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USE OF DIFFERENT FUNGICIDES IN WHEAT UNDER WATER DEFICIT CONDITIONS

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ABSTRACT

The study aimed to evidence the efficiency of fungicides in disease control and the economic and productive effects under water deficit conditions in wheat. In addition, it sought to list the best management of fungicides so that the active principles can be more efficient in controlling diseases and, therefore, in the production of wheat grains. The experiment was carried out in São Borja, Rio Grande do Sul State - Brazil, in a randomized block design, with twenty treatments (fungicide management), in four replications, in 80 plots. The management composed by Versatilis + Versatilis potentiated the expression of cob length, number of grains per plant, leaf rust. Fusão + Fusão treatment promoted the lowest cob weight and grain weight per plant, similarly to Cypress + Mancozeb treatment. Orkestra + Fusão treatment enhanced grain yield and showed the best cost benefit, close to the value of the control treatment, proving to be the most profitable.

Keywords: Diseases, pathogens, *Triticum aestivum*, linear correlation, principal components

INTRODUCTION

The culture of wheat (Triticum aestivum) has been widely used since ancient times, being of prime importance for the development and food of the people. Currently, wheat has been widely cultivated by Brazilian farmers even with great difficulties in cultivation, due to climatic factors. These cause production instability and thus promote low profitability when compared to other crops. It has relation to the uncertainties for the implantation of this species, associated with the climate, grain productivity, reduction of sown areas and mainly the commercialization prices.

The Brazilian states of Paraná and Rio Grande do Sul lead the production of wheat, accounting for 87% of all national wheat grain production, with Rio Grande do Sul being the largest national producer of wheat grains in the 2021 harvest (CONAB, 2022). Although there is a significant production of grains in the South region, it is not enough to meet the entire domestic demand of the country. As a result, the development of practices that enhance the performance of the culture is substantial to meet market demands.

For this, the managements carried out in the production areas, such as the use of fungicides, are fundamental, since they act in the control of diseases that cause a decrease in production. However, its use must ensure sustainability, so that its use must have a direction according to the needs of the crop, and with the climatic conditions, so that the inappropriate use of fungicides does not occur, since it can cause disease tolerance and modes of action, as well as increasing production costs due to its high value.

Research related to the use of fungicides in different crops has been the focus of study to enhance the performance of species and avoid the indiscriminate use of fungicides. Knebel et al. (2019) showed that in soybeans, the non-use of fungicides reduced the grain yield of the crop by 35%, and the combination of different active ingredients maximized disease control. Mendes et al. (2018) observed that the association of fungicides in wheat promotes greater efficiency in controlling leaf rust and enhances grain yield.

However, weather conditions during wheat cultivation are determinant for the incidence of diseases. Under water deficit conditions, the incidence of pathogens can be very different, making it necessary to change the management of fungicides. In this context, the study aimed to evidence the efficiency of fungicides in disease control and the economic and productive effects under water deficit conditions in wheat.

MATERIAL AND METHODS

The study was carried out in the municipality of São Borja, Rio Grande do Sul State - Brazil in the district of São Miguel, with latitude 28°30'53.3" S and longitude 55°47'54.6"' W, with an elevation of 127 meters. The characterization of the soil is Typical Dystroferric Red Nitosol, with clay contents of up to 70%. According to the Köppen climate classification, the climate of the region is *Cfa* type.

The experimental design used randomizing blocks with twenty treatments (fungicide management) in four replications. The fungicides used were Aproach Prima, Tilt, Cypress, Mancozeb, Fusão, Tridium, Orkestra, Versatilis, Tebuconazole, no fungicide and different combinations between fungicides (Table 1). The experimental units consisted of 18 seeding rows spaced 0.17 meters apart and 20 meters long, totaling a plot area of 61.2 meters².

Table 1. Description of treatments applied. São Borja, Rio Grande do Sul State – Brazil, July 2021 to November 2021.

	Application 1			Application 2		
Treat	**Fungicide**	**Active Principle**	**Dose**	**Fungicide**	**Active Principle**	**Dose**
1	Ausência			Ausência		
2	Aproach	Picoxystrobin, Cyproconazole	300 ml	Aproach	Picoxistrobina, Cyproconazole	300 ml
3	Tilt	Propiconazole	500 ml	Tilt	Propiconazole	500 ml
4	Fusão	Tebuconazole, Metominostobin	725 ml	Fusão	Tebuconazole, Metominostobin	725 ml
5	Orkestra	Picoxystrobin, Fluxapyroxad	350 ml	Orkestra	Picoxystrobin, Fluxapyroxad	350 ml
6	Versatilis	Phenpropimorph	1000 ml	Versatilis	Phenpropimorph	1000 ml
7	Tebuconazole	Tebuconazole	750 ml	Tebuconazole	Tebuconazole	750 ml
8	Cypress	Difenoconazole; Cyproconazole	50 ml	Cypress	Difenoconazole; Cyproconazole	50 ml
9	Mancozeb	Mancozeb	3 kg	Mancozeb	Mancozeb	3 kg
10	Tridium	Tebuconazole, Mancozeb, Azoxystrobin	2 kg	Tridium	Tebuconazole, Mancozeb, Azoxystrobin	2 kg
11	Aproach	Picoxystrobin, Cyproconazole	300 ml	Tilt	Propiconazole	500 ml
12	Tilt	Propiconazole	500 ml	Aproach	Picoxistrobina, Cyproconazole	300 ml
13	Fusão	Tebuconazole, Metominostobin	725 ml	Aproach	Picoxistrobina, Cyproconazole	300 ml
14	Orkestra	Picoxystrobin, Fluxapyroxad	350 ml	Fusão	Tebuconazole, Metominostobin	725 ml
15	Versatilis	Phenpropimorph	1000 ml	Orkestra	Picoxystrobin, Fluxapyroxad	350 ml
16	Tebuconazole	Tebuconazole	750 ml	Cypress	Difenoconazole; Cyproconazole	50 ml
17	Cypress	Difenoconazole; Cyproconazole	50 ml	Mancozeb	Mancozeb	3 kg
18	Mancozeb	Mancozeb	3 kg	Tridium	Tebuconazole, Mancozeb, Azoxystrobin	2 kg
19	Tridium	Tebuconazole, Mancozeb, Azoxystrobin	2 kg	Tebuconazole	Tebuconazole	750 ml
20	Orkestra	Picoxystrobin, Fluxapyroxad	350 ml	Versatilis	Phenpropimorph	1000 ml

Prior to sowing, in the first half of July, the area was desiccated using 2 kg of Glifosato WG + 500 ml of Cletodin + 500 ml of Mineral Oil + 100 ml of Flumizin + 125 ml of Kaiso + Spraytec adjuvant and anti-drift Naft. Carrying out sowing of the area in the first half of July with the aid of a quad-model Khun seeder with 60 sowing rows and a spacing of 0.17 meters between rows. The cultivar used was Tbio Ponteiro, with a medium to late cycle, medium plant height, less susceptible to lodging.

The sowing density used was 70 seeds per linear meter, with fertilization in line of 250 kg ha^{-1} of the chemical fertilizer N-P-K containing 10% nitrogen, 30% phosphorus and 20% potassium in its composition. About 24 days after sowing, carrying out weed control, remaining from the first herbicide application and aiming to control ryegrass to reduce competition. For this, using herbicides, at a dose of 300 ml Topik + 7.5 g Metsuram + Naft + Spraytec. The tillering of the plants began on July 18 and the application of carrying out urea under ideal climatic conditions, with a maximum distribution of 150 kg ha^{-1} of N max at a fixed rate with the aid of a solid distributor of the Jacto model 5030 brand. NPK with application range of 38 meters and application speed of up to 24 km h^{-1}.

Each fungicide treatments was applied twice during the crop development cycle, the first applications on September 11th and the second applications on September 27th, with a backpack sprayer with a flow rate of 150 L ha^{-1}. The evaluations of plant diseases took place in the first half of October and the carrying out harvest on November 1, 2021.

The variables analyzed were, plant height (PH, cm), plant stand (STAND, units), percentage of leaf rust (LR, %), fib (FIB, %), yellow spot (YS, %), brown spot (BS, %), foot disease (FD, %), cob length (CL, cm), cob weight (CW, g), grain weight per plant (GWP, g), thousand grain weight (TGW, g), number of grains per cob (NGC, unit) and grain yield (GY, kg ha^{-1}), measured at ten random points per experimental unit. The meteorological information mean temperature (°C), minimum and maximum air (°C), precipitation (mm), wind speed (km h^{-1}), relative humidity (%) and incident radiation (Gy) were expressed in order to better understand the results obtained (NASA POWER, 2021).

The submitting data obtained to the assumptions of the statistical model, normality of errors by Shapiro Wilk and homogeneity of residual variances by Bartlett's test. Descriptive carrying out analysis to understand the nature of treatments and variables. Afterwards, performing analysis of variance at 5% probability using the F test to verify the variability between treatments. Submitting significant variables to the Scott Knott grouping of means test at 5% probability. Subsequently, using linear correlation in order to understand the tendency of the association between the variables measured, and its significance supported by the t test at 5% probability. Carrying out analysis of the BIPLOT principal components in order to establish a multivariate association between the measured variables and the treatments, obtained by the distance matrix and plotted simultaneously. The packages used for the statistical analyzes were Exp.Des.pt, ggplot2 and metan through the R software (R CORE TEAM, 2021).

RESULTS AND DISCUSSION

As can be seen in Figure 1, precipitation is one of the main factors that negatively influenced the development of this species, and in the month of July, when the plant was in the tillering period, the values were low (about 25 mm). According to Moraes (2019), the ideal water availability for this period is around 122 millimeters, causing this lack of water in the soil to interfere with the low development of tillers, resulting in low leaf area and a considerable increase in ground temperature.

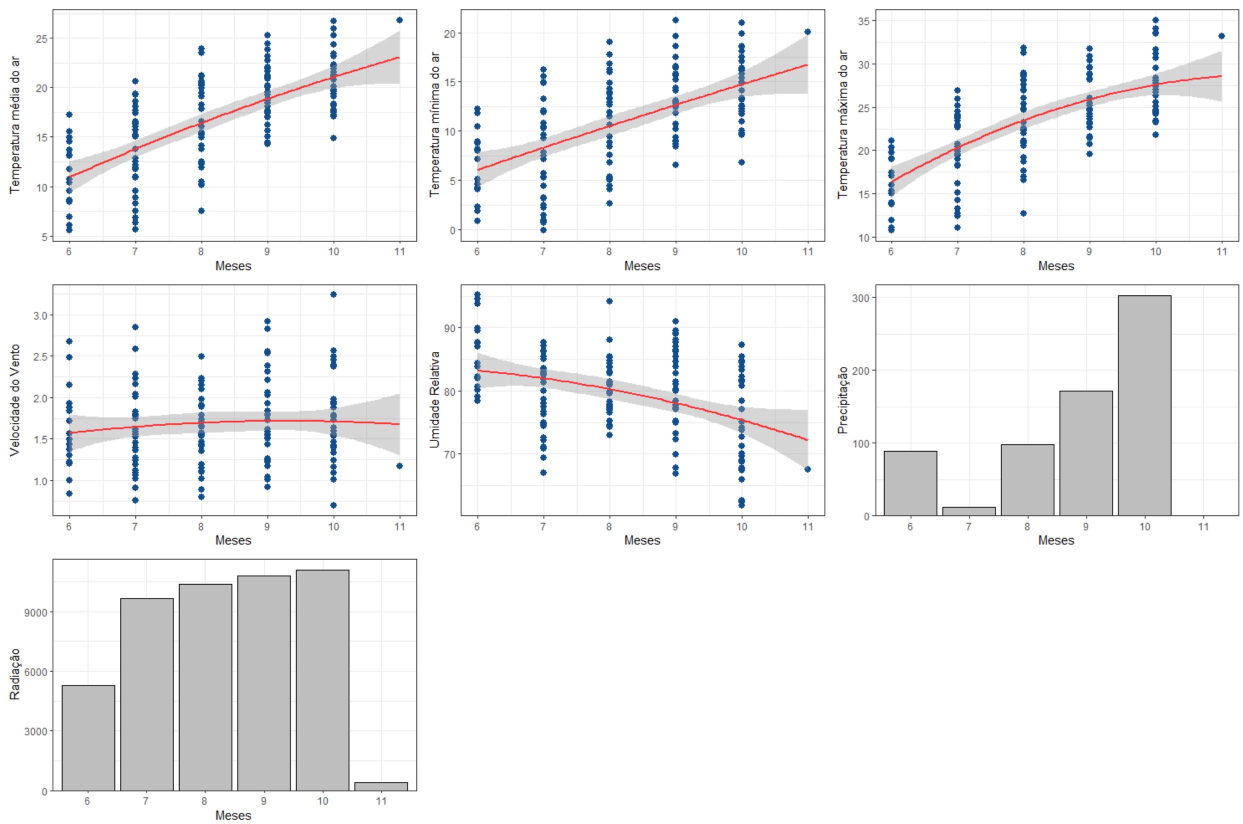

Figure 1. Climatic data during the crop 120 days cycle, São Borja, Rio Grande do Sul State – Brazil, 2021.

The average air temperature in the tillering phase, together with the precipitation, caused the plant to reduce the leaf area, and the lack of water for this period added to the high temperatures contributed to the delay in the application of nitrogen fertilization, causing thus reduction in production. In the period before flowering, unfavorable conditions such as high radiation, high temperature and air humidity were fundamental for defining the number of fertile flowers. Such conditions also caused, after the flowering period, a reduction in the establishment of grains in the plant. In addition, if the plant enters the cob growth period under these conditions, a limit occurs by the decrease in the number of grains per cob, thus having a direct effect on final productivity (CUNHA et al., 2019).

Solar radiation is one of the main climatic factors, having a direct relationship with the development of the wheat crop. The leaf area has the role of intercepting radiation and thus carrying out the photosynthetic process, causing the plant to have an adequate development (TAIZ et al., 2017). However, the high value of leaf area does not guarantee a greater interception of solar radiation. Loro et al. (2021) revealed that the largest portion of photo assimilates is destined for the main plant, regardless of the number of tillers produced, and the performance of some cultivars may be superior at low density, due to greater radiation interception and less competition between plants.

Regarding plant stand (STAND), plant height (PH), cob weight (CW), number of grains per cob (NGC), grain weight per plant (GWP) and grain yield (GY) the values did not differ statistically according to the analysis of variance table, except the thousand grain weight (TGW) and cob length (CL) were statistically different, as shown in Table 2.

For the variable plant stand (Figure 2A), the treatment Versatilis + Versatilis presented 61 plants per linear meter, lower values were observed in the treatment Tridium + Tebuco with 48.50 plants per meter. This difference may have a relation to the unfavorable climate at the beginning of the cycle, such as high temperatures and lack of precipitation during the period of establishment of the crop in the area. The height (PH) (Figure 2B) measured in the study showed a difference between the treatments, when the management with Tilt + Tilt the plants had lower heights than the other treatments, with about 70.50 cm, higher heights were observed in the treatment of Versatilis + Versatilis with 74 cm.

Management performed with Versatilis + Versatilis, was superior for cob length (CL) (Figure 3A), with 8.28 cm and the treatment with the shortest length was Fusão + Fusão, with cobs around 6.90 cm. The product Versatilis, which presented higher values, is composed of Fenpropimorph, a morpholine that acts in the synthesis of ergosterol of the fungus present in the plant, this is one of the main constituents of the plants, present in the cell membrane. The active ingredient acts on the membrane, causing the fungus to die. As it is a systemic product, after its absorption by the plant, having a translocation through the xylem, helping to control the fungi present, resulting in higher yields and number of grains per plant (TOFOLI, 2016).

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Table 2. Analysis of variance table, São Borja, Rio Grande do Sul State - Brazil, 2021.

Variation Factor	MS[1]	FC	Pr>Fc
STAND (p m^{-1})			
TREATMENTS	402,000	0,78818	0,71059
BLOCKS	0,0020	0,00004	10,000
RESIDUE	510,030		
CV (%)	12,7		
PLANT HEIGHT (cm)			
TREATMENTS	45,060	0,9562	0,5221
BLOCKS	575,380	122,094	0,0000
RESIDUE	47,130		
CV (%)	2,99		
COB LENGTH (cm)			
TREATMENTS	0,33097	19,915	0,02373**
BLOCKS	0,14899	0,8965	0,44866
RESIDUE	0,16619		
CV (%)	5,38		
COB WEIGHT (g)			
TREATMENTS	0,044134	13,549	0,18757
BLOCKS	0,041622	12,778	0,2907
RESIDUE	0,032574		
CV (%)	12,4		
NUMBER OF GRAINS PER COB (Und)			
TREATMENTS	22,412	0,97763	0,49885
BLOCKS	35,974	156,924	0,20678
RESIDUO	22,925		
CV (%)	12,58		
GRAIN WEIGHT PER PLANT (g)			
TREATMENTS	0,026264	12,699	0,23947
BLOCKS	0,018659	0,9022	0,44582
RESIDUE	0,020681		
CV (%)	12,75		
GRAIN YIELD (kg h^{-1})			
TREATMENTS	463857	124,629	0,25578
BLOCKS	59632	0,16022	0,92265
RESIDUE	372192		
CV (%)	16,19		
THOUSAND GRAIN WEIGHT (g)			
TREATMENTS	7,966	206,438	0,01846**
BLOCKS	29,592	0,76688	0,51733
RESIDUE	38,588		
CV (%)	6,53		

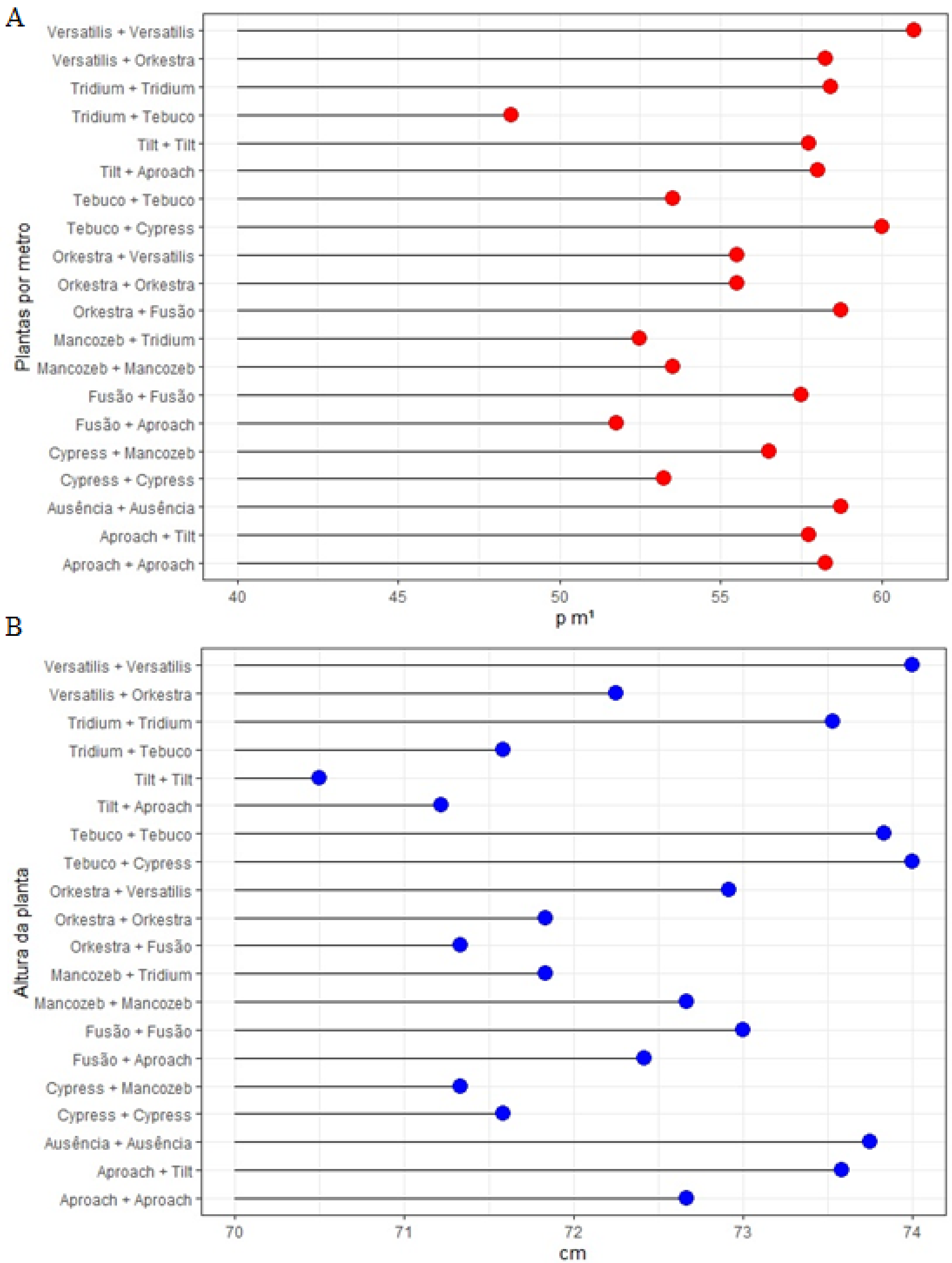

Figure 2. Descriptive analysis of plant stand and plant height (cm) for the different treatments, São Borja, Rio Grande do Sul State - Brazil, 2021.

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For cob weight (CW) (Figure 3B), the treatment that obtained the best average was Aproach + Fusão, while the treatment with the lowest average was Fusão + Fusão and Cypress + Mancozeb. This character is directly related to the cob length and the number of grains per plant, so the greater these two factors, the greater the cob weight. Aproach is composed of Picoxystrobin and Cyproconazole, being two mechanisms of action of triazoles and strobilurins, attacking the disease through several sites, either in the synthesis of ergosterol or in the transport of electrons in the mitochondria, leading to death more quickly.

For number of grains per cob (NGP) (Figure 4A), some treatments showed a higher average number obtained, such as Versatilis + Versatilis, with 43.50 grains and Fusão + Fusão, with 33.45 grains. These values have a direct relation to the grain weight per plant, however, higher values of number of grains are not in the largest weight. Versatilis + Versatilis treatment, has a greater number of grains, but its weight is of 1.20 g, being smaller than the treatment composed of Fusão+ Aproach, which has a weight of 1.32, being the highest value. The Fusão + Aproach treatment provided a larger stem diameter, being essential for the stock of photo assimilates, and then their translocation to fill the grains, a small value, but it becomes a big difference with an analysis in the area.

Higher values of grain yield obtained for the Orkestra + Fusão treatment (4,338.10 kg ha^{-1}), higher than the Aproach + Tilt treatment (4,008 kg ha^{-1}) (Figure 4B). This difference has a relation to the plant stand, as Fusão + Aproach treatment showed a lower plant stand, but with greater grain weight, thus having a correlation between all these factors that determine the final yield. Aproach + Tilt treatment was the sixth treatment with the highest productivity, surpassing the 4,000 kg ha^{-1} range. In Rio Grande do Sul, the average yield of wheat grains per hectare in the last five years is 4,600 kg, which is lower than the value obtained in the experiment (CONAB, 2022).

Thousand grain weight (TGW) was higher for the Orkestra + Orkestra treatment, with 34.18 g (Figure 5A). It may be related to the product that has a double mechanism of action through its active ingredients, which have superior plant protection, due to its action in inhibiting the germination of spores, as it has a curative action with systemic action through the active principle Fluxapyroxade (TOFOLI, 2016).

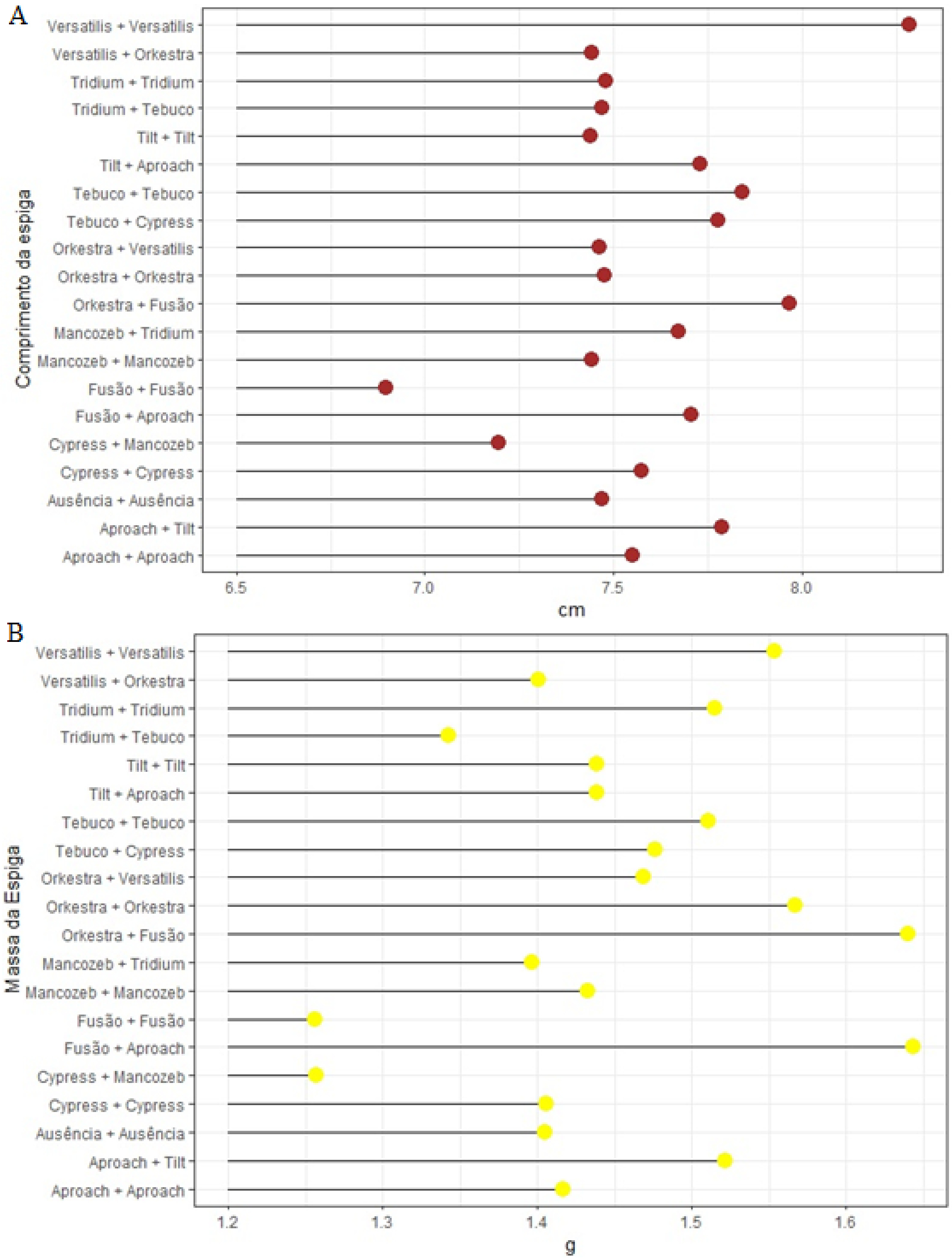

Figure 3. Cob length (cm) and Cob weight (g) for the different treatments, São Borja, Rio Grande do Sul State - Brazil, 2021.

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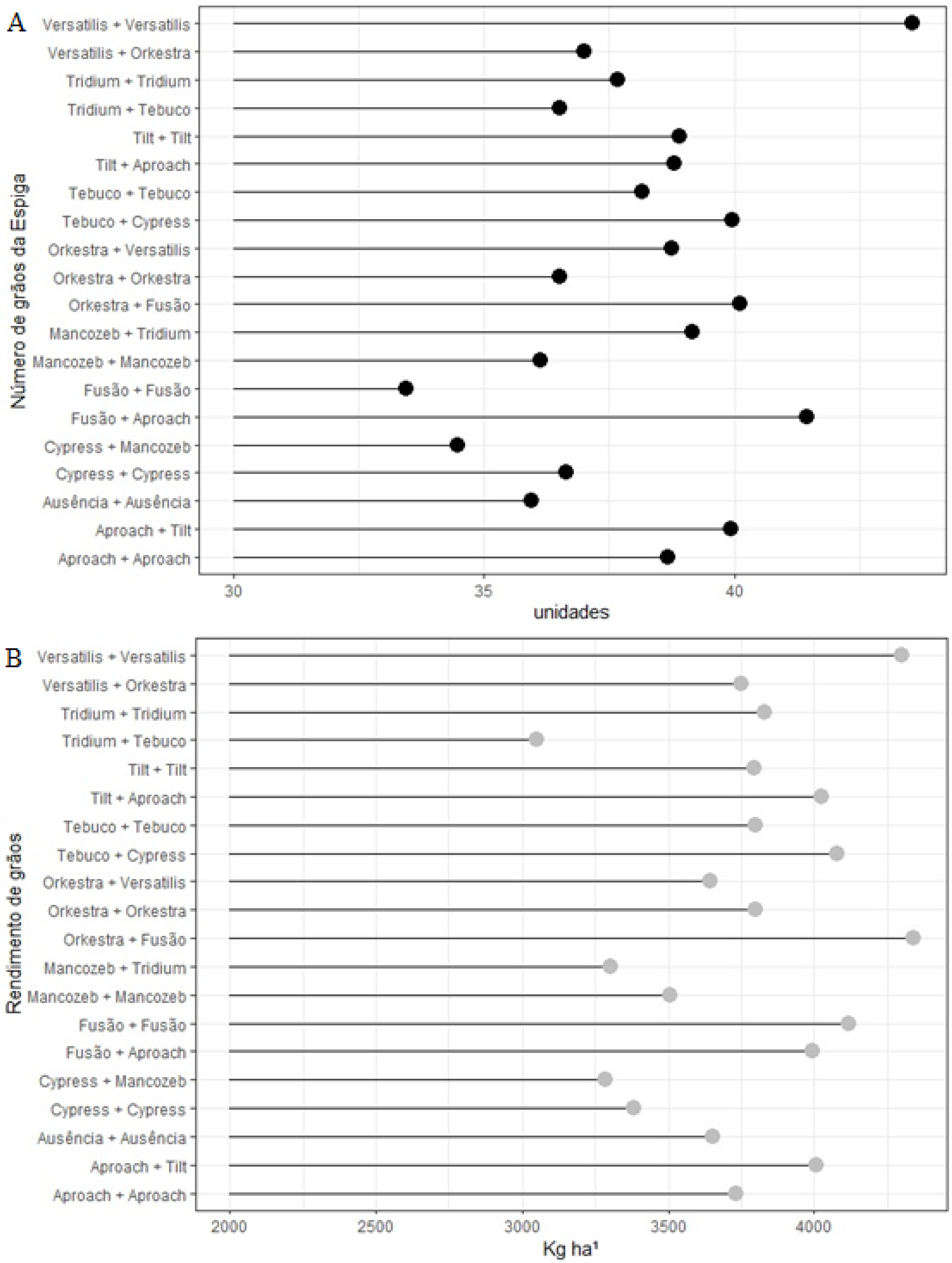

Figure 4. Number of grains per cob (und) and grain yield (kg ha^{-1}) for the different treatments, São Borja, Rio Grande do Sul State - Brazil, 2021.

In the BIPLOT main components methodology (Figure 5B), the treatment that has the highest grain yield is treatment 11 composed of Aproach + Tilt, with affinity for plant stand and average cost, with a production of 4,008 kg ha^{-1}. On the other hand, treatment 13 with Fusão + Aproach has a strong relationship with grain yield, cob weight and grain weight per plant and does not have the highest productivity, but contains 3,995 kg ha^{-1}. The treatment that presents the highest production is 14, which correlated between cob length and number of grains per plant, presenting a final production of 4,338 kg ha^{-1}, with a cost of BRL 3,164.00 ha^{-1} very close to the average cost of treatments, which is BRL 3,166.28 ha^{-1}. On the other hand, treatment 6 composed of Versatilis + Versatilis has the highest cost, being BRL 3,497.97 ha^{-1} and its production is the second highest, with 4,299 kg ha^{-1}, and containing no affinity.

Linear correlation observes the relationships between the variables. This methodology is strongly applied in studies with plants (SZARESKI et al., 2015; OLIVOTO et al., 2016; FERRARI et al., 2018; BUBANS et al., 2021; FERREIRA et al., 2021; MOURA et al., 2021), as it indicates the relationship between variables that can be used for indirect selection in plant breeding. It can be seen that leaf rust and costs (-0.39) are negatively correlated, showing that the lower the investment in fungicides, the greater the incidence of rust in the treatments (Table 3). This also happens for the correlation between leaf rust (LR) and plant height (PH), Fib (FIB) and maximum air temperature (Tmax), Fib (FIB) and height (PH) and brown spot (BS) and wind speed (WS). On the other hand, the other values have positively correlation, such as cob weight and grain yield (0.57), so the increase in one, consequently increases the other.

Leaf rust, a character analyzed in Figure 6A, is a disease caused by the fungus *Puccinia triticina*, which causes yellow and brown pustules on the plant to appear on the entire surface of the leaf. The highest value with low control was with the treatment without fungicides, which showed 12.75% of disease infestation. On the other hand, the best treatment for this control was Versatilis + Versatilis, which provided only 3.75% infestation. The greatest control for Versatilis has a link to its chemical group, as it belongs to a morpholine, which acts on the biosynthesis of sterols in the fungal membrane, but with a different mechanism from triazoles, inhibiting different enzymes.

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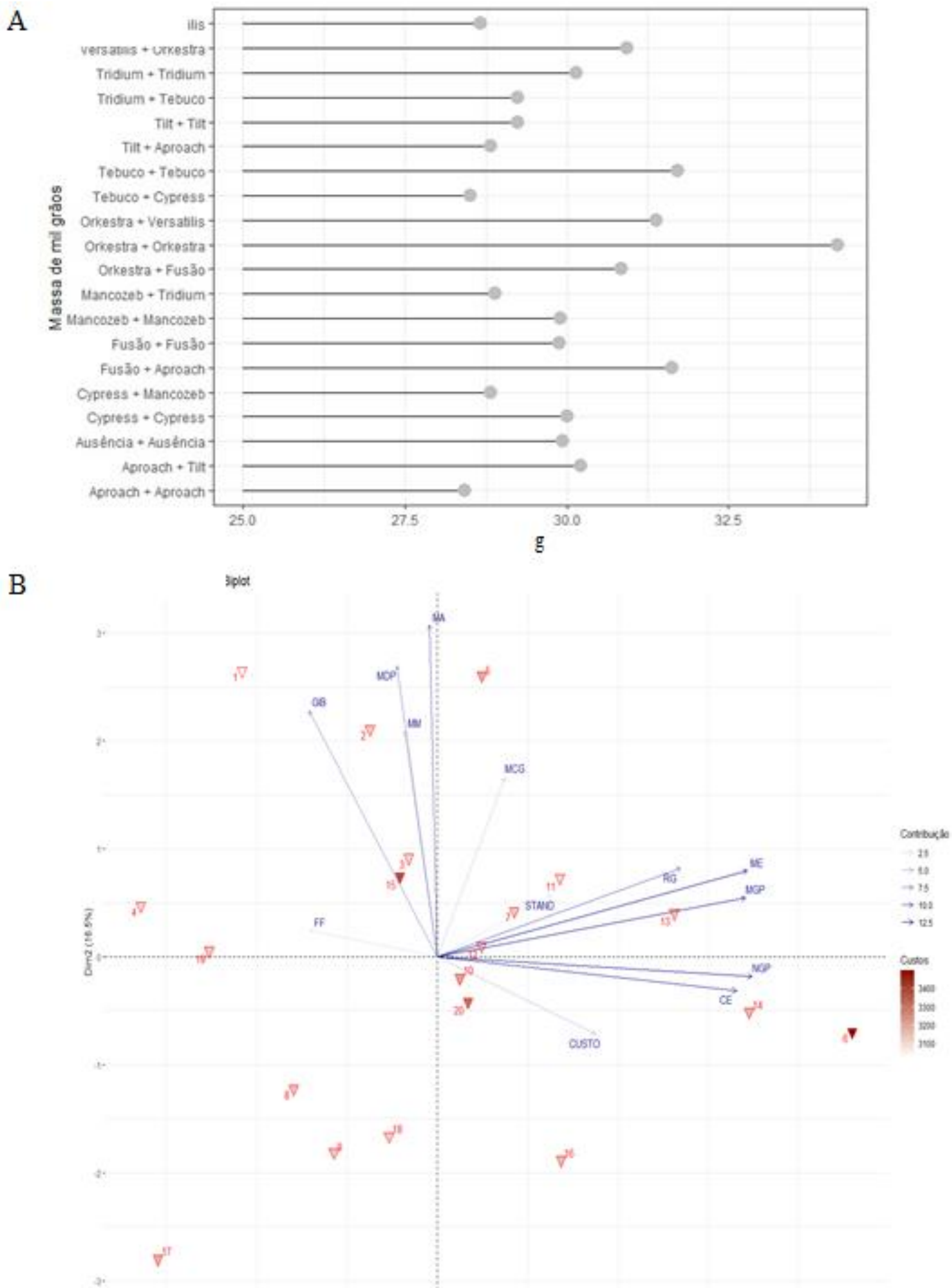

Figure 5. Thousand grain weight (A) for the different treatments and yield components Biplot (B), São Borja, Rio Grande do Sul State – Brazil, 2021. Cost (COST), Plant Stand (STAND), Leaf Rust (LR), Fib (FIB) , Yellow Spot (YS), Brown Spot (BS) Foot Disease (FD), Cob Length (CL), Cob Weight (CW), Grain Weight per Plant (GWP), Thousand Grain Weight (TGW), Number of Grains per Cob (NGC), Grain Yield (GY), red triangles indicate the cost.

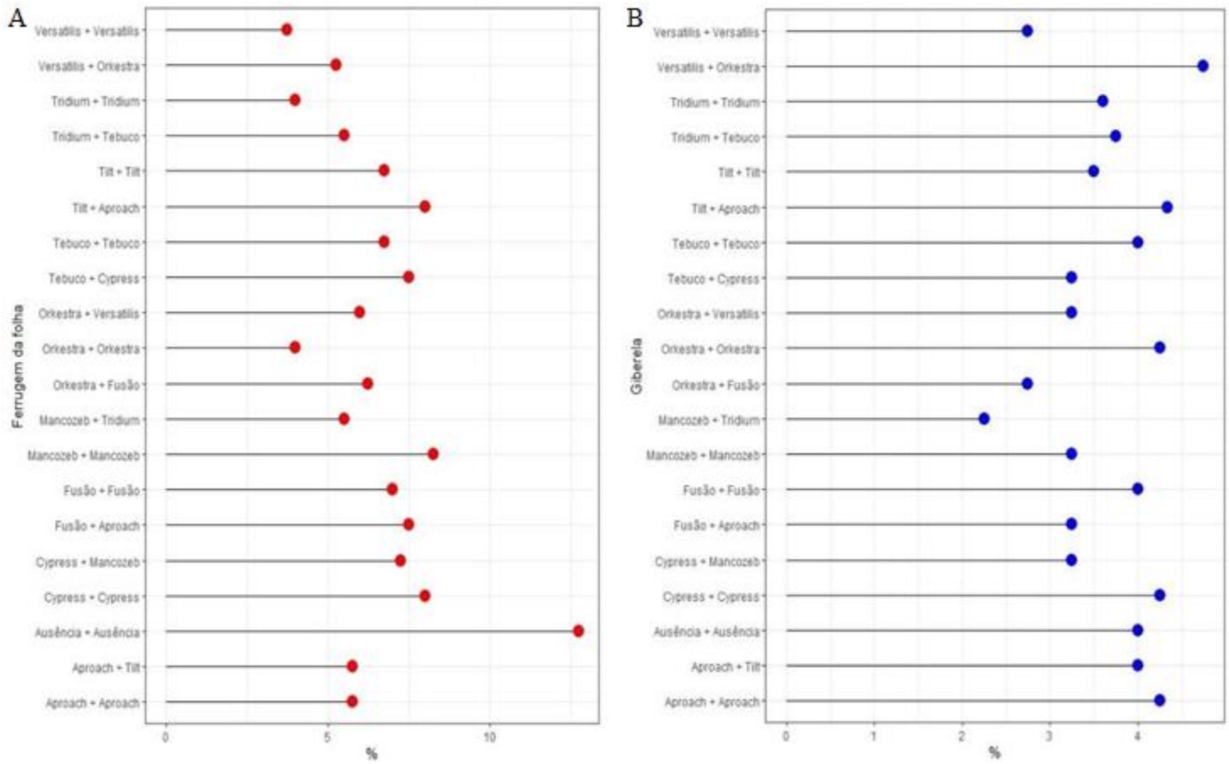

Figure 6. Index of infection (%) by leaf rust and infection (%) by FHB in the different treatments in the different treatments, São Borja, Rio Grande do Sul State - Brazil, 2021.

Figure 6B shows a better control of FHB with the Mancozeb + Tridium treatment, with about 2.25 of infestation, whereas the most deficient treatment was Versatilis + Orkestra, in the order of 4.75% of infestation. The treatment composed of Mancozeb provided greater control as well as an increase in grain yield of 27%. These higher values has a relation to the contact and protective mechanisms of action, acting at several points of action, different from site-specific products, thus attacking the fungus through different routes, making its control more efficient.

The treatment (Figure 7A) that showed the best control over brown spot was composed of Versatilis + Orkestra with a value of 2.25% of infestation. On the other hand, the treatment of Tridium + Tridium had the worst control, in the order of 5, 60% infestation. The treatment (Figure 7B) with the worst control for yellow spot was Ausência + Ausência of fungicides with 10.75% of incidence, and the one with the best control was composed of Tebuco + Cypress with 7.75% of infestation. Both Tebuco and Cypress belong to the group of triazoles that act to inhibit the biosynthesis of ergosterol, which is an important element for the formation of fungal membranes, in turn, the inhibition of ergosterol formation leads to cell collapse.

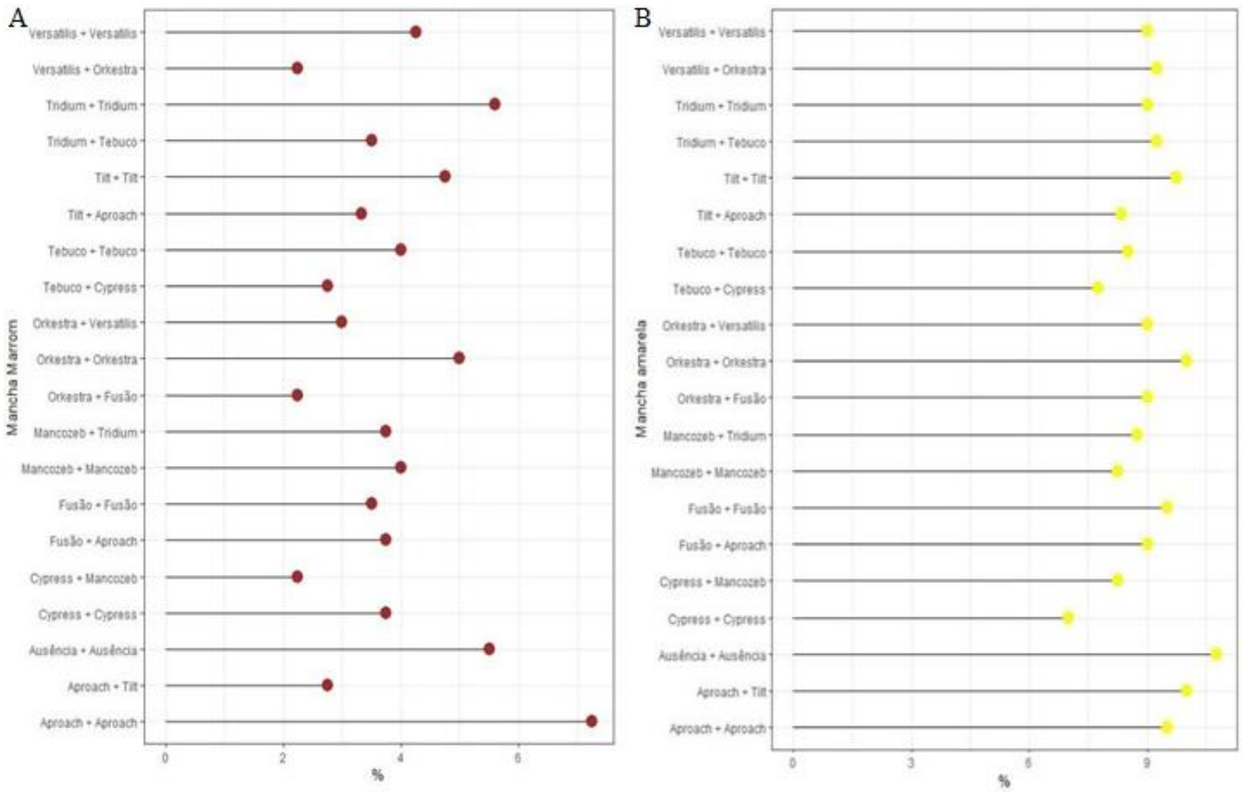

Figure 7. Infection rate (%) by brown spot and infection rate (%) by yellow spot in the different treatments, São Borja, Rio Grande do Sul State – Brazil, 2021.

The treatments (Figure 8A) that had low control for foot disease were Aproach + Aproach and Tridium + Tebuco with 10% infestation. On the other hand, the best control was for Mancozeb + Mancozeb treatment with 5.50 infestation. This difference may have relation to the existence of pathogens in the soil, since infections are common in tumbleweeds, thus causing infections in certain parts of the crop, since for the control of this fungus it is necessary a crop rotation with non-hosts plants of the pathogen.

Each treatment (Figure 8B) has its costs calculated by quantifying the amount spent on seeds, fertilization, weed control products, nitrogen application and insecticides, totaling an equal value for all treatments, adding to this the cost of each fungicide treatment. With the lowest cost, the treatment of ausência + ausência is BRL 3,093.23 ha^{-1}. For this, only the values of the items mentioned above has quantification, differing the cost of the fungicides used, therefore, the treatment with the highest cost was with Versatilis + Versatilis with BRL 3,497.97 ha^{-1}.

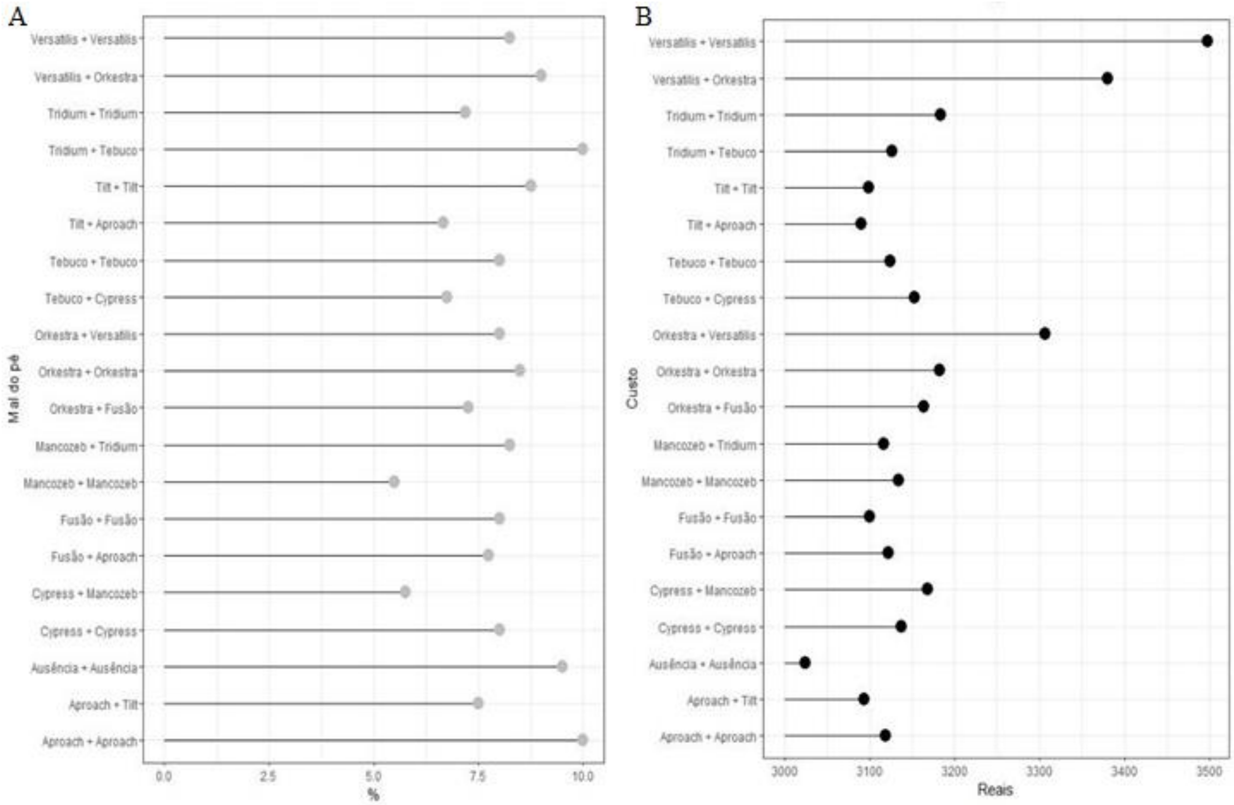

Figure 8. Infection rate (%) by foot disease and costs in the different treatments (BRL), São Borja, Rio Grande do Sul State - Brazil, 2021.

CONCLUSION

The management composed by Versatilis + Versatilis potentiated the expression of cob length, number of grains per plant, leaf rust.

Fusão + Fusão treatment promoted the lowest cob weight and grain weight per plant, similarly to the Cypress + Mancozeb treatment.

Orkestra + Fusão treatment enhanced grain yield and showed the best cost benefit, close to the value of the control treatment, proving to be the most profitable.

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