Bulgarian Journal of Agricultural Science, 32 (No 5) 2026, 1075–1084

DOI: https://doi.org/10.61308/GXSP9223

Feasibility of early sowing of irrigated rice based on the choice of cultivar

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Abstract

Martins-Júnior, M. C., Sangoi, L. & Souza, C. A. (2026). Feasibility of early sowing of irrigated rice based on the choice of cultivar. *Bulg. J. Agric. Sci., 32*(5), 1075–1084

The early sowing of irrigated rice at the end of winter reduces plant growth and yield due to low water and air temperatures. This work aimed to assess the response of different rice cultivars to the early sowing time in the southern region of Brazil, and to determine the viability of this management practice. The experiment was set in a randomized block design, arranged in split plots at a latitude of approximately 29°11′ S and an altitude below 50 m. Two sowing dates were tested in the main plots: September 01 (early sowing date) and October 15 (preferential sowing date). Four cultivars were evaluated in the subplots: IRGA 424 RI, SCS116 Satoru, SCS 121CL and SCS122 Miura. The experiments were conducted over two growing seasons (2020/21 and 2021/22), using the pre-germinated system. Plant stand, grain yield, and yield components were determined. The early sowing date reduced plant stands at both growing seasons. Grain yield ranged from 7856 to 10213 kg/ha in 2020/21 and 9320 to 11114 kg/ha in 2021/22 season. Considering the average of cultivars, differences in yield obtained in the early sowing date, when compared with the preferential sowing date, were 11 kg/ha and 324 kg/ha, in the first and second growing season, respectively. SCS 116 Satoru was the only cultivar that did not show a reduction in grain yield when sown in September compared with October. The correct choice of cultivar is a management practice that can enable the early sowing of rice at the end of winter in the South of Brazil.

Keywords: rice; sowing dates; variety; phenology; yield

Introduction

Irrigated rice plays an important socioeconomic role in the states of Rio Grande do Sul and Santa Catarina. These two states are responsible for approximately 80% of Brazilian rice production (Conab, 2025). Santa Catarina is the second largest national rice producer. In the 2024/25 season, 146.6 thousand hectares were cultivated, with a productivity around 8374 kg/ha (Conab, 2025). The producing region in the extreme south of Santa Catarina (Araranguá microregion) stands out in the state. It accounted for 41% of the cultivated area in the 2024/25 season, reaching a productivity of 8602 kg/ha (Conab, 2025).

In recent years, there has been a trend towards bringing forward the sowing of irrigated rice in the south of the state of Santa Catarina to the end of the winter period (second half of August to first half of September). One of the reasons justifying this practice was the increase in the area cultivated per farmer. There was a 26% increase when compared to the period from 2006 to 2017. This was due to the increase in land leasing, which, in this period, increased from 13% to 60% of the area under leasing (Santa Catarina, 2023). The increase in cultivated area makes greater staggering of the sowing season necessary. Other factors that encourage early sowing are the need for staggering due to lack of water to irrigate crops, the expectation of obtaining better prices when selling the crop due to the harvest prior to the period of greatest grain availability, and the cultivation of rice regrowth (Ferrari et al., 2018).

Early sowing until the end of winter is a solution that farmers in Santa Catarina have found to increase the prof-

itability of their crops. However, this management strategy can generate some drawbacks. Among them are reductions in plant stand, tillering, leaf area, plant height, and increased pest and disease incidence associated with an increase in phyllochron (Grohs et al., 2022). All these problems are caused by the greater occurrence of air temperatures below 15°C, and the persistence of these temperatures for a longer period when compared to sowing at the preferred time during spring (Grohs et al., 2022).

To alleviate the problems caused by early rice sowing, there are some management strategies that can be implemented. One of them is the choice of cultivar, since different cultivars are adapted to different environments and present different responses to the thermal conditions of the environment (Mahdavi et al., 2025; Pachecoy et al., 2014). A field assay carried out by Wang et al. (2024) and Mahdavi et al. (2025) detected differences in tolerance to this environmental condition.

This work had two main objectives: a) to evaluate the response of cultivars to early sowing of irrigated rice at the end of the winter period in the southern region of Brazil; b) to identify the best cultivar for early sowing in southern Brazil.

Materials and Methods

Study site and cultivars

The experiment was conducted in the municipality of Praia Grande, SC, Brazil, which is located in the South Coast rice-producing region of Santa Catarina. The climate in the region is classified as Cfa (subtropical climate with hot summer) according to the classification described by Kottek et al. (2006). The characteristics of the soil at the experimental site are described in Table 1.

In the 2020/21 growing season, two sowing dates were tested in the main plot: September 01, 2020 (early season) and October 15, 2020 (preferred season). Four cultivars were evaluated in the subplots: IRGA 424 RI, SCS116 SATORU, SCS 121CL and SCS122 MIURA. In the 2021/22 growing season, in the main plot, sowing occurred on September 01, 2021 (early season) and October 15, 2021 (preferred season). Three cultivars were tested in the subplots: SCS116 SATORU, SCS 121CL and SCS122 MIURA (due to seed availability). To choose the cultivars, the information contained in the technical recommendations for irrigated rice cultivation (Sosbai, 2022) was taken into account, in addition to prior consultation with breeders from IRGA and Epagri, so that they could indicate the genotypes with the greatest potential for success in the work.

Cultivation technology

The study was carried out using a pre-germinated rice system under field conditions. Sowing was carried out, in a water depth of approximately 5 cm, with pre-germinated seeds. The seed density was 120 kg/ha, following the recommendations of Sosbai (2022). Certified seeds of all cultivars with a germination higher than 90% were used. Phosphate fertilization was applied 10 days after sowing, when the plants were at the V2 stage (Counce et al., 2000). A total of 70 kg/ha as equivalent of P_2O_5 was applied, with triple superphosphate as the source. Potassium fertilization was split into two applications, with 50% of the dose applied at V3–V4 and 50% at R0 (floral primordium differentiation). A total of 105 kg/ha of K_2O was applied, with potassium chloride as the source. The phosphorus and potassium doses were defined based on the results of the soil analysis carried out in June 2020, aiming for a grain productivity of 10 t/ha, following the recommendations of CQFS RS/SC (2016) for Rio Grande do Sul and Santa Catarina states.

In both seasons, 150 kg/ha N were applied. Nitrogen was applied as a top dressing at stages V3-V4 and R0 for the medium-cycle cultivar (IRGA 424 RI) and at stages V3-V4, V8-V9 and R0 for the long-cycle cultivars (SCS116 SATORU, SCS 121CL and SCS122 MIURA). The N source used was urea.

Pest, disease and weed control was carried out in accordance with Brazilian Guide for irrigated rice (Sosbai 2022). For weed control, the herbicide florpyrauxifen-benzyl (Loyant®) was applied at a rate of 0.8 L/ha. For pest control, thiamethoxam (Actara®) was applied at a rate of 150 g/ha and cypermethrin (Cipermetrina®) at a rate of 60 mL/ha. For preventive disease control, two scheduled fungicide applications were carried out. The first was done at stage R2 before

Table 1. Results of soil analysis carried out prior to the implementation of the experiments in the 2020/21 and 2021/22 growing seasons

Season	Clay	pH		OM *	P	K	Ca^{2+}	Mg^{2+}	Al^{3+}
	%	H_2O	SMP	%	---mg/dm^3---		------ cmolc/dm^3 ------		
2020/21	29	5.4	5.5	2.5	4.0	108.5	4.6	2.4	0.4
2021/22	29	5.2	4.8	2.5	5.1	85.7	2.9	1.0	2.4

*OM: Organic matter; SMP: Shoemaker, McLean and Pratt method, $P_{Mehlich-1}$ and $K_{Mehlich-1}$; Ca^{2+}, Mg^{2+} and Al^{3+} were extracted with KCl 1 mol/L.

Source: Authors' own elaboration

panicle extrusion and the second application 15 days later. In the first application, the fungicides trifloxystrobin + tebuconazole (Nativo®; dose of 0.75 l/ha) were applied, together with tricyclazole (Bim® dose of 0.3 kg/ha) and addition of mineral oil adjuvant at a proportion of 0.5% on the spray volume. In the second application, the fungicides epoxiconazole + cresoxim-methyl (Brio®; dose of 1.0 l/ha), associated with the fungicide tricyclazole (Bim®; dose of 0.3 kg/ha), and addition of mineral oil adjuvant at a proportion of 0.5% on the spray volume. The volume of spray used was 150 l/ha.

Crop phenology was evaluated using the scale proposed by Counce et al. (2000). The dates on which the following phenological stages occurred were determined: beginning of tillering (V4), differentiation of floral primordium (R0), full flowering (R4) and harvest maturity (R9).

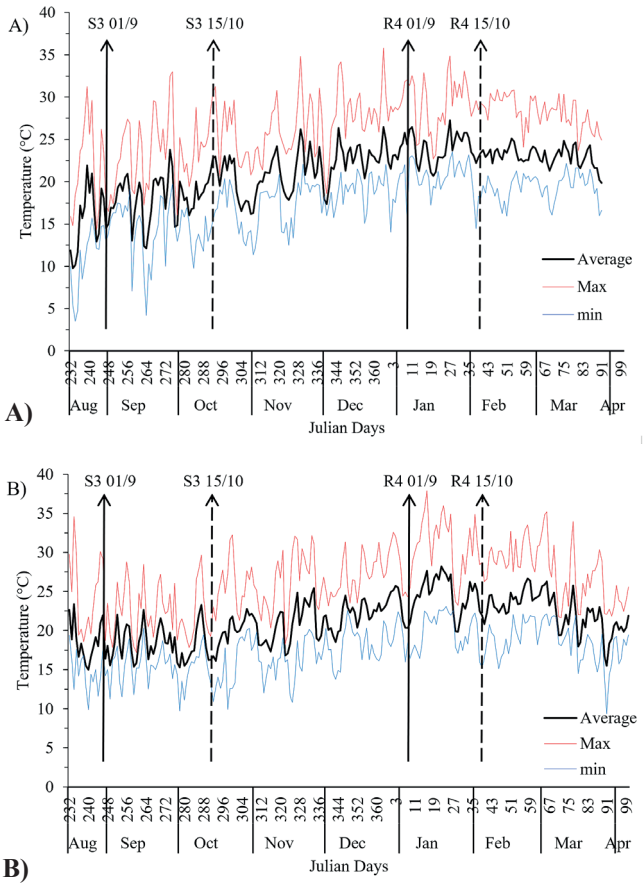


Fig. 1. Average, maximum and minimum air temperatures from: A) August 20th to April 10th in the 2020/21 and B) August 20th to April 10th in the 2021/22 growing seasons in the municipality of Praia Grande, Santa Catarina, Brazil

Vertical arrows indicate critical development stages at two sowing dates for irrigated rice according to the scale of Counce et al. (2000).

Source: Authors' own elaboration

Climatic conditions

The meteorological data used were from INMET's Meteorological Station of Praia Grande – SC, Brazil located at 29°11′49″ S latitude, longitude 49º57′09″ west and altitude of 45 m. Figures 1A and 1B describe the maximum, minimum and average air temperatures for the municipality of Praia Grande, SC, in the 2020/21 and 2021/22 growing seasons, respectively.

Comparing the two growing seasons, the thermal amplitude was similar, with the 2020/21 season having lower minimum temperatures (3°C) when compared to the 2021/22 season (9°C). However, when comparing the persistence of these temperatures, it is possible to observe that in the 2021/22 season, minimum temperatures close to 10°C occurred until the second half of November, while in the 2020/21 season these temperatures occurred until the second half of October.

When comparing the information shown in Fig. 1A and 1B, it can be observed that there was a greater thermal amplitude in early sowing than when irrigated rice was sown at the recommended time. In this sense, the amplitude was between 10 and 35°C in the second season and between 3 and 35°C in the first, demonstrating inadequate thermal conditions for rice cultivation in both growing seasons. Comparing the thermal variations recorded in the two growing seasons when the crop was planted at the recommended time (Figure 1A and 1B), it is possible to observe that there were few episodes with a minimum temperature close to 10°C in the initial phase of crop development and that they were more frequent in the 2021/22 season. The maximum temperature recorded in the second season was also higher (38°C), when compared to the first season (35°C). The minimum temperatures in the two growing seasons were 11°C and 10°C, respectively.

Traits evaluated

Plant stand was determined when the crop was at the V2-V3 stage (two to three expanded leaves on the main stem), according to the scale of Counce et al. (2000). This evaluation was carried out in an area of 0.25 m², delimited by a square of 0.5 m × 0.5 m, randomly arranged in each subplot, consisting of three replicates per subplot.

The number of panicles was determined by counting the number of panicles/m² in an area of 0.25 m², in three replicates per subplot. This was done on the harvest day of each experiment. To determine grain yield, an area of 2 m² delimited by a rectangle measuring 2 m × 1 m was harvested, randomly arranged in the subplots, respecting a minimum

border of 0.5 m from the ends of the plot. At the time of the growing season, 20 panicles were randomly removed from each subplot to determine the number of grains/panicle, number of sterile grains/panicle and thousand-grain weight. This procedure was based on previous work (Martins-Júnior, 2020).

Statistical analysis

The data were subjected to analysis of variance using the F test. The F values for the main effects and interactions were considered significant at the 5% significance level ($P < 0.05$). When significant, the means were compared using Tukey's test ($P < 0.05$), using the Assistat statistical software (Silva and Azevedo, 2002).

Results and Discussion

There were differences in the date of some important phenological stages, such as differentiation of the floral primordium, full flowering and harvest maturity. These differences occurred due to the variation in the sowing date, the cultivar cycle and the growing season. When analyzing the harvest date in the 2020/21 growing season, with the 45-day advancement of the sowing date, harvest was advanced by 22 days for the IRGA 424 RI cultivar and 28 days for the Epagri cultivars. In the 2021/22 growing season, the difference in harvest dates between sowing seasons was greater (31 days) for the Epagri cultivars (Table 2).

Bringing sowing forward 45 days to the preferred time demonstrated that the lower temperatures recorded at the beginning of crop development reduce the difference in harvest advance. Analyzing the 2020/21 season, with the early sowing to the beginning of September, the harvest was brought forward by just 22 days for the IRGA 424 RI cultivar and 28 days for the long-cycle Epagri cultivars. In the 2021/22 season, the harvest was brought forward by 31 days. Similar harvest dates can be achieved by using medium- or early-cycle cultivars sown at the preferred time. This demonstrates that it is possible to harvest earlier without bringing forward sowing and subjecting the crop to climatic conditions that are unfavorable to crop development.

Early sowing of irrigated rice is limited by thermal constraints. The most important of these is the incidence of temperatures below 15°C, at sowing and at the beginning of seedling development (Pachecoy et al., 2014). Just as low temperatures affect the initial development of plants, values above 30°C that coincide with crop flowering are also detrimental (Li et al., 2023).

Early sowing to early September significantly reduced the plant stand, in relation to that obtained at the preferred time, in both growing seasons (Table 3). This reduction was mainly caused by the occurrence of air temperatures below 15°C, which are very common at this time of year in the region, as can be seen in Figures 1A and 1B.

According to Sosbai (2022), the ideal plant stand for an irrigated rice crop range from 150 to 300 plants/m^2. There were no significant differences ($P>0.05$) between cultivars regarding plant stand in the early sowing of the first crop, and only SCS 121 CL achieved a number of emerged plants greater than 200. In the October 15 sowing, all evaluated cultivars had more than 200 emerged plants/m^2. In both sowing seasons, the cultivar SCS 116 Satoru had the lowest numerical plant stand values.

In the 2021/22 season, a stand above 200 pl/m^2 was obtained in early sowing, reaching 247 pl/m^2, on average for cultivars. For the preferred season, there was an increase

Table 2. Sowing dates (S3), beginning of tillering (V4), differentiation of the floral primordium (R0), full flowering (R4) and harvest (R9) of four cultivars of irrigated rice in two sowing seasons and two different growing seasons

Cultivar	2020/21 season					2021/22 season				
	S3[1]	V4	R0	R4	R9	S3	V4	R0	R4	R9
	Early sowing date (September, 01)									
IRGA 424 RI	01/09	05/10	14/11	15/12	04/02	--	--	--	--	--
SCS 116 Satoru	01/09	05/10	26/11	05/01	26/02	01/09	06/10	23/11	05/01	19/02
SCS 121 CL	01/09	05/10	26/11	05/01	26/02	01/09	06/10	23/11	05/01	19/02
SCS 122 Miura	01/09	05/10	26/11	09/01	26/02	01/09	06/10	23/11	05/01	19/02
	Preferential sowing date (October, 15)									
IRGA 424 RI	15/10	05/11	13/12	10/01	26/02	--	--	--	--	--
SCS 116 Satoru	15/10	05/11	26/12	04/02	25/03	15/10	05/11	22/12	04/02	22/03
SCS 121 CL	15/10	05/11	26/12	04/02	25/03	15/10	05/11	22/12	04/02	22/03
SCS 122 Miura	15/10	05/11	26/12	04/02	25/03	15/10	05/11	22/12	04/02	22/03

[1]According to Counce codes (Counce et al., 2000).

Source: Authors' own elaboration

Table 3. Plant stand (pl/m²) of irrigated rice cultivars, in two sowing dates, in the 2020/21 and 2021/22 growing seasons

Cultivar	Sowing time			
	01/09	15/10	average	CV (%)
	2020/21 season			
	----------n°----------			
Irga 424 RI	161 aB	428 aA	294	17.17
SCS 116 Satoru	132 aB	217 cA	174	
SCS 121CL	208 aB	387 abA	297	
SCS 122 Miura	160 aB	296 bcA	228	
Average	165	345		
CV (%)	10.85			
	2021/22 season			
SCS 116 Satoru	249 ns	424	337	17.22
SCS 121CL	245	393	319	
SCS 122 Miura	245	349	297	
Average	247 B	389 A		
CV (%)	10,14			

[1/]Means followed by the same lowercase letter in the column and uppercase letter in the row do not differ statistically from each other by the Tukey test ($P < 0.05$). NS: Not significant ($P > 0.05$). CV: coefficient of variation. For the 2021/22 season, the IRGA 424RI cultivar was not analyzed due to lack of seeds.

Source: Authors' own elaboration

in the plant stand to 389 pl/m². In both sowing seasons, the number of emerging plants was higher in preferred season than in the early sowing. This increase in the plant population was mainly due to differences in atmospheric temperature. In the early sowing, it was 13°C on average in September and 16°C in October. In the second growing season, it was 15°C on average in September and 17°C in October (Figures 1A and 1B). The higher air temperatures in the second growing season directly affected the soil temperature, favoring plant emergence. According to Grohs et al. (2022), a significant reduction in plant stand and emergence rate in irrigated rice sown in September, as temperatures below 15°C delay germination and reduce the emergence percentage (Mertz et al., 2009).

According to the agroclimatic zoning for the rice cultivars used in the 2020/21 growing season in Praia Grande, SC, the optimal sowing period is between September 11 and November 20. Sowings prior to this period are more likely to suffer cold damage to the leaf area and tillering during the beginning of seedling development (Brasil, 2021). In the rice pre-germinated cultivation system, the water temperature has a greater influence on the plants than the air temperature, and temperatures below 20°C can harm the initial formation of the seedlings, reducing the plant stand and, subsequently, its tillering (Marschalek et al., 2023a; Sosbai, 2022). In the 2020/21 season, considering the presence of minimum temperatures below 15°C from sowing to the R0 stage, 30 episodes were observed in the IRGA 424 RI cultivar and 33 episodes in the Epagri cultivars (SCS 116 Satoru, SCS 121CL and SCS 122 Miura), with early sowing. With sowing at the preferred time, this number was only 15 episodes for all cultivars. In the 2021/22 season, the number of episodes of temperatures below 15°C was 27 for early sowing and 22 for preferential sowing. These data help to understand the reduction in plant stands in both seasons, demonstrating that early sowing of irrigated rice increases the probability of unfavorable conditions during the initial development of the plants.

In the 2020/21 season, the cultivar IRGA 421 RI reduced the number of panicles/m² when sown at the preferred time. The cultivars SCS 121CL and SCS 122 Miura presented a higher number of panicles/m² at the preferred time. In the 2021/22 season, there was no significant effect of the sowing time on the number of panicles/m² produced by the cultivars (Table 4). Higher values of this yield component were found by Marschalek et al. (2023a and 2023b), where the cultivar SCS 116 Satoru, which produced 920 panicles/m² and the cultivar SCS 122 Miura showed 724 panicles/m², when it's sown at the preferred time (October 24, 2019). These differences are linked to local environmental characteristics and sowing time.

The absence of a restrictive effect of early sowing on the number of panicles produced by the IRGA 424 RI and SCS116 Satoru cultivars in the 2020/21 season and by all three cultivars in the 2021/22 season shows that these cultivars may have plasticity mechanisms to overcome the adversities caused by early sowing. Alternatives to compensate for stand losses include the production and survival of tillers

Table 4. Number of panicles/m² of irrigated rice cultivars, in two sowing dates, in the 2020/21 and 2021/22 growing seasons

Cultivar	Sowing time			
	01/09	15/10	average	CV (%)
	2020/21 season			
	----------n°----------			
Irga 424 RI	592 aA	439 aB	515	11.44
SCS 116 Satoru	447 bA	503 aA	475	
SCS 121CL	385 bB	525 aA	455	
SCS 122 Miura	409 bB	504 aA	457	
average	465	469		
CV (%)	4.98			
	2021/22 season			
SCS 116 Satoru	485 ns	493	489	5.13
SCS 121CL	496	491	494	
SCS 122 Miura	474	510	492	
average	485	498		
CV (%)	3.77			

[1]/Means followed by the same lowercase letter in the column and uppercase letter in the row do not differ statistically from each other by the Tukey test ($P < 0.05$). NS: Not significant ($P > 0.05$). CV: coefficient of variation. For the 2021/22 season, the IRGA 424RI cultivar was not analyzed due to lack of seeds. *Source*: Authors' own elaboration

and the increase in the number of grains/panicle (Huang et al., 2023). This situation was observed by Martins-Júnior et al. (2021), who did not detect significant differences in the number of panicles/m² as a function of early sowing to September 10.

The greater number of panicles/m² produced by IRGA 424 RI in the early season demonstrates the great plasticity of this cultivar in overcoming abiotic stress caused by low temperatures. This behavior may be linked to the high tillering capacity of this genotype, which confers a greater capacity for closing the area and gives it a longer flowering period, helping with productive stability. According to Sosbai (2022) and Zhu et al. (2023), in conventional cultivars the ideal is to have 500 to 600 panicles/m² to achieve high grain yields. In general, the values of this yield component recorded in the experiment (Table 4) were lower than this reference, being reached mainly in the preferential sowing season.

In the 2020/21 season, there was an increase in the number of grains/panicle of the Irga 424 RI cultivar from early sowing to preferential sowing, while the opposite behavior was observed for the Epagri cultivars, with a reduction in the number of grains/ panicle (Table 5).

The period that defines the number of grains/panicle is between the R0 stage (floral primordium differentiation) and R4 (anthesis) according to the Counce et al. (2000) scale. The optimal temperatures for these periods are 25 to 30°C and 25 to 28°C, respectively (Streck et al., 2007). From the R0 stage onwards, temperatures below 17°C for a recurring period of five days can reduce the number of spikelets/panicle (Brasil, 2021). With these reductions, there is a lower number of grains/panicle. If the stress condition extends until closer to flowering, there is an increase in spikelet sterility.

Comparing the flowering dates of the Irga cultivar and the Epagri cultivars in the early season, there is a difference of 20 days, while in the preferential sowing the period was 25 days. The main difference in temperatures is the number of episodes with temperatures less than or equal to 17°C, where for the Irga 424 RI cultivar in the early sowing it was 13 episodes, and for the Epagri cultivars it was 9 episodes. Another important factor is also the absolute minimum temperature which for the IRGA cultivar was 12°C during the period and for the Epagri cultivars it was 14°C. These data indicate that early sowing to the beginning of September can favor the increase in the number of grains/panicle in long-cycle cultivars (Grohs et al., 2022). In the 2021/22 season, an increase in the number of grains/panicle was observed with the early sowing (105) in relation to the preferred period (86). This condition was also observed in the 2020/21 season in the Epagri cultivars, where the preferred period presented approximately 89 grains and the early period, approximately 101 grains. Observing the average maximum temperatures between the R0 and R4 stages, which comprise the panicle development period, for the early period the temperature was 27°C and for the preferred period the temperature was 30°C, considering that the optimum temperature for this period is 25 to 30°C at the R0 stage and 25 to 28°C at the R4 stage (Streck et al., 2007). Thus, it is pos-

Table 5. Number of grains per panicle of irrigated rice cultivars, in two sowing dates, in the 2020/21 and 2021/22 growing seasons

Cultivar	Sowing date			
	01/09	15/10	average	CV (%)
	2020/21 season			
	----------n°----------			
Irga 424 RI	84 bB	114 aA	99	6.80
SCS 116 Satoru	97 abA	82 bB	90	
SCS 121CL	98 abA	92 bA	95	
SCS 122 Miura	109 aA	93 bB	101	
average	95	98		
CV (%)	3.35			
	2021/22 season			
SCS 116 Satoru	111 [ns]	87	99	8.84
SCS 121CL	101	76	88	
SCS 122 Miura	103	95	99	
average	105 a	86 b		
CV (%)	5.63			

[1/]Means followed by the same lowercase letter in the column and uppercase letter in the row do not differ statistically from each other by the Tukey test ($P < 0.05$). NS: Not significant ($P > 0.05$). CV: coefficient of variation. For the 2021/22 season, the IRGA 424RI cultivar was not analyzed due to lack of seeds.
Source: Authors' own elaboration

sible to infer that the early sowing provided better temperatures during the period of panicle formation and pollination/fertilization of spikelets, generating more grains/panicle for long-cycle cultivars in both years.

The cultivars showed significant differences ($P < 0.05$) in spikelet sterility only in the first growing season, ranging from 8.4% for SCS 121CL to 17.8% in IRGA 424 RI (Table 6).

Table 6. Spikelet sterility (SS) and thousand grain weight (TGW) in two sowing dates and different irrigated rice cultivars, in the 2020/21 and 2021/22 growing seasons

	Traits/season			
	2020/21 season		2021/22 season	
Sowing date	SS (%)	TGW (g)	SS (%)	TGW (g)
01/09	15.4 a	28.9 b	11.3 ns	29.9 ns
15/10	11.3 b	30.2 a	12.4	29.7
CV (%)	11.53	1.67	20.91	2.90
Cultivar				
	2020/21 season		2021/22 season	
Irga 424RI	17.8 a	25.1 c	- -	- -
SCS 116 Satoru	13.2 ab	31.4 a	12.9 ns	29.9 ab
SCS 121CL	8.4 b	32.2 a	10.1	30.6 a
SCS 122 Miura	14.2 a	29.5 b	12.5	28.9 b
CV (%)	22.93	2.81	15.25	2.09

[1/]Means followed by the same lowercase letter in the column do not differ statistically from each other by the Tukey test ($P < 0.05$). NS: Not significant ($P > 0.05$). CV: coefficient of variation. For the 2021/22 season, the IRGA 424RI cultivar was not analyzed due to lack of seeds.
Source: Authors' own elaboration

These values are within the range reported for cultivars grown in Rio Grande do Sul, which according to Cruz et al. (2007) can vary from 15 to 25%. For the second season (2021/22), there were no significant differences ($P > 0.05$). Numerically, sterility ranged from 10.1% in the SCS 121CL cultivar to 12.9% in SCS 116 Satoru. Spikelet sterility is linked to abiotic stress conditions during flowering and pre-flowering, in addition to the presence of pests and diseases at the beginning of grain filling (Chen et al., 2024). In the present experiment, it was more closely associated with high- and low-temperature conditions during flowering, in addition to genetic factors of each cultivar. Stürmer et al. (2019) reported spikelet sterility values ranging from 9.3% to 63.6% according to the genotype analyzed, with emphasis on the cultivars SCS 121CL and SCS 122 Miura with 17.3%, demonstrating that spikelet sterility varies according to the genotype and environmental condition. These values differed from those found in the present study, which were lower for SCS 121CL (9.9% under early sowing) but higher for SCS 122 Miura (18.3% under the same conditions). For SCS 121 CL, the values found in this study were lower than those obtained by Verdi et al. (2020) in field conditions with late sowing, which were between 13 and 17%.

Early sowing reduced the 1000-grain weight from 30.2 g in the preferred season to 28.9 g in the September 01 season in the first harvest (Table 6). In the same growing season, unlike the TGW, sterility increased with early sowing, with values of 15.4% and 11.3% of sterile spikelets in the early

and preferred seasons, respectively. The Epagri cultivars also produced heavier grains than the IRGA cultivar in the first evaluation harvest. For the 2021/22 growing season, there was a difference between the 1000-grain weight for the SCS 121CL cultivar (30.6 g) and the SCS 122 Miura cultivar (28.9 g).

Grain yield ranged from 7856 to 10213 kg/ha in the 2020/21 growing season (Table 7). Considering the average of the four cultivars, it was 9294 kg/ha in early sowing and 9 305 kg/ha in the preferred period.

In the first growing season (2021/22), there was no decrease in grain yield of any of the four cultivars with early sowing. For the September 1 sowing, the highest yields were obtained with cultivars SCS 122 Miura (9950 kg/ha) and SCS 121CL (9600 kg/ha), not differing statistically from cultivar SCS 116 Satoru (9258 kg/ha). These results indicate a potential trend of these cultivars for use in early sowing, evidencing that the correct choice of cultivar by the producer is an adequate strategy to make this cultural practice viable.

In the second growing season (2021/22), the grain yield obtained in the experiment ranged from 9320 kg/ha to 11114 kg/ha (Table 7). The two extremes of productivity were obtained with early sowing (September 01), with the highest yield obtained by SCS 116 Satoru (11114 kg/ha) and the lowest by SCS 121CL (9320 kg/ha). In this second season, it was observed that early sowing can be beneficial, depending on the cultivar. In early sowing (September 01), the grain yield range among the three cultivars was 1794 kg/ha, while in the preferred period the range was only 332 kg/ha. In the preferred period (October 15), the cultivars did not differ from each other.

Considering the average of the cultivars, the differences in grain yield between the sowing carried out on September 1 and October 15 were 11 kg/ha in the 2020/21 season and 324 kg/ha in the 2021/22 season. Analyzing the two years of cultivation, it is noted that the cultivar SCS116 Satoru demonstrated potential for use in early sowing. In the 2020/21 season, it produced below the productive potential of 9.4 t/ha (9258 kg/ha) (Epagri, 2022), but did not differ from the other cultivars. In the 2021/22 season, it produced above 9.4 t/ha (11114 kg/ha), being superior to the others. In both growing seasons, this cultivar did not show a decrease in grain yield with early sowing on September 1, in relation to the preferred time (October 15). The maintenance of grain yield in early sowing, despite the large loss in plant stand (Table 3), is linked to the high plasticity of rice cultivars. This characteristic is emphasized by the high tillering capacity of current cultivars. However, the greater survival of tillers generated an increase in panicle formation, and the difference in the number of panicles in both periods was small in both crop seasons (Table 4). Martins-Júnior et al. (2021) reported that the number of panicles/m^2 was not affected by early sowing. This fact, combined with the greater number of grains produced per panicle (Table 5), contributed to the long-cycle SCS116 Satoru cultivar, resulting in grain yields similar to or higher than those obtained in the preferred period. The other long-cycle cultivars presented similar results only in the 2020/21 season, while in the 2021/22 season, the culti-

Table 7. Grain yield (kg/ha) of irrigated rice cultivars in two sowing dates and in two growing seasons

Cultivar	Sowing date			
	01/09	15/10	average	CV (%)
	2020/21 season			
	----------kg/ha----------			
Irga 424 RI	8369 bA	7856 cA	8112	4.00
SCS 116 Satoru	9258 abA	10213 aA	9735	
SCS 121CL	9600 aA	9133 bA	9366	
SCS 122 Miura	9950 aA	10019 abA	9985	
average	9294	9305		
CV (%)	4.06			
	2021/22 season			
SCS 116 Satoru	11114 aA	10368 aB	10741	2.27
SCS 121CL	9320 cB	10517 aA	9918	
SCS 122 Miura	10178 bB	10700 aA	10439	
average	10204	10528		
CV (%)	1.28			

[1]Means followed by the same lowercase letter in the column and uppercase letter in the row do not differ statistically from each other by the Tukey test ($P < 0.05$). NS: Not significant ($P > 0.05$). CV: coefficient of variation. For the 2021/22 season, the IRGA 424RI cultivar was not analyzed due to lack of seeds.
Source: Authors' own elaboration

vars SCS 121CL and SCS 122 Miura had lower productive performance when subjected to early sowing. Grohs et al. (2022), using the long-cycle cultivar Epagri 108, concluded that long-cycle cultivars benefit from early sowing, demonstrating that the best sowing period for these genotypes is from September 15 to October 10 under the environmental conditions of Santa Catarina.

The Epagri cultivars were more productive than the Irga cultivar in both sowing seasons of the first harvest. This is initially linked to the cycle of the IRGA cultivar being shorter than that of the Epagri cultivars (long-cycles), with sensitive developmental stages coinciding with periods of unfavorable temperatures, mainly due to adverse temperatures in the microsporogenesis and anthesis phases (Stinghen, 2015). Temperatures below 17°C in the microsporogenesis phase compromise the formation and viability of pollen grains, directly affecting grain yield (Cruz and Millach, 2000).

Observing a period of five days prior to flowering (R4), it is possible to detect several episodes of temperatures below 17°C and above 30°C (Figure 1A and 1B). However, analyzing the data and temperatures, it is possible to deduce that what most affected the Irga 424 RI cultivar in early sowing was the thermal amplitude from 34°C to 17°C (Δ = 17°C) and from 29°C to 14°C (Δ = 17°C) in preferential sowing. For long-cycle cultivars, the amplitude varied from 32°C to 15°C (Δ = 17°C) in early sowing and from 33°C to 20°C (Δ = 13°C). Stürmer et al. (2019) and Souza (2020) demonstrated that cultivars respond differently to specific episodes of cold and heat in the pre-flowering and during the flowering stages.

Conclusions

Taken together, the results indicate that early sowing of irrigated rice to the beginning of September reduced the plant stand of all cultivars but had a relatively small impact on grain yield, because of cultivar plasticity and high effective tillering capacity.

The cultivar SCS116 Satoru stood out from the others because its grain yield did not decrease under early sowing compared with the preferred sowing date in either year, in relation to the preferred time, in both years of cultivation.

The results provide valuable information for cultivar selection, which can enable early sowing of irrigated rice at approximately 29°11′ S and at an altitude below 50 m.

Acknowledgements

The authors would like to thank CNPq, CAPES, FAPESC/UDESC/PAP, UDESC/PIC, UDESC/PROMOP and UNIEDU/FUMDES, for their financial support of this study and the scholarships granted to the authors.

Author contributions

Marcos Cardoso Martins-Júnior and Luís Sangoi planned the experiments; Marcos Cardoso Martins-Júnior, Luís Sangoi and Clovis Arruda Souza interpreted the results and wrote the manuscript; and Marcos Cardoso Martins-Júnior and Luís Sangoi performed the statistical analyses and prepared the illustrations.

Conflict of interest

All authors declare no conflict of interest.

Data availability

Data presented in this study are available from the corresponding author upon reasonable request.

Ethics approval

Not applicable to this paper.

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Received: **April, 23, 2025**; *Approved*: **May, 27, 2025**; *Published*: **October, 2026**