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Influence of sowing time on the performance of soybean cultivars grown in contrasting environments

Abstract – The objective of this work was to evaluate the effect of different sowing times and cultivars on the expression of yield components of soybean grown in contrasting environments. Three experiments were carried out in two environments. In Condor, RS, Brazil, experiments were established in the 2018/2019 and 2022/2023 growing seasons, at two sowing times: November 8 and 25, in 2018/2019; and November 5 and 25, in 2022/2023. The evaluated cultivars were 53I54RSF IPRO, 6563RSF IPRO, and 5958RSF IPRO. In São Borja, RS, Brazil, the 2022/2023 experiment included the cultivars 57I52RSF IPRO, 55I57RSF IPRO, 6101XTD, O590 I2X, 5995I2X, and 64I61RSF IPRO. Variables were grouped as follows: plant stature (plant height, and first pod insertion height); plant architecture (fertile nodes and branches); pod distribution by grain number (on main stem and branches); grain yield; and thousand-grain weight. Data were subjected to the analysis of variance and to the Tukey's test at 5% significance. In Condor, the sowing in the first half of November was more favorable under good weather (2018/2019), while the sowing in the second half of that month was better under adverse conditions (2022/2023). In São Borja, the 6101XTD cultivar showed the highest grain yield in 2022/2023, standing out under extreme drought conditions.

Index terms: *Glycine max,* agronomic characters, drought tolerance, grain yield.

Influência da época de semeadura sobre o desempenho de cultivares de soja cultivadas em ambientes contrastantes

Resumo – O objetivo deste trabalho foi avaliar o efeito de diferentes épocas de semeadura e cultivares sobre a expressão dos componentes de produtividade da soja cultivada em ambientes contrastantes. Três experimentos foram realizados em dois ambientes. Em Condor, RS, os experimentos foram realizados em duas safras e duas épocas de semeaduras: na safra de 2018/2019, em 8 e 25 de novembro; e na safra de 2022/2023, em 5 e 25 de novembro. As cultivares avaliadas foram 53I54RSF IPRO, 6563RSF IPRO e 5958RSF IPRO. Em São Borja, RS, o experimento de 2022/2023 incluiu as cultivares 57I52RSF IPRO, 55I57RSF IPRO, 6101XTD, O590 I2X, 5995I2X e 64I61RSF IPRO. As variáveis foram agrupadas conforme a seguir: estatura de planta (altura da planta e altura de inserção da primeira vagem); arquitetura de planta (nós férteis e ramos), distribuição de vagens por número de grãos (no caule principal e nos ramos), rendimento de grãos e massa de mil grãos. Os dados foram submetidos à análise de variância e ao teste de Tukey a 5% de significância. Em Condor, a semeadura na primeira quinzena de novembro foi

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mais favorável sob boas condições climáticas (2018/2019), enquanto a segunda quinzena foi mais vantajosa sob condições adversas (2022/2023). Em São Borja, a cultivar 6101XTD apresentou o maior rendimento de grãos em 2022/2023, destacando-se em condições de extrema seca.

Termos para indexação: *Glycine max*, características agronômicas, tolerância à seca, rendimento de grãos.

Introduction

Soybean (*Glycine max*) is a crop of great importance, as it meets the oil and protein demands of millions of people around the world (Rani et al., 2023). The favorable soil and climate characteristics, and the high economic return from soybean cultivation have made Brazil the largest producer of this crop in the world, with a production increase of 257% in the last 20 years (Winck et al., 2023). Given this potential and the aiming at a growing demand for food, it is essential to select cultivars of high and stable productivity, which can show tolerance to biotic and abiotic stresses (Eltaher et al., 2021). In addition to the above mentioned factors, the correct positioning of these cultivars within the recommended sowing window is a key element in converging with favorable environmental conditions that allow of high grain yield potential to be achieved.

For Tagliapietra et al. (2021), water deficit and sowing time are the two main factors that cause productivity gaps in soybean cultivation. Many farmers use the sowing time and the relative maturity group (RMG) as parameters to manage the scheduling of plant maturation, in order to minimize field losses at the time of harvest (Bateman et al., 2020). Maturity group is used to group soybean cultivars according to their response to the photothermal stimulus of the environment (Wen et al., 2022). However, climatic inconsistencies and unfavorable sowing conditions have led to uncertainties in the positioning of the same cultivar in a similar way over the years (Lindsey et al., 2017), especially with regard to sowing time and density. This is mainly due to the effect of the genotype x environment interaction on the expression of the characteristics of a given genotype.

In general, the genetic constitution (G), environment (E) and GxE interaction are the factors that influence the expression of any physiological or morphological characteristic of plants (Rani et al., 2023). Therefore, the performance evaluation of cultivars in multi-environment trials is an important way of understanding the effect of the GxE interaction for classifying genotype performance (Mwiinga et al., 2020). Due to the polygenic nature, productivity and other quantitative characteristics are continuously controlled by associated genes that have high interaction with the environment (Said et al., 2022). In a decomposition for soybean productivity, gaps were attributed as follows: 22.4% to genotype x environment interaction, 45.2% water deficit, and 23.4% management (Winck et al., 2023). Therefore, as it is an easy practice to implement, defining the sowing time best suited to specific genotypes can be the difference to obtain increases in soybean productivity.

There are several factors responsible for the difference in the productive potential of a genotype subjected to a specific cultivation region. The environments of the municipalities Condor and São Borja, both in the state of Rio Grande do Sul (RS), were selected to carry out the experiment because they are widely contrasting. The physiographic region of Condor is characterized by having deep soils, which allows of a greater water storage capacity than the soils of São Borja, in addition to superior natural fertility. Another important factor is the El Niño-Southern Oscillation phenomenon that has a marked influence on climate variability in different regions of Brazil, where the impacts on precipitation regimes are the best known (Nóia Júnior et al., 2020). Therefore, it is known that the precipitation regime in the Condor region shows higher precipitation accumulations than in the São Borja region, which defines the regions as having high/medium and low productive potential, respectively. The assessment of the most appropriate sowing time for each growing environment can lead to gains in productive potential for soybean cultivars.

The objective of this work was to evaluate the effect of different sowing times and cultivars on the expression of yield components of soybean grown in contrasting environments.

Materials and Methods

The experiments were conducted in dry farming, in the municipality of Condor (28º12'40"S, 53º28'12"W, at 442 m altitude), in the state of Rio Grande do Sul (RS), Brazil, in the 2018/2019 and 2022/2023 harvest seasons. The soil in the experimental area is classified as a Latossolo Vermelho distrófico típico, according to the Brazilian Soil Classification System (Santos et al., 2018), i.e., typical dystrophic Ferralsol, with relief characterized as gently undulating and a Cfa-type climate (humid subtropical) (Alvares et al., 2013).

A randomized block experimental design was applied in 2x3 factorial arrangement, with two sowing times and three soybean cultivars. The sowing of the first cultivation took place at the following times: the first on November 8; and the second on November 22. In the second harvest, the times were: first sowing time on November 5; and second sowing season on November 25. In both harvests, the cultivars 53I54RSF IPRO, 6563RSF IPRO and 5958RSF IPRO were evaluated, with sowing densities of 14, 10, and 13 seed per linear meter, respectively.

The experimental units were composed of lines spaced at 0.45 m apart, with an area of 3.15 x 5.0 m, totaling 15.75 m^2. Fertilization was carried out at the time of sowing, with 200 kg ha^{-1} of the formula N-P-K 4-28-08 plus 180 kg ha^{-1} of potassium chloride (00-00-60) applied two days before sowing. The management of invasive plants, insect pests, and diseases was carried out to avoid the unwanted effect of biotic factors on the results of the experiment.

In each experimental unit, five plants were sampled, to evaluate the productivity components as follows: plant height (PH, cm); first pod insertion height (FPIH, cm); number of fertile nodes on the main stem (NFMS, units); number of fertile nodes on the branches (NFB, units); number of branches (NB, units); number of pods on the main stem with one (NPMS1, units), two (NPMS2, units), and three or more grains (NPMS3, units); number of pods on branches with one (NPB1, units), two (NPB2, units), and three or more grains (NPB3, units); grain yield (GY, kg ha^{-1}); and thousand-grain weight (TGW, g). Grain yield was determined by manually harvesting the plants of the central rows of each experimental unit, excluding the borders, with grain moisture corrected to 130 g kg^{-1}.

The third experiment was carried out in the municipality of São Borja (28º39'45"S, 56º00'14"W, at 123 m altitude), RS, Brazil, in the 2022/2023 harvest season in dry farming. The soil in the experimental area was classified as a Nitossolo Vermelho distroférrico típico, according to the Brazilian Soil Classification System (Santos et al., 2018), i.e., typical distroferric Nitisol, with a relief characterized as smooth, and a climate classified as Cfa (humid subtropical).

A randomized block experimental design was carried out with six soybean cultivars and three replicates. The cultivars used were 57I52RSF IPRO, 55I57RSF IPRO, 6101XTD, O590 I2X, 5995I2X and 64I61RSF IPRO. The experimental units were composed of 13 sowing lines spaced at 0.45 m apart, with a useful area of 4.95x4 m, totaling 19.8 m^2. Sowing was carried out in the second half of November 2022, using a fertilizer seeder for the following sowing densities: 14.6 seed m^{-1}, for 57I52RSF IPRO; 17.8 seed m^{-1} for 55I57RSF IPRO; and 13.1 seed m^{-1} for 6101XTD, O590 I2X, 5995I2X, and 64I61RSF IPRO. Fertilization was carried out at the time of sowing, with 200 kg ha^{-1} of formula N-P-K 2-23-23. Phytosanitary management was performed preventively, to reduce the impact of biotic factors on the results of the experiment.

The variables plant height (PH, cm), first pod insertion height (FPIH, cm), number of fertile nodes on the main stem (NFMS, units), number of infertile nodes on the main stem (NIMS, units), number of pods on the main stem with one (NPMS1, units), two (NPMS2, units) and three or more grains (NPMS3, units), thousand grain weight (TGW, g) and grain yield (GY, kg ha^{-1}) were sampled from five random plants from each experimental unit. Grain yield was determined by manually harvesting the central rows of each experimental unit, excluding the borders, with grain moisture corrected to 130 g kg^{-1}. Satellite meteorological data on maximum and minimum air temperatures (ºC) and precipitations (mm) were obtained with the help of the Nasa Power platform (Nasa, 2023), using the geographic coordinates, and the sowing and harvesting dates for each experimental phase.

The data were subjected to the assumptions of normality of errors, homogeneity of variances, and independence of errors, using the Shapiro-Wilk's, Bartlett's, and Durbin-Watson's tests, respectively. From the assumptions met, an individual variance analysis was carried out for each phase, at 5% probability, using the F-test. The factor means were confirmed by the Tukey's mean comparison test, at 5% probability. All analyses were performed with the R software (R Core Team, 2023), with the aid of the AgroR package (Shimizu et al., 2023).

Results and Discussion

Meteorological data on air temperature and daily precipitation for the 2018/2019 and 2022/2023 harvest seasons in Condor, and for the 2022/2023 harvest season in São Borja are presented (Figure 1). The mean air temperature was above 20ºC throughout the soybean growing cycle in all environments, both in 2018/2019 and 2022/2023 harvests. The optimal temperature for maximum soybean grain yield is between 23 and 25ºC, according to Alsajri et al. (2020). Nonetheless, the optimum temperature was observed as 30/22ºC for day/night, with significant losses with the occurrence of temperatures above 38ºC by Thenveettil et al. (2024). The mean air temperature was not a limiting factor in Condor; however, the high temperatures in São Borja, in January, may have caused flower abortion and low pod retention.

Adverse air temperature conditions occurred together with low-average daily precipitation in São Borja, which may have limited the conditions for the establishment and initial vegetative growth of soybean. This fact may have led to losses of plant stand and reduced grain yield potential, especially in earlier cultivars that tend to be less resilient to environmental stresses. The data show a good distribution of precipitation (2−5 mm) in the 2018/2019 harvest in

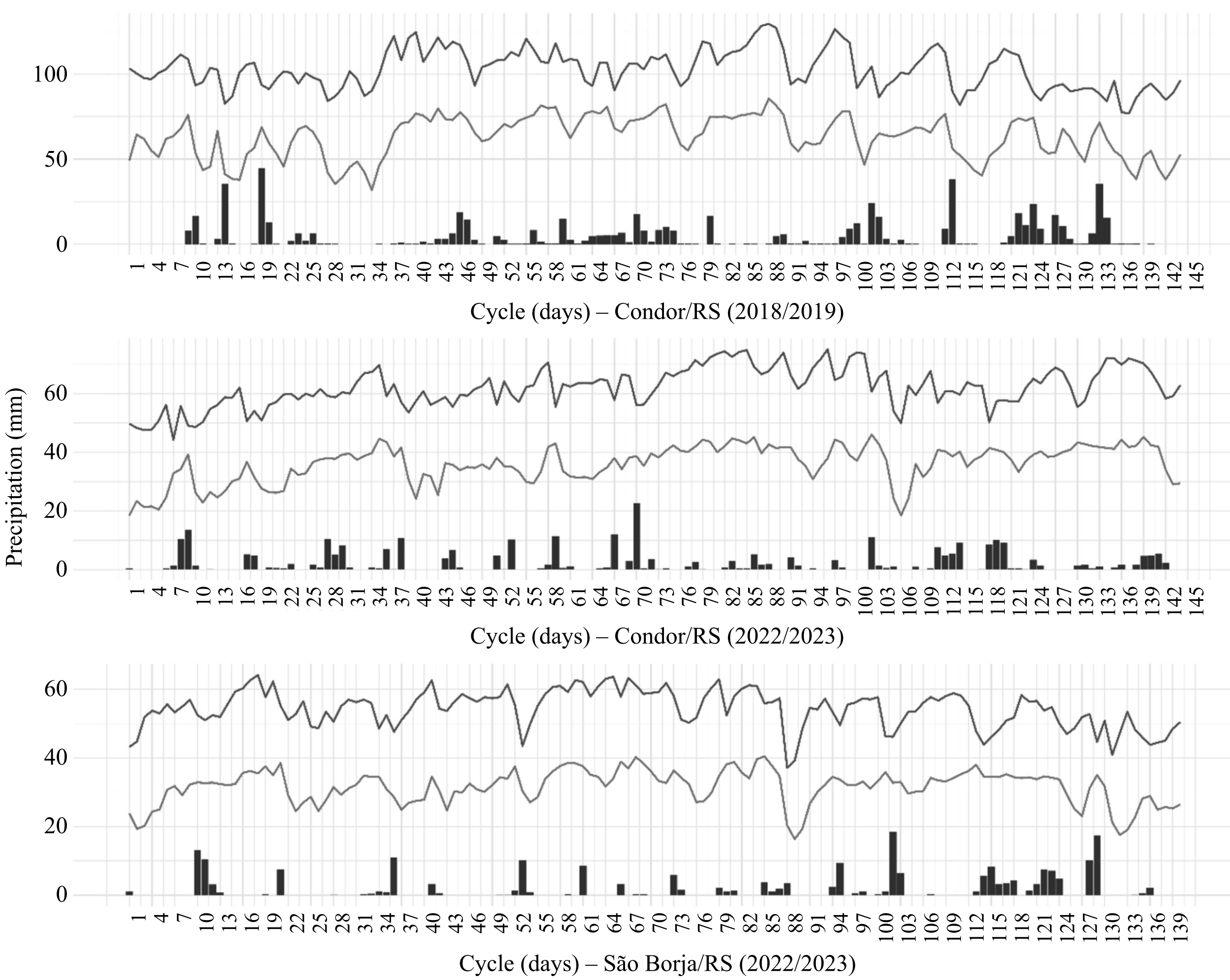

Figure 1. Meteorological data on maximum and minimum air temperature (ºC), and daily precipitation (mm) for soybean harvests in the Brazilian municipalities of Condor (in 2018/2019 and 2022/2023) and São Borja (in 2022/2023), both in the state of Rio Grande do Sul.

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Condor, during the establishment and vegetative growth, in addition to daily averages that met the water requirements of the reproductive period. In 2022/2023, the precipitation was favorable in the initial periods, but it was close to 2 mm, which is below the ideal value for the reproductive period. Anapalli et al. (2022) observed that the daily evapotranspiration of soybean in rainfed conditions varied between 2.3 and 5.8 mm per day, with an average of 4.7 mm, based on data obtained in three sowing seasons.

The analysis of variance showed the effects of sowing time, cultivars, and interaction between sowing time and cultivars on the agronomic components of soybean, in the 2018/2019 harvest, in Condor (Table 1). The effect of interaction between sowing time and cultivar was significant for the number of pods in branches with two grains and for grain yield. Both factors were significant for plant height and insertion of the first pod. Sowing time was significant for the number of fertile nodes on the main stem, while the effect of cultivar was significant for the number of pods on the main stem with two grains.

There was not a significant difference between the cultivars for the number of pods in branches with two grains, in the first sowing season (Table 2), while the 5958RSF IPRO cultivar expressed the lowest average in the second sowing season, with 2.53 pods. This same cultivar showed little variation for grain yield, with 4,331 and 4,350 kg ha^{-1}, in the first and second sowing seasons, respectively. The evaluation of the performance of cultivars within each season showed that 53I54RSF IPRO produced the highest grain yield, in the first sowing season (4,831 kg ha^{-1}), being statistically superior to the others. The 5958RSF IPRO genotype was statistically superior in the second sowing season, whereas 6563RSF IPRO and 53I54RSF IPRO cultivars did not differ from one another (4,023 and 3,974 kg ha^{-1}, respectively). A productivity gap of 1,437 kg ha^{-1} was identified referring to improvements in the management of cultivation practices, and 995 kg ha^{-1} were attributed to cultivar selection (Winck et al., 2023). This same study also estimated that the probability of achieving yields equal to or greater than 3,000 kg ha^{-1} is 80%, for sowing until October 31, falling to 42% for sowing from the beginning of December. These cultivars were subjected to sowing time evaluation as they present different maturation groups, in order to evaluate the difference in behavior between cycles.

Statistically higher means were obtained for the variables plant height, insertion of the first pod, and number of fertile nodes on the main stem, in the first sowing season, with 91.71 cm, 19.67 cm and 15.09 nodes (Table 2). These results show that the anticipation of sowing resulted in larger plants, with an average increase of 1.22 fertile nodes on the main stem, even though there was an increase of 3.45 cm at the insertion of the first pod. Sowing time was the

Table 1. Analysis of variance of the effect on the agronomic components of soybean in the 2018/2019 harvest, in the municipality of Condor, in the state of Rio Grande do Sul, Brazil, for the following parameters: sowing time (first one on August 11; second one on November 22); cultivars (53I54SRF IPRO, 5958RSF IPRO, and 6563RSF IPRO); and interaction between sowing times and cultivars.

Source of variation	DF	PH	FPIH	NFMS	NFB	NPMS1	NPMS2	NPMS3	NPB1	NPB2	NPB3	NB	TGW	GY
		Pr(F)												
T	1	0.04*	0.01*	0.03*	0.10	0.65	0.37	0.11	0.10	0.19	0.26	0.91	0.82	0.00*
Cultivar (C)	2	0.00*	0.00*	0.26	0.20	0.08	0.01*	0.06	0.07	0.03*	0.14	0.07	0.21	0.00*
Block	2	0.10	0.63	0.61	0.84	0.92	0.73	0.60	0.90	0.71	0.29	0.69	0.44	0.60
T x C	2	0.40	0.87	0.27	0.13	0.92	0.44	0.08	0.26	0.02*	0.09	0.09	0.10	0.00*
Residual	10	-	-	-	-	-	-	-	-	-	-	-	-	-
CV (%)	-	5.14	12.11	7.02	38.79	54.29	17.99	51.23	50.79	34.19	38.88	31.52	4.20	1.75

Productivity components: plant height (PH, cm); first pod insertion height of the first pod (FPIH, cm); number of fertile nodes on the main stem (NFMS, units); number of fertile nodes on the branches (NFB, units); number of main stem pods with one grain (NPMS1, units); number of main stem pods with two grains (NPMS2, units); number of main stem pods with three or more grains (NPMS3, units); number of pods on the branch with one grain (NPB1, units); number of pods on the branch with two grains (NPB2, units); number of pods on the branch with three or more grains (NPB3, units); number of branches (NB, units); thousand-grain weight (TGW, g); and grain yield (GY, kg ha^{-1}). DF: degree of freedom. T: sowing time. T x C: interaction between sowing times and cultivars. CV: coefficient of variation. Pr(F): probability of the F-test. *Significant at 5% probability by the F-test.

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most important variable in productivity variation in crops with both high and low productive potential, according to Tagliapietra et al. (2021). Even though they are cultivars with indeterminate growth, the delay in sowing may have brought forward the beginning of flowering, which culminated in the lower number of total reproductive nodes in the second sowing season. Based on climate change models, Bigolin & Talamini (2025) explained that extreme warming is expected in January and February, posing less risk to late-sown crops in their vegetative stage, while crops sown from October to December may face heat stress during flowering, due to climatic extremes.

Network trials are effective for evaluating the general performance of cultivars, but subjecting these genotypes to evaluation, in contrasting environments, leads to an understanding of the expression of intrinsic characteristics, which allows farmers to make specific adjustments to generate productivity increases. Larger plants were evaluated for 53I54RSF IPRO, with an average of 95.67 cm, which statistically differed from 5958RSF IPRO and 6563RSF IPRO that showed respectively 87.87 and 84.03 cm (Table 2). The cultivars 53I54RSF IPRO and 5958RSF IPRO expressed the highest averages for insertion of the first pod, and they were statistically superior to 6563RSF IPRO with 12.37 cm average. These results are positive, as it is estimated that this cultivar obtain the largest production zone with a smaller size, which includes the insertion of the first pod up to the apex of the plant. The genotype 5958RSF IPRO achieved the highest average for the number of pods on the main stalk with two grains, while 6563RSF IPRO obtained the lowest average.

Table 2. Effect of sowing times, cultivars, and interaction between sowing times and cultivars on the agronomic components of soybean, in the 2018/2019 harvest, in the municipality of Condor, in the state of Rio Grande do Sul, Brazil[1].

Simple effects of cultivars and sowing times					
Cultivar	Sowing times				
	November 8	November 22		November 8	November 22
	NPB2			GY	
53I54RSF IPRO	2.87aB	7.73aA		4,831aA	3,974bB
5958RSF IPRO	4.60aA	2.53bA		4,331bA	4,350aA
6563RSF IPRO	6.47aA	7.20aA		4,323bA	4,023bB
Mean	5.23			4,305.32	
Main effects of sowing times					
Sowing time	PH		FPIH	NFMS	
November 8	91.71a		19.67a	15.09a	
November 22	86.67b		16.22b	13.87b	
Mean	89.19		17.94	14.48	
Main effects of cultivars					
Cultivar	PH		FPIH	NPMS2	
53I54RSF IPRO	95.67a		21.97a	11.67ab	
5958RSF IPRO	87.87b		19.50a	14.70a	
6563RSF IPRO	84.03b		12.37b	9.60b	
Mean	89.19		17.94	11.99	

[1]Means followed by equal letters, lowercases in the columns and uppercases in the rows, do not differ statistically from each other, by the Tukey's test, at 5% probability. Productivity components: plant height (PH, cm); first pod insertion height (FPIH, cm); number of fertile nodes on the main stem (NFMS, units); number of pods on the main stem with two grains (NPMS2, units); number of pods on the branch with two grains (NPB2, units); and grain yield (GY, kg ha^{-1}). Sowing times: first one, on November 8; second one, on November 22.

The effect of the interaction between sowing time and cultivar was significant for the variables number of fertile nodes on branches, number of pods on branches with three or more grains, number of branches, and grain yield, in the 2022/2023 harvest in Condor (Table 3). Both factors were significant for plant height, insertion of the first pod and thousand-grain weight. A significant effect of cultivar was observed for the number of fertile nodes on the main stem and for the number of pods on the main stem with one and two grains. Only the effect of sowing time was significant for the number of pods on branches with one grain.

The highest average for the number of fertile nodes in the branches was evaluated in the 53I54RSF IPRO cultivar sown in the first sowing season (8.73 nodes), differing statistically from the others, in addition to being the only one with a significant difference between seasons (Table 4). This is due to the superior number of branches evaluated for this cultivar in the first sowing season (2.47), which resulted in the highest average number of pods in branches with three or more grains (5.40 pods). In contrast, 53I54RSF IPRO showed a reduction in the number of branches in the second sowing season, which impacted the number of fertile nodes and the number of pods in the branches. However, the results prove that the greater number of branches for 53I54RSF IPRO sown in the first season was counterproductive, with grain yield statistically lower than in the second sowing season, with a difference of 359 kg ha^{-1}. These results may be, in part, related to water deficit, which can reach 2,006 kg ha^{-1} according to Winck et al. (2023).

The positioning of soybeans in the first sowing season promoted statistically higher averages for plant height, insertion height of the first pod, number of pods on branches with one grain and thousand grain weight, with values of 76.44 cm, 16.58 cm, 1.27 pods and 181.84 g, respectively (Table 4). For the cultivar effect, with the exception of the number of pods on the main stem with two grains, 5958RSF IPRO obtained a higher average for the other variables on which the cultivar effect was significant. Using cultivars with a medium cycle, as is the case with 5958RSF IPRO, can be a strategy for maintaining productive potential in years that are unfavorable for cultivation, by delaying the beginning of the reproductive period. Soybean stress during the reproductive period can reduce the number of flowers, pods and branches, resulting in lower seed production (Machado et al., 2020).

The analysis of variance of the 2022/2023 harvest, in São Borja, showed a significant effect of cultivar for the following variables: plant height; insertion of the first pod; number of fertile nodes on the main stem; number of infertile nodes on the main stem; number of pods on the main stem with three grains or more; thousand-grain weight; and grain yield (Table 5). For these variables, the coefficient of variation varied between 4.60% and 18.71%, which are considered low

Table 3. Analysis of variance of the effect of sowing times (the first one, on November 5; and the second one, on November 25), cultivars (53I54SRF IPRO, 5958RSF IPRO, and 6563RSF IPRO) and interaction between sowing times and cultivars on the agronomic components of soybean, in the 2022/2023 harvest, in the municipality of Condor, in the state of Rio Grande do Sul, Brazil.

Source of variation	DF	PH	FPIH	NFMS	NFB	NPMS1	NPMS2	NPMS3	NPB1	NPB2	NPB3	NB	TGW	GY
		Pr(F)												
T	1	0.00*	0.00*	0.15	0.01*	0.11	0.52	0.77	0.01*	0.34	0.20	0.00*	0.00*	0.00*
Cultivar (C)	2	0.02*	0.00*	0.00*	0.00*	0.01*	0.00*	0.10	0.09	0.12	0.00*	0.63	0.00*	0.00*
Block	2	0.78	0.89	0.62	0.86	0.19	0.63	0.80	0.15	0.51	0.22	0.58	0.81	0.96
T x C	2	0.27	0.10	0.56	0.00*	0.48	0.73	0.80	0.06	0.25	0.00*	0.01*	0.07	0.00*
Residual	10	-	-	-	-	-	-	-	-	-	-	-	-	-
CV (%)	-	3.21	8.91	5.80	23.09	27.67	14.15	11.72	31.41	44.57	25.82	23.62	3.00	3.24

Productivity components: plant height (PH, cm); first pod insertion height (FPIH, cm); number of fertile nodes on the main stem (NFMS, units); number of fertile nodes on the branches (NFB, units); number of pods on the main stem with one grain (NPMS1, units); number of pods on the main stem with two grains (NPMS2, units); number of pods on the main stem with three or more grains (NPMS3, units); number of pods on the branch with one grain (NPB1, units); number of pods on the branch with two grains (NPB2, units); number of pods on the branch with three or more grains (NPB3, units); number of branches (NB, units); thousand-grain weight (TGW, g); and grain yield (GY, kg ha^{-1}). DF: degree of freedom. T: sowing time. T x C: interaction between sowing times and cultivars. CV: coefficient of variation. Pr(F): probability of the F-test. *Significant at 5% probability by the F-test.

(less than 10%) and medium (from 10 to 20%) (Vaz et al., 2017).

The results show that the soybean performance was strongly impacted by water deficit and high temperatures in São Borja, which allows us to infer which cultivars were more resilient (Table 6). The 64I61RSF IPRO cultivar obtained the highest mean for plant height (52.22 cm), which is not statistically different from the 6101XTD (50.22 cm) (Table 6). The lowest mean was observed for 57I52RSF IPRO (41.89 cm), which did not differ statistically from 55I57RSF IPRO, 5995I2X, and O590 I2X, respectively with 42.78, 43.44, and 44.44 cm. The cultivar 57I52RSF IPRO obtained the highest mean insertion height of the first pod (23.56 cm), which resulted in a smaller production zone than those for

Table 4. Effect of sowing times, cultivars, and interaction between sowing times and cultivars on the agronomic components of soybean, in the 2022/2023 harvest in the municipality of Condor, in the state of Rio Grande do Sul, Brazil[(1)].

Simple effects of cultivars and sowing times				
	Sowing times			
Cultivar	November 5	November 25	November 5	November 25
	NFB		NVB3	
53I54RSF IPRO	8.73aA	3.73aB	5.40aA	1.67aB
5958RSF IPRO	2.80bA	3.33aA	0.93bB	2.60aA
6563RSF IPRO	4.53bA	3.73aA	1.93bA	2.73aA
Mean	4.48		2.54	
	Sowing times			
	November 5	November 25	November 5	November 25
Cultivar	NB		GY	
53I54RSF IPRO	2.47aA	0.87aB	2,943aB	2,852aA
5958RSF IPRO	1.47bA	1.47aA	2,339aA	2,442cA
6563RSF IPRO	1.80abA	1.47aA	2,107bB	2,658bA
Mean	1.59		2,481.99	
Main effects of sowing times				
Sowing time	PH	FPIH	NPB1	TGW
November 5	76.44a	16.58a	1.27a	181.84a
November 25	69.69b	13.84b	0.76b	169.45b
Mean	73.07	15.21	1.01	175.64
Main effects of cultivars				
Cultivar	PH	FPIH	NFMS	NPMS1
53I54RSF IPRO	75.53a	18.87a	11.63a	2.93a
5958RSF IPRO	72.87ab	15.77b	10.93ab	2.57a
6563RSF IPRO	70.80b	11.00c	10.00b	1.43b
Mean	73.07	15.21	10.86	2.31
Cultivar	NPMS2		TGW	
53I54RSF IPRO	8.77b		189.02a	
5958RSF IPRO	11.93a		179.21b	
6563RSF IPRO	7.53b		158.70c	
Mean	9.41		175.64	

[(1)]Means followed by equal letters, lowercases in the columns, and uppercases in the rows, do not differ statistically from each other, by the Tukey's test, at 5% probability. Productivity components: plant height (PH, cm); first pod insertion height (FPIH, cm); number of fertile nodes on the main stem (NFMS, units);, number of fertile nodes on the branches (NFB, units); number of pods on the main stem with one grain (NPMS1, units); number of pods on the main stem with two grains (NPMS2, units); number of pods on the branch with one grain (NPB1, units); number of branches (NB, units); thousand-grain weight (TGW, g); and grain yield (GY, kg ha^{-1}). First sowing time: November 5; second sowing time: November 25.

other cultivars. In this sense, the 6101XTD cultivar had the best performance, with the 16.00 cm as insertion height of the first pod, which resulted in the highest production zone of all cultivars. The genetic effect of 34% and 27% was estimated for insertion height of the first pod and plant height, representing an environmental effect greater than 65%, according to the study by Carvalho et al. (2023).

The lowest number of fertile nodes and the highest number of infertile nodes on the main stem were observed for 57I52RSF IPRO. The results show that this cultivar has a greater tendency to abort reproductive structures in cases of environmental stress. The cultivar 6101XTD had the highest number of pods on the main stem, with three or more grains (9.67 legumes), while 55I57RSF IPRO had the worst performance (3.89 legumes), with little difference from the other cultivars. However, 55I57RSF IPRO and 6101XTD had the best performance for thousand-grain weight, with 123.75 and 117.33 g, respectively, which is statistically superior to the other cultivars. The larger production zone, number of fertile nodes and, subsequently, a good distribution of photoassimilates to grains promoted the highest grain yield for 6101XTD (641.14 kg ha^{-1}), which did not differ statistically from 5995I2X (581.31 kg ha^{-1}). These results show that these cultivars had the greatest resilience to adverse climatic conditions. The cultivar O590 I2X expressed the lowest grain yield (406.55 kg ha^{-1}), which is not statistically different from 64I61RSF IPRO and 57I52RSF IPRO (430.68 and 445.45 kg ha^{-1}, respectively).

The work is limited by the fact that the growing conditions in each of the harvests were different, especially with regard to precipitation. The 2018/2019

Table 5. Analysis of variance of the effect of cultivars (64I61RSF IPRO, 6101XTD, O590 I2X, 5995I2X, 55I57RSF IPRO and 57I52RSF IPRO) on the agronomic components of soybean, in the 2022/2023 harvest, in the municipality of São Borja, in the state of Rio Grande do Sul, Brazil.

Source of variation	DF	PH	FPIH	NFMS	NIMS	NPMS1	NPMS2	NPMS3	TGW	GY
		Pr(F)								
Cultivar	5	0.00*	0.00*	0.00*	0.00*	0.67	0.13	0.00*	0.00*	0.00*
Block	2	0.57	0.66	0.89	0.03	0.43	0.83	0.14	0.88	0.78
Residual	10	-	-	-	-	-	-	-	-	-
CV (%)	-	4.60	8.13	8.69	5.17	67.91	34.59	18.71	6.28	6.57

Productivity components: plant height (PH, cm); first pod insertion height(FPIH, cm); number of fertile nodes on the main stem (NFMS, units); number of infertile nodes on the branches (NIMS, units); number of pods on the main stem with one grain (NPMS1, units); number of pods on the main stem with two grains (NPMS2, units); number of pods on the main stem with three or more grains (NPMS3, units); thousand-grain weight (TGW, g);and grain yield (GY, kg ha^{-1}). DF: degree of freedom. Pr(F): probability of the F-test. CV: coefficient of variation. *Significant at 5% probability by the F-test.

Table 6. Effect of cultivars on the agronomic components of soybean (*Glycine max*), in the 2022/2023 harvest, in the municipality of São Borja, in the state of Rio Grande do Sul, Brazil[(1)].

Cultivar	PH	FPIH	NFMS	NIMS	NPMS3	TGW	GY
64I61RSF IPRO	52.22a	20.78ab	9.22a	5.56cd	6.78ab	92.80b	430.68cd
6101XTD	50.22ab	16.00c	9.44a	5.00d	9.67a	123.75a	641.14a
O590 I2X	44.44bc	18.67bc	8.00ab	4.89d	6.78ab	82.38b	406.55d
5995I2X	43.44c	20.44abc	7.89ab	6.78b	6.44ab	93.33b	581.31ab
55I57RSF IPRO	42.78c	21.56ab	7.22bc	5.89c	3.89b	117.33a	524.55bc
57I52RSF IPRO	41.89c	23.56a	5.56c	7.67a	7.00ab	83.33b	445.45cd
Mean	45.83	20.17	7.89	5.96	6.76	98.82	504.95

[(1)]Means followed by equal lowercase letters, in the columns, do not differ statistically from each other, by the Tukey's test, at 5% probability. Productivity components: plant height (PH, cm); first pod insertion height (FPIH, cm); number of fertile nodes on the main stem (NFMS, units); number of infertile nodes on the branches (NIMS, units); number of pods on the main stem with three grains or more (NPMS3, units); thousand-grain weight (TGW, g); and grain yield (GY, kg ha^{-1}).

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harvest was marked by a greater water supply than that of the 2022/23 harvest, both in Condor and São Borja, which is a situation requiring the evaluation of more similar years, to validate the difference of potential between the evaluated genotypes.

Conclusions

1. In the 2018/2019 harvest, which presents favorable meteorological conditions, sowing in the first half of November favors soybean (*Glycine max*) productivity in Condor, RS, whereas in year with adverse conditions, such as the 2022/2023 harvest, sowing in the second half of November proves more advantageous.
2. The 53I54RSF IPRO and 5958RSF IPRO cultivars express the highest grain yield in the first and second sowing times, respectively, in the 2018/2019 harvest in Condor, RS, with the 53I54RSF IPRO cultivar being more suitable for sowing in November 8.
3. The comparison of harvests of the first and second seasons shows that the 5958RSF IPRO cultivar is the only one that does not show a significant difference for grain yield in Condor, RS, displaying good stability in response to variations in sowing time.
4. The 6101XTD cultivar expressed the highest grain yield in the 2022/2023 harvest, in São Borja, RS, and proves to be resilient to adverse growing conditions under extreme water deficit.

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No generative artificial intelligence (AI) was used in this study.

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