz híbrido. O trabalho foi realizado na Embrapa Clima Temperado, nas safras de 2015/2016 e 2016/2017, utilizando-se sementes dos híbridos H7 e BRS AH 703 CL e do cultivar Puitá INTA-CL, como polinizador. Nas proporções de 0%, 0,75%, 1,50%, 3,00%, 6,00%, 12,00% e 24,00% no primeiro ano e 0,00%, 0,75%, 1,50%, 3,00%, 6,00%, 12,00% e 24,00%, 50,00% e 100,00% para o segundo ano. O delineamento experimental foi de blocos ao acaso com quatro repetições e os dados submetidos à análise de variância. A semeadura foi realizada nos meses de novembro e outubro respectivamente aos anos de cultivo. As parcelas foram de 5 metros de comprimento com 4 metros de área útil, avaliando-se: Número de plantas.m^{-2}, Número de colmos.m^{-2}, Número de panículas.m^{-2}, Comprimento da panícula, Produtividade de grãos, Uniformidade de parcela, Altura de plantas, Percentagem de grãos inteiros, Grãos quebrados. Plantas oriundas de sementes hibridas de arroz em mistura, não houve efeito para os componentes do rendimento. Plantas provenientes de sementes híbridas apresentaram uniformidade de parcela semelhantes a plantas provenientes de autofecundação. A qualidade industrial dos grãos foi semelhante a grãos de plantas autofecundadas, mas diferindo-se nas misturas intermediárias utilizadas.

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Email (corresponding author)*: pauloeduardorochaeberhardt@yahoo.com.br

SECTION EDITOR IN CHARGE
Michael Silveira Thebaldi

INTRODUCTION

The hybrids of rice, whose main characteristics are high potential production and production stability (KEMPE & GILS, 2011), can bring benefits directly linked to food security. Therefore, it can be possible to guarantee the production of a staple food of the Brazilian population, the sustainability of agricultural activity, with greater profitability to the rural producer and, also the environmental protection. Thus, there will be seek incessant for optimization of the cultivated area with greater food production by area.

In this way, to make possible the production of hybrid rice seeds, the male sterility in the recipient plants became fundamental, allowing one of the plants involved in the hybridization to be considered the pollinator and the other, the recipient, which is the producer of the seeds. Nowadays, the multiplication of hybrid seeds is performed in an area with lines or blocks of parental pollinator and lines or blocks of parental recipients in 2/1 and up to 1/1 proportions between parents, which results in a high cost of production per bag of seed. This fact occurs since in addition to the difficulties for cross-pollination, only part of the production field is harvested, reflecting low seed productivities, which 1,000 e 3,500 $kg.ha^{-1}$ (PENG & HARDY, 2011).

Another technique that can be used is to separate the pollinator seeds from the hybrid seeds in post-harvest processing if there are differential characteristics of the pollinator seeds, such as seed sizes (ZHU *et al.,* 2011) or different characteristics in grain coloring (MARUYAMA *et al.,* 1991; SOSBAI, 2012).

Therefore, science provides the basis for increasing the productivity and efficiency of rice-based systems, while advanced technologies allow farmers to grow more rice in a smaller area with less water, labor, and agrochemicals, reducing damage to the environment. At the same time, there is a reduction in costs and an improvement in product quality (OCDE-FAO, 2015).

It is known that hybrid rice cultivars may be more adaptable to different environments and therefore they have higher yield stability. Heterosis not only increases productivity but allows the improvement of adaptability and resistance to environmental stress, such as drought, salinity, floods, winds (WALDOW *et al.,* 2015).

According to Virmani and Kumar (2014), the great challenges for the large-scale adoption of hybrid rice technology by farmers are still linked to low productivity in the seed production fields and the high cost from the commercialized material.

The use of hybrid rice technology is determined by comparing the yield increase with the extra cost of the seed. Hybrid rice technology may be more utilized if the yield advantages of the hybrid are one ton per hectare and the additional cost of the hybrid seed is less than the 200 kg unpolished rice (OLIVEIRA, 2011).

Hybrid seed production requires care such as cultivation under specific conditions (NEVES, P., 2014). These are some of the reasons that make the process with a high cost of seed production and time consuming, which is related to the low use of technology in Brazil. Therefore, the growth of the cultivated area with hybrid rice is directly related to its productivity performance.

In total, 95% of the hybrids are based on crossings between Oryza indica lines and 5% are based on intersections between Japanese Oryza lines (LONGIN *et al.,* 2012).

Thus, this work aimed to evaluate the behavior of populations composed of mixtures of hybrid seeds of irrigated rice with different proportions of seeds of the pollinator strain, on the agronomic behavior of these populations, grain yield and industrial quality of the grains produced, as well as on possible deleterious competitive effects.

MATERIAL AND METHODS

The study was developed at Embrapa Clima Temperado, Lowlands Station, located in Capão do Leão, RS, Brazil, at the coordinates -31.80282, -52.40901, and was performed during the 2015/2016 and 2016/2017 harvests. Seeds of hybrid rice H7 and BRS AH 703 CL and PUITÁ INTA - CL cultivar were used and the soil in which the experiment was cultivated was a Planossolo (EMBRAPA, 2018). The climate classification was wet subtropical climate, Köppen-Geiger climate classification: Cfa.

The experimental design was a randomized block design with four repetitions, and the data were analyzed through polynomial regressions for parent line mix levels. The data of the experiment were submitted to analysis of variance and, where there was significance, polynomial regression or mean comparaison test were performed when necessary. Statistical analysis was performed at 5% probability level using the Winstat Statistical Analysis System version 1.0 (MACHADO & CONCEIÇÃO, 2003).

In Tables 01 and 02, the climatological data for the period of cultivation of the irrigated rice crop can be observed, for the months from October to April of each cultivation year, comprising the months of sowing and harvesting. It demonstrates the climatic conditions from the two years of conducting the experiments.

To evaluate the intraspecific competition of hybrids when in mixtures, the proportions of pollinator parental lines, 0.00%, 0,75%, 1.50%, 3.00%, 6.00%, 12.00% and 24.00% were used in the first year of evaluation and 0.00%, 0.75%, 1.50%, 3.00%, 6.00%, 12.00% and 24.00%, 50.00% and 100.00% for the second year of cultivation, as treatments, in which case treatments consisting of mixtures of seeds.

Sowing was done in November for the first year of the experiment driving and in October for the second year of the experiment driving, using sowing plots. The sowing density used was 40 kg.ha^{-1}. The plots consisted of 9 lines of 5 meters in length, spaced of 0.2 m, using the two lateral lines as a border and 0.5 m in each head of the plots as border, being used as a useful area of the plot the 5 central lines with 4 meters long, with 9 m^2 of total area and 4 m^2 of plot area.

Two linear meters were marked in two lines of the useful area of each plot, where several parameters were determined. At maturity, the panicles present in these 4 meters of line were counted and the number of panicles per square meter and number of panicles per plant were determined.

Table 1. Climatological data for the period from October to April of the years 2015/2016. Agroclimatological Station: Capão do Leão - RS (Embrapa/ETB - UFPel Campus). Embrapa/UFPel/INMET Agreement

Climatological Standards Period: 2015/2016 (Monthly)							
Variables	Oct	Nov	Dec	Jan	Feb	Mar	Apr
Average Temperature (°C)	16.7	19.1	22.4	23.9	24.5	20.9	20.0
Average Low Temperature (°C)	13.7	15.8	18.9	19.8	20.3	17.4	17.3
Average Maximum Temperature (°C)	20.6	23.1	26.8	29.0	30.3	25.8	24.1
Rainfall (mm)	199.1	158.7	156.9	68.8	91.0	190.2	249.2
Relative humidity (%)	85.5	81.3	82.1	79.6	80.2	86.1	87.3
Global Solar Radiation (cal.cm^{-2}.day^{-1})	315.0	401.3	441.6	486.0	499.1	342.2	196.9
Number of Fog Days	2	9	7	16	14	15	10

Table 2. Climatological data for the period from October to April of the years 2016/2017. Agroclimatological Station: Capão do Leão - RS (Embrapa/ETB - UFPel Campus). Embrapa/UFPel/INMET Agreement

Climatological Standards Period: 2016/2017 (Monthly)							
Variables	Oct	Nov	Dec	Jan	Feb	Mar	Apr
Average Temperature (°C)	17.5	19.6	22.7	23.8	24.9	21.6	19.0
Average Low Temperature (°C)	17.5	14.6	18.1	19.7	21.0	17.4	15.5
Average Maximum Temperature (°C)	22.1	25.2	28.5	28.9	30.3	27.1	24.3
Rainfall (mm)	84.4	111.9	99.0	130.2	122.8	103.6	66.1
Relative humidity (%)	84.0	77.0	78.4	82.5	85.5	83.9	81.9
Global Solar Radiation (cal.cm^{-2}.day^{-1})	330.2	502.1	505.6	489.3	427.6	389.7	279.4
Number of Fog Days	13	17	4	7	0	14	12

Evaluated variables

Number of plants.m^{-2}: counting the plants present in the four linear meters previously demarcated, in the development stage before the tillering period and before the moment of the irrigation water entering the plots. The results were transformed into number of plants.m^{-2}.

Number of stems.m^{-2}: The total number of stalks in the pre-harvest period, within the four linear meters premarked within the useful area of each plot, were counted. The results were transformed into number of culms.m^{-2}.

Number of panicles.m^{-2}: the total number of panicles within the pre-marked lines within each plot were counted.

Panicle length: the panicles were harvested for the determination of the number of grains before threshing. It was measured using a graded ruler and after the average panicle length was determined.

Grain yield was determined by weighing the harvested grains in the useful area of the plots, and the moisture content corrected to 13%, expressed in kg.ha^{-1}.

Particle uniformity was determined using a visual scale ranging from 1 to 5, with 1 being completely heterogeneous and 5 being completely uniform. The evaluation was performed during the flowering period.

Height of plants: it was determined using a graduated ruler to measure ten plants chosen randomly from the useful area of the plots.

Percentage of whole grains: it was determined using samples of 100 g with 13% humidity, which were submitted to the processing test, for a period of one minute. Then, the polished honed grains were sort for the separation of the grains in which it was processed for thirty seconds. The grains that remained in the trieur were weighed, obtaining the yield of whole grains, expressed in percentage.

RESULTS AND DISCUSSION

Capão do leão, 2015/2016 harvest

In the table of analysis of variance (Table 3) it can be observed that in the experiment conducted in Capão do Leão, RS, Brazil, in the 2015/2016 harvest, the variables related to agronomic characteristics and yield components were not affected by the mixtures treatments of hybrid seeds with different proportions of seeds of the pollinator strain. Furthermore, it can be verified that the grain yield, also was not affected by the seed mixtures.

Productivity observed in this harvest is relatively low, compared to the productivities currently affected by irrigated rice in Rio Grande do Sul (CONAB, 2021). This fact is due to the high rainfall occurred in the months of October and November, which only allowed the sowing of the experiment on November 26. Sartori *et al.,* (2013), evaluating the sowing time of irrigated rice in Santa Maria, Rio Grande do Sul, concluded that sowing at the beginning of the recommended season, which coincides with the beginning of October, resulted in a higher grain yield because the crop develops under suitable meteorological conditions of temperature, solar radiation, and rainfall.

Also, in Table 3, it is verified that only the uniformity variable of the plot was affected by the mixtures of the hybrid seeds with seeds of the pollinator lineage. Observing Table 4, the treatment in which there is no contamination, that

Table 3. Summary of variance analysis for plant height (cm), number of plants per m^2, number of shoots per m^2, number of panicles per m^2, number of stems per plant, number of panicles per plant, length of panicles (kg.ha^{-1}), uniformity of plots (grades 1 to 5), in hybrid rice populations grown in mixtures with different proportions with self-fertilized seeds of pollinator plants, Pelotas, 2015/2016

	Medium Squares									
Treatment (% mixing)	Plant height (cm)	N° of Plants. m^{-2}	N° of Steams. m^{-2}	N° of Panicles. m^{-2}	Nº of Steams. Plant^{-1}	Nº of Panicles. Plant^{-1}	Panicle length (cm)	Nº of Panicles. Colmo^{-1}	Productivity (kg.ha^{-1})	Uniformity of plots
	11.630^{NS}	25.670^{NS}	51.910^{NS}	53.540^{NS}	0.830^{NS}	0.270^{NS}	1.150^{NS}	0.005^{NS}	149485.200^{NS}	0.510*
Average	90.20	55.00	200.00	162.00	3.70	3.10	20.90	0.81	6738.00	3.75
CV (%)	2.50	27.50	16.10	12.90	31.20	23.400	3.75	11.90	14.50	10.10

^{NS}F not significant; *F significant at 5% probability level

is, the pure hybrid, was more uniform than the other treatments submitted to contamination with the pollinator lineage. Even treatments with low levels of contamination with the pollinator strain, such as treatments with 0.75% and 1.50% parental contamination, were less uniform than the free contamination treatment, which contained only hybrid rice seeds. This result demonstrates that the material that gives rise to the hybrid, the pollinator lineage, presents a certain degree of unevenness in relation to the hybrid plants derived from it.

Observing the analysis of the variance for the variables related to the industrial quality of rice grains (Table 5), it is verified that only the whole grain yield variable was affected by the mixture with seeds of the pollinator lineage.

It is observed that there was an increase in the yield of whole grains with the highest proportion of the pollinator line in mixture with the seeds of the hybrid, mainly in the highest proportions (Table 6). This result may indicate that the pollinator lineage exhibits the characteristic of having a higher percentage of whole grains than the hybrid under study, increasing its proportion in the blend to increase the percentage of whole grains in the resulting population.

Table 4. Uniformity of plots (grades 1 to 5) in hybrid rice populations grown in mixtures with different proportions with self-fertilized seeds of pollinator plants, Capão do Leão, 2015/2016

Treatment (% mixing)	Uniformity of plots
0.00	4.4 a*
0.75	3.5 b
1.50	3.7 b
3.00	3.5 b
6.00	3.8 b
12.00	3.8 b
24.00	3.7 b
CV (%)	10.1

*Averages followed by the same letter do not differ by the Duncan test at 5% probability

Table 5. Summary of variance analysis for yield of whole grains (%), vitreous grains (%), grains up to 1/3 grains (%), grains up to 2/3 grains (%) and grains up to 3/3 grains %) in populations of hybrid rice cultivated in a mixture with different proportions with self-fertilized seeds of pollinating plants, Capão do Leão, 2015/2016

Treatment (% mixing)	Yield of integers (%)
Average	3.56*
	62.9
CV (%)	1.6

^{NS}F not significant; *F significant at 5% probability level

Table 6. Yield of whole grains (%) in hybrid rice populations grown in mixtures with different proportions with self-fertilized seeds of pollinator plants, Capão do Leão, 2015/2016

Treatment (% mixing)	Yield of integers (%)
0.00	62.0 b*
0.75	61.8 b
1.50	64.1 a
3.00	62.9 ab
6.00	62.8 ab
12.00	63.8 a
24.00	63.8 a
CV (%)	1.6

*Averages followed by the same letter do not differ by the Duncan test at 5% probability

Capão do leão, 2016/2017 harvest

In the experiment performed in Capão do Leão in the 2016/2017 harvest, the variables related to the agronomic characteristics, yield components and productivity were also not affected by the mixture in different proportions of hybrid seeds and pollinator lineage (Table 7). Furthermore, in this table it is verified that only the variables uniformity of plots and yield of whole grains were affected by the mixtures of hybrid seeds with seeds of the pollinator lineage, in this harvest.

The productivity, although not affected by the seed mixtures, was higher than the one observed in the previous harvest in Capão do Leão, due to the better environmental conditions that occurred in this harvest (Table 7), which allowed sowing at a more adequate time. In the second year of the experiment, a treatment with the pure pollinator strain was used, as well as a 50:50 ratio of the hybrid seed and the pollinator lineage. It was verified that the hybrid and pollinator lineage productivities were similar, not occurring superiority of the hybrid, as would be expected.

In Figure 1 is shown that the uniformity of the plots and the yield of whole grains showed a similar behavior trend, where the intermediate proportions of the hybrid mixture with the pollinator caused decreases in these variables. The increase in the proportion of the blend tended to reduce the uniformity.

These decreases in the uniformity show a certain degree of unevenness between the hybrid plants and the pollinator lineage plants. This behavior also occurred in the 2015/2016 harvest, although the hybrids were different.

From the results presented, it can be observed that the hybrid seed mixture with different proportions of seeds of the pollinator strain did not cause variation in agronomic characteristics, yield components and yield of irrigated rice.

Table 7. Summary of analysis of variance for plant height (cm), number of plants per m^2, number of culms per m^2, number of panicles per m^2, number of stems per plant, number of panicles per plant, length of panicles ($kg.ha^{-1}$), uniformity of plots (grades 1 to 5), in hybrid rice populations grown in a mixture with different proportions with self-fertilized seeds of pollinating plants, Capão do Leão, 2016/2017

	Medium Squares										
Treatment (% mixing)	Height of plant (cm)	Number of Plants.m^{-2}	No. of Steams.m^{-2}	No. of Panicles.m^{-2}	No. of Steams. Plant^{-1}	Nº of Panicles. Plant^{-1}	Panicle Length (cm)	Nº of Panicles. Steams^{-1}	Productivity (kg ha^{-1})	Uniformity of plots	Yield of integers (%)
	3.200^{NS}	472.310^{NS}	803.230^{NS}	2714.810^{NS}	1.680^{NS}	0.800^{NS}	0.220^{NS}	0.015^{NS}	739776.000^{NS}	0.170*	11.600*
Average	98.70	107.10	329.90	288.90	3.80	2.80	23.30	0.87	8221.70	3.80	65.20
CV (%)	1.9	20.9	10.5	14.4	29.6	27.4	3.2	9.6	9.9	6.4	2.8

NSF not significant; *F significant at 5% probability level

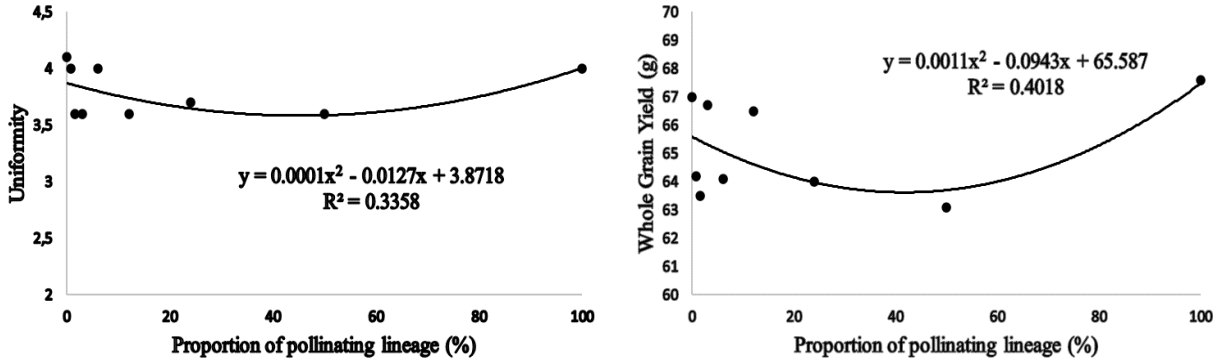

Figure 1. Uniformity of plots (A) and Yield of whole grains (B) of hybrid rice plants grown in different proportions with self-fertilized seeds of pollinating plants, Capão do Leão, 2016/2017

Although the height of plants was not affected by the mixing ratios used, and in the 2016/2017 harvest the isolated pollinator lineage did not differ from the hybrid in this characteristic, some authors commented that the plants coming from hybrid rice seeds tend to have a height higher than the pollinator strain (VIRMANI, 2002). Therefore, Silva (1999), using 36 accessions of rice, observed that the plant height character can be useful for the differentiation of cultivars.

The grain yield was not affected by the different mixing ratios of the hybrid seeds with pollinator seed in any of the two experiments. It should be considered that in the 2016/2017 harvest, the proportion of 50:50 of the hybrid and the pollinator was used, as well as a treatment with the pure pollinator. Even so, no productivity differences were observed for any of the mixtures, although the productivity levels were different, due to the environmental conditions to which the experiments were submitted. It is possible that one of the causes of these similarities of productivity is due to the productivity levels reached by the hybrid under pure stand cultivation, which did not differ from the isolated pollinator, which would not be expected in the cultivation of rice hybrids. According to some authors, a hybrid of rice may show superior productivity at levels of 15% to 20% in relation to improved high yield varieties (FAO, 2004).

Oliveira (2011), however, observed that the productivity of the INOV rice hybrid when contaminated with 10%, 20% and 30% levels of self-fertilized mother seed under different sowing densities (25, 35 and 55 kg.ha^{-1}) was reduced proportionally to the increase of the lineage known as "selfie", and this decrease of productivity was maintained at all seeding densities tested. One of the causes of this contrasting behavior, which may have contributed to the fact that productivity was not reduced by the increase in the self-fertilized seed mixture in the present study, would be because the contaminating material was the pollinator strain, which is an elite cultivar of high productivity.

Likewise, Castro *et al.* (2014), using contamination with the female parent, in a population derived from a simple corn hybrid concluded that the height of plants and ears was affected in conjunction with grain yield. However, 1% of plants from the female parent reduced the grain yield, by area, to 58.4 kg.ha^{-1}, demonstrating that for this case plants from open-pollinated seeds were less productive than plants from hybrid seeds. This fact corroborates the hypothesis that the hybrid vigor promotes a significant increase in species mainly allogamous, but which can also occur in autogamous species such as rice.

The difference in productivity observed between the 2015/2016 and 2016/2017 harvests in Capão do Leão was primarily due to the reduced plant population in the first crop, due to unfavorable environmental conditions at the time of sowing, during this harvest. This difference in plant population was reflected in the number of panicles per square meter, which was lower in that first crop, since the number of panicles per plant, although it showed a characteristic of compensation of the lower population, was not able to provide grain yield at a similar level.

In general, it is observed that the expression of hybrid vigor occurs in morphological characteristics such as vigorous root system and large tillering capacity, which ensures a large number of panicles.m^{-2}, and lower sowing rates per hectare (OLIVEIRA, 2011). In the same way, Soares *et al.* (2010) concluded that the higher tillering contributed to high yields together with a greater efficiency in the filling of grains obtained by the hybrid rice cultivar used. Medeiros (2016) found that densities above ten kilograms of seeds per hectare of the hybrid BRS AH 703 CL, are already sufficient for maximum yields, in an experiment conducted in two locations in Rio Grande do Sul.

However, the delay in sowing that occurred in the 2015/2016 harvest due to high rainfall in October, November and December 2015 (Table 3), did not allow vigorous tillering and also induced the reproductive and grain filling periods to occur in unfavorable conditions for rice cultivation (Table 3 and 4), which reflected reduced yields.

In this way, the number of panicles is a variable that can contribute significantly to the increase of productivity, since it is one of the components of the rice crop yield, including the number of panicles.m^{-2}, number of spikelets.m^{-1}, spikelet fertility and a thousand grain mass (SORATO *et al.,* 2010). According to, Mielezrski *et al.,* (2008),

number of panicles.plant^{-1} and grain yield, are closely related variables. According to Sartori (2013) the number of panicles produced may contribute to the increase in grain yield. Also, Mielezrski (2008), working with isolated plants of hybrid rice, observed a high number of panicles per plant. In this way the number of panicles per plant is a very important characteristic in hybrid rice cultivars, in which lower seeding densities are used (NEVES M., 2010).

CONCLUSIONS

- Plants derived from hybrid rice seeds do not present better yield components when compared to plant populations with mixed or total self-fertilized seeds.
- The blend of hybrid and self-fertilized seeds provides greater unevenness in equivalent proportions.
- The industrial quality of grains originated from hybrid rice seeds presents similar quality to self-fertilized plant grains.

AUTHORSHIP CONTRIBUTION STATEMENT

EBERHARDT, P.E.R.: Data curation, Formal Analysis, Investigation, Writing – original draft, Writing – review & editing; **SCHUCH, L.O.B.:** Project administration, Supervision, Visualization, Writing – original draft, Writing – review & editing; **MONDO, V.V.:** Conceptualization, Funding acquisition, Project administration, Supervision, Visualization; **FRANCO, D.F.:** Conceptualization, Funding acquisition, Project administration, Supervision, Visualization; **MEDEIROS, L.R.:** Formal Analysis, Investigation; **RADKE, A.K.:** Data curation, Investigation.

DECLARATION OF INTERESTS

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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