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Original Article

Active ingredients for industrial seeds treatment in wheat crop[1]

Princípios ativos para tratamento industrial de sementes na cultura do trigo

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HIGHLIGHTS:

Seed treatment with Neonicotinoids improves wheat performance.
The use of Carboxamide fungicides increases plant density.
Industrial treatment with fungicides and insecticides maximizes grain yield.

ABSTRACT: Industrial seed treatment is a modern agricultural practice that aims to provide protection of seeds and seedlings from pests, diseases, and pathogens in the early stages of crops. The research with wheat cultivars aims to evaluate the effects of industrial seed treatments and their influence on agronomic and morphological traits. A randomized block design was used, arranged in a factorial scheme (10 × 2 × 2), with 10 treatments Imidacloprid; Thiodicarb; Imidacloprid + Thiodicarb; Pyraclostrobin (Thiophanate-methyl + Fipronil); Fluxapyroxad; Fluxapyroxad + Imidacloprid; Fluxapyroxad + Thiodicarb; Fluxapyroxad + Imidacloprid + Thiodicarb; Fluxapyroxad + Pyraclostrobin (Thiophanate-methyl + Fipronil); control (without any product application), two cultivars (TBIO Sossego and ORS 1401), two sowing dates (June and July) and four replicates. The following variables were evaluated: plant stand, number of tillers, hectoliter weight, 1000-grain weight, and grain yield. The means of the variables were subjected to individual variance analysis and grouped by the Scott-Knott test at $p \leq 0.05$. Additionally, 15 non-orthogonal contrasts were performed. The neonicotinoid active ingredient in the industrial treatment increased the number of tillers, 1000-grain weight, and grain yield. The carboxamide fungicide, alone or in combination, positively affected the plant stand. Treatment with fungicides or insecticides increases the grain yield of the evaluated cultivars. The agronomic and morphological traits were influenced by the sowing dates, with the second date showing the best grain yield. The TBIO Sossego cultivar showed higher values for plant stand, thousand-grain weight, and grain yield than ORS 1401 under the field conditions evaluated.

Key words: *Triticum aestivum* L., fungicide, insecticides, stand, grain yield

RESUMO: O tratamento industrial de sementes é uma prática agrícola moderna que visa fornecer proteção de sementes e mudas contra pragas, doenças e patógenos nos estágios iniciais das culturas. A pesquisa com cultivares de trigo visa avaliar os efeitos dos tratamentos industriais de sementes e sua influência em características agronômicas e morfológicas. Foi utilizado o delineamento em blocos casualizados, arranjados em esquema fatorial (10 × 2 × 2), com 10 tratamentos Imidacloprido; Tiodicarbe; Imidacloprido + Tiodicarbe; Piraclostrobina (Tiofanato-metil + Fipronil); Fluxapiroxade; Fluxapiroxade + Imidacloprido; Fluxapiroxade + Tiodicarbe; Fluxapiroxade + Imidacloprido + Tiodicarbe; Fluxapiroxade + Piraclostrobina (Tiofanato-metil + Fipronil); controle (sem aplicação de produto), duas cultivares (TBIO Sossego e ORS 1401), duas épocas de semeadura (junho e julho) e quatro repetições. Foram avaliadas as seguintes variáveis: estande de plantas, número de perfilhos, peso hectolitro, massa de 1000 grãos e produtividade de grãos. As médias das variáveis foram submetidas à análise de variância individual e agrupadas pelo teste de Scott-Knott com $p \leq 0,05$. Adicionalmente, foram realizados 15 contrastes não ortogonais. O ingrediente ativo neonicotinoide no tratamento industrial aumentou o número de perfilhos, a massa de 1000 grãos e a produtividade de grãos. O fungicida carboxamida, sozinho ou em combinação, afetou positivamente o estande de plantas. O tratamento com fungicidas ou inseticidas aumenta a produtividade de grãos das cultivares avaliadas. As características agronômicas e morfológicas foram influenciadas pelas épocas de semeadura, sendo a segunda época a que apresentou melhor produtividade de grãos. A cultivar TBIO Sossego apresentou maiores valores de estande de plantas, massa de mil grãos e produtividade de grãos do que a ORS 1401 nas condições de campo avaliadas.

Palavras-chave: *Triticum aestivum* L., fungicida, inseticidas, estande, produtividade de grãos

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Introduction

Several factors contribute to achieving satisfactory grain yield in wheat (*Triticum aestivum* L.), including the use of high-quality seeds and advanced genetics, which offer high yield potential and profitability, along with a high percentage of seedling emergence and uniform plant stand. These factors are considered essential (Abati et al., 2014; Cunha et al., 2015). Seed treatment is an important technology to ensure a suitable plant population. In addition to homogenizing the germination process, it shortens germination time, thereby reducing the need for reseeding and has a low environmental impact (Rubert et al., 2021).

Several products, such as micronutrients, bioregulators, insecticides, fungicides, inoculants, drying powders, and polymers, can be part of seed treatment, either isolated or combined, and can promote bioactive responses that positively influence several processes, such as germination (Camargo et al., 2022; Reis et al., 2023). To choose the correct seed treatment, industrial or conventional, it must consider the benefits it will provide to the crop, such as soil covering and efficiency, while also considering its potential influence on cultivar germination and vigor (Freiberg et al., 2017a).

Some active ingredients used in seed treatment interfere with plant metabolism, which may or may not benefit the crop (Reis et al., 2023). Studies evaluating the use of active ingredients in treating seeds for winter cereals are still scarce in Brazil. Many studies report results related to soybean crops (*Glycine max*), demonstrating either beneficial or phytotoxic effects depending on the active ingredient and its interaction with the crop—particularly during early seedling development—by providing protection in the initial growth stages and contributing to overall plant health (Cunha et al., 2015; Camargo et al., 2022).

The cultivars TBIO Sossego (developed by Biotrigo Genética) and ORS 1401 (developed by OR Sementes) were selected due to their medium plant height and suitability for grain production aimed at the baking industry (bread). Both cultivars exhibit resistance to major diseases, including mosaic virus, leaf rust, Fusarium head blight (gibberella), and blast.

This study evaluated the effects of industrial seed treatments on wheat, focusing on their impact on seedling development and their influence on the agronomic and morphological traits of field-grown plants, using two cultivars and two sowing dates.

Material and Methods

This study was conducted at the School Farm Experimental Field of the Universidade Estadual do Centro-Oeste (UNICENTRO), located in Guarapuava, Paraná state, Brazil, on a soil classified as Oxisol (Soil Survey Staff, 2022). The experimental field is 25° 22’ 58” S, 51° 33’ 10” W, with an altitude of 1,105 m. The experiment was performed under a no-tillage (NT) system, whose predecessor crop was soybean (*Glycine max* L.). Meteorological data on maximum and minimum temperatures (°C) and rainfall (mm) were collected from the meteorological station at Instituto Agronômico do Paraná (IAPAR), located at UNICENTRO, Guarapuava, Paraná state, Brazil.

The experiment was conducted using a randomized block design in a triple factorial arrangement (10 × 2 × 2), consisting of 10 industrial seed treatments (ISTs), two wheat cultivars, and two sowing dates (June and July), with four replicates, totaling 160 plots. Each plot consisted of nine rows, 5 m in length, spaced 0.20 m apart, resulting in a total area of 9 m² per plot. Sowing was performed at a depth of 4 cm, with a seeding density of 400 viable seeds per square meter (equivalent to 80 seeds per meter). The three central rows (5 m long) were considered for evaluation purposes, totaling a useful area of 3 m² per plot.

The evaluated cultivars were TBIO Sossego and ORS 1401, both recommended for the region of Guarapuava. These seeds exhibited the same initial traits regarding category, physical purity, germination, and agricultural production.

Table 1 shows the seed treatments performed before sowing. For the treatment of each sample, 1 kg of seeds per batch was used, along with the active ingredients, which were stirred for 30 s in an industrial seed treatment machine (model Hege 11) from the WINTERSTEIGER® brand. For each sample, the quantities of each active ingredient were added to 5 mL of distilled water, forming a homogeneous mixture.

The management of the crops was carried out according to the needs of the plants. Disease and insect control, aiming to prevent interference with the quality of the experiment, was

Table 1. Active ingredients and doses used in industrial wheat seed treatments

Treatment	Dose C.P.*	Active ingredient	Class	Conc Off A.I**	Chemical group
1	1 mL	Imidacloprid	I	600 g L^{-1}	Neonicotinoid
2	1 mL	Thiodicarb	I	350 g L^{-1}	Oxime methylcarbamate
3	2.5 mL	Imidacloprid + Thiodicarb	I+I	150 + 450 g L^{-1}	Neonicotinoid, Oxime methylcarbamate
4	1.0 mL	Pyraclostrobin+ (Thiophanate-methyl + Fipronil)	F+F+I	25 +225 + 250 g L^{-1}	Strobilurins, (Benzimidazole, Pyrazole)
5	1.0 mL	Fluxapyroxad	F	363 g L^{-1}	Carboxamide
6	2.0 mL	Fluxapyroxad + Imidacloprid	F+I	363 + 250 g L^{-1}	Carboxamide, Neonicotinoid
7	2.5 mL	Fluxapyroxad + Thiodicarb	F+I	363 g +350 g L^{-1}	Carboxamide, Oxime methylcarbamate
8	3.5 mL	Fluxapyroxad + Imidacloprid + Thiodicarb	F+I+I	363 + 600 + 350 g L^{-1}	Carboxamide, Neonicotinoid, Oxime methylcarbamate
9	2.0 mL	Fluxapyroxad + Pyraclostrobin + (Thiophanate-methyl + Fipronil)	F+F+F+I	363 + 0.25 + 225 + 250 g L^{-1}	Carboxamide, Strobilurins, (Benzimidazole, Pyrazole)
10	Control: No addition of active ingredients				

*C.P. - Commercial Product per 1 kg of seed; Class - Insecticide I; Fungicide F; ** A.I. - Dose of the Active Ingredient per 1 L of C.P; TREAT - Treatment; CONC – Concentration based on Technical Information for wheat and triticale (2017). Basic fertilization and topdressing were performed according to the soil analysis of the site.

The seed harvest for the first sowing date (06/29/2018) was carried out in November (11/13/2018), and for the second sowing date (07/25/2018) in December (12/03/2018), when the grains had around 14% moisture. Manual harvesting was carried out by collecting the three central rows of each experimental plot, which were used for evaluations. Samples were processed using a WINTERSTEIGER® plot harvester.

The following agronomic traits were evaluated: plant stand (ST); number of tillers (NT), expressed as the number of tillers per plant; hectoliter weight (HW); 1000-grain weight (P1000), expressed in grams; and grain yield (GY). Data were tested for homogeneity of variances using the Hartley test. Subsequently, analysis of variance (ANOVA) and the Scott–Knott grouping method at $p \leq 0.05$ were performed using SISVAR® software (Ferreira, 2019).

Fifteen non-orthogonal contrasts were also performed (CON vs. I; CON vs. F; I vs. F; NEO vs. MET; NEO vs. NEO + MET; MET vs. NEO + MET; CARB vs. NEO; CARB vs. NEO + MET; CARB vs. MET; ASSOC vs. MET; ASSOC vs. NEO; ASSOC vs. NEO + MET; CARB vs. ASSOC; S1 vs. S2; and C1 vs. C2), aiming to compare the seed treatments in both crops and at the two sowing dates concerning plant stand (ST), number of tillers per plant (NT), hectoliter weight (HW), 1000-grain weight (P1000), and grain yield (GY).

Results and Discussion

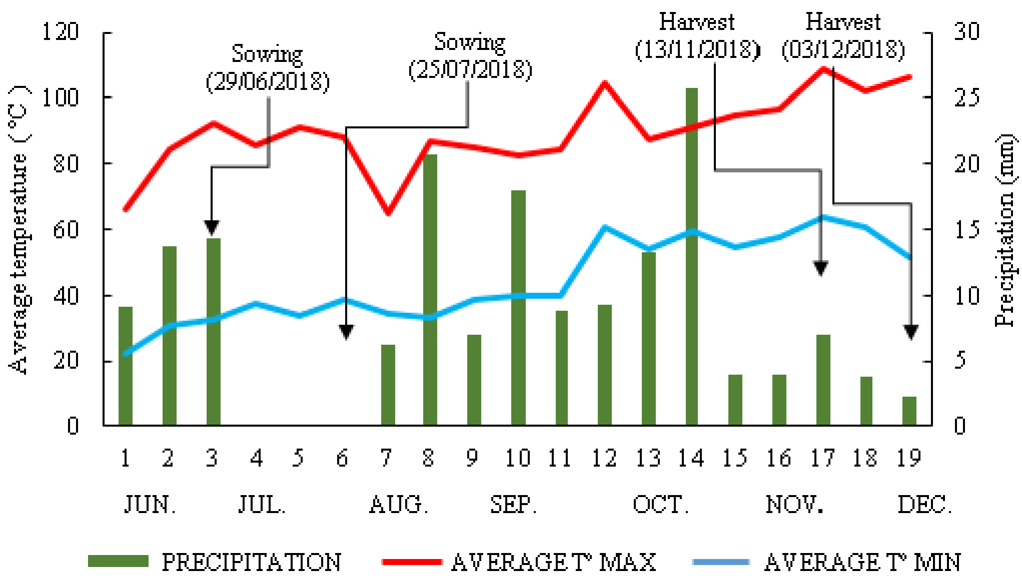
The first sowing occurred in the last ten-day period of June (Figure 1) under adequate soil moisture conditions. However, soon after, there was a long period of drought with low rainfall in July (4th, 5th, and 6th ten-day periods). During this period, the plants were developing tillers (first sowing - June) and seedling growth (second sowing - July).

Drought periods during plant development can affect the soil-plant-atmosphere system, which is explained by the increased demand for water, nutrients, and CO_2 after germination. This higher demand is used to supply energy needs for a higher rate of evapotranspiration, photosynthesis, plant respiration, and development. Therefore, when these factors are insufficient, it will increase plant stress, harming its development (Eberbach et al., 2019).

It is worth mentioning that there were different weather conditions after the implementation of the experiments when the two sowing dates were evaluated. Thus, it is possible to demonstrate the benefit of using or not using different active ingredients in the IST under field conditions since, according to research, some active ingredients are capable of assisting plants during stress periods (Sartori et al., 2023; Medeiros et al., 2023).

Therefore, the crop from the first sowing date completed the cycle in 144 days with a total precipitation of 398 mm (Figure 1). For the crop from the second sowing date, the cycle lasted 131 days with a total precipitation of 438 mm. Considering that the duration of each subperiod at each stage of the crop is influenced by environmental conditions, up to the eighth ten-day period, the average minimum temperature was 10 °C, and the average maximum temperature was 25 °C, with temperature dropping below 6 °C (Figure 1). Hossain et al. (2012) concluded that for wheat and barley, temperatures above 20-25 °C affect the development, growth, and phenology of these cereals. Thus, due to the temperature increase, there was a decrease in the crop cycle duration for the second sowing date (Medeiros et al., 2023).

Based on the analysis of variance results presented in Table 2, significant effects ($p \leq 0.05$) were observed for all evaluated variables. For plant stand (ST), there was a significant triple interaction among the factors cultivar × treatment × sowing season (C × T × S). The same triple interaction was observed for the number of tillers (NT) and hectoliter weight (HW). For 1000-grain weight (P1000), significant double interactions were found between cultivar × treatment (C × T) and cultivar × sowing season (C × S). Additionally, for grain yield, a



Source: Meteorological Station, UNICENTRO; T° MAX – Maximum temperature; T° MIN – Minimum temperature

Figure 1. Precipitation and average air temperature data by ten-day period, from the 1st ten-day period of June (1) to the 1st ten-day period of December (19), in Guarapuava, Paraná state, Brazil

Table 2. Summary of the analysis of variance for plant stand (ST), number of tillers per plant (NT), hectoliter weight (HW), thousand-grain weight (P1000), and grain yield (GY), according to different industrial seed treatments in the wheat cultivars TBIO Sossego and ORS 1401, across two sowing seasons, in Guarapuava, Paraná state, Brazil

Source of variation	DF	Mean squares				
		ST	NT	HW	P1000	GY
Cultivar (C)	1	823.66*	0.018 ns	60.27 *	837.63 *	2139631.41 *
Treatment (T)	9	229.11 ns	0.0766 *	14.02 *	62.99 *	1349335.59 *
Season (S)	1	3970.06 **	3.606 *	834.93 *	75.14 **	2655011.11 *
Blocks	3	166.61 ns	0.449 ns	2.40 ns	21.36 ns	399579.45 ns
C × T	9	61.60 ns	0.239 ns	10.61 *	24.91 **	360819.53 ns
C × S	1	2318.01 **	0.140 ns	9.95 ns	79.93 **	577284.71 ns
T × S	9	253.17 **	0.601 **	13.50 *	15.34 ns	449495.5 **
C × T × S	9	362.58 **	0.655 **	9.41 *	12.82 ns	422660.96 ns
Error	114	124.89	0.275	2.72	12.56	218157.75
Mean		64.59	1.98	72.35	21.8	3287.86
CV (%)		17.3	26.44	2.28	16.26	14.21

DF – Degrees of freedom; *, **, ns – Significant at $p \leq 0.05$, $p \leq 0.01$, and not significant, respectively, according to the F-test

significant interaction was observed between treatment × sowing season (T × S).

Analyzing the results obtained for the plant stand (Table 3), which presented a significant triple interaction between the factors, it was found that for the sowing time factor, the second sowing time (July) presented an increase of 16.73% in the number of plants concerning the first sowing time (June). Where greater water stress occurred (Table 1), the seed treatments with Pyraclostrobin + (Thiophanate methyl + Fipronil) and Fluxapyroxad + Imidacloprid + Thiodicarb allowed a better plant stand when evaluating the cultivar TBIO Sossego. The cultivar ORS 1401 had a better stand in the second sowing season (July) for the seed treatment with Pyraclostrobin + (Methyl Thiophanate + Fipronil) and Thiodicarb.

The first sowing occurred with adequate soil moisture, but subsequently, there was a 30-day period of low precipitation. During this interval, the seeds germinated, but there was not enough water for their initial development, which damaged the final stand.

Therefore, using technologies that lead to homogenization of the germination process is essential, as well as reducing the germination time among batches (Sartori et al., 2023). Thus, seed treatment can be an essential practice, aiding in the initial development of plants in unfavorable soil and climate conditions.

Some studies have reported that certain active ingredients may reduce germination and seedling survival in the field when applied to seeds. This effect, as observed by Freiberg et al. (2017a), is attributed to specific active ingredients that can disrupt the ionic balance in seedlings, thereby interfering with various physiological processes.

The number of tillers (Table 4) showed a significant three-way interaction among cultivar, treatment, and sowing date. Regarding the average number of tillers across sowing dates, values were higher for the first sowing date than the second.

Higher temperatures during germination and emergence of winter cereals are significant factors in interfering with the development of tillers per plant (Ma et al., 2018), as verified in this study. A significant difference between cultivars was observed only for the first sowing date concerning the number of tillers (Table 4), with the Thiodicarb treatment resulting in lower values than the others. Seed treatments with Imidacloprid and Thiodicarb positively influenced tiller production in the cultivar ORS 1401 during the first sowing season (June). In another study on wheat using Imidacloprid for seed treatment (ST), Camargo et al. (2021) concluded that using this active ingredient is more advantageous than not performing ST. This statement is because ST is financially viable, even if there is no incidence of pests, due to the higher grain yield than the control.

The hectoliter weight (HW) (Table 5) showed a three-way significant interaction between the factors cultivar x treatment x season (C × T × S). This result is due to environmental conditions since HW is highly influenced by them. However,

Table 3. Plant stand (ST) according to the different industrial seed treatments in the wheat cultivars TBIO Sossego and ORS 1401 on two different sowing dates in Guarapuava, Paraná state, Brazil

Treatment	June		July	
	TBIO Sossego	ORS 1401	TBIO Sossego	ORS 1401
Imidacloprid	50.38 bAβ	40.00 aAβ	67.37 aAα	72.88 aAα
Thiodicarb	70.50 bAα	51.13 aBβ	62.00 aAα	74.88 aAα
Imidacloprid + Thiodicarb	64.25 bAα	54.13 aAβ	61.50 aAα	72.00 aAα
Pyraclostrobin + (Thiophanate-methyl + Fipronil)	86.87 aAα	57.00 aBβ	64.13 aAβ	75.63 aAα
Fluxapyroxad	60.75 bAβ	56.25 aAβ	82.50 aAα	72.75 aAα
Fluxapyroxad + Imidacloprid	60.00 bAα	55.88 aAα	73.00 aAβ	64.88 aAα
Fluxapyroxad + Thiodicarb	67.37 bAα	54.38 aAβ	68.13 aAα	74.13 aAα
Fluxapyroxad + Imidacloprid + Thiodicarb	79.50 aAα	56.00 aBβ	60.75 aAβ	74.38 aAα
Fluxapyroxad + Pyraclostrobin + (Thiophanate-methyl + Fipronil)	66.62 bAα	50.25 aBα	71.38 aAα	66.00 aAα
Control	50.75 bAβ	60.25 aAα	69.75 aAα	63.50 aAα

Means followed by the same lowercase Roman letter within a column do not differ significantly between treatments. Means followed by the same lowercase Greek letter within a column do not differ significantly between periods for the same cultivar. Means followed by the same uppercase Roman letter within a row indicate that cultivars across periods belong to the same group, according to the Scott-Knott test ($p \leq 0.05$)

Table 4. Number of tillers per plant (NT) according to the different industrial seed treatments in wheat cultivars TBIO Sossego and ORS 1401 in two different sowing dates in Guarapuava, Paraná state, Brazil

Treatment	June		July	
	TBIO Sossego	ORS 1401	TBIO Sossego	ORS 1401
Imidacloprid	2.9 aAα	3.1 aAα	1.9 aAβ	1.8 aAβ
Thiodicarb	1.5 bBα	2.8 aAα	1.7 aAα	1.5 aAβ
Imidacloprid + Thiodicarb	1.7 bAα	1.9 bAα	2.0 aAα	1.6 aAα
Pyraclostrobin + (Thiophanate-methyl + Fipronil)	1.4 bAα	2.1 bAα	1.7 aAα	1.7 aAα
Fluxapyroxad	2.4 aAα	2.0 bAα	1.5 aAβ	1.8 aAα
Fluxapyroxad + Imidacloprid	2.3 aAα	1.9 bAα	1.8 aAα	2.0 aAα
Fluxapyroxad + Thiodicarb	2.1 aAα	2.0 bAα	2.0 aAα	1.8 aAα
Fluxapyroxad + Imidacloprid + Thiodicarb	1.4 bAα	1.6 bAα	2.0 aAα	1.5 aAα
Fluxapyroxad + Pyraclostrobin+ (Thiophanate-methyl + Fipronil)	2.4aAα	1.9 bAα	1.6 aAα	1.9 aAα
Control	2.4 aAα	1.9 bAα	1.8 aAα	2.1 aAα

Means followed by the same lowercase Roman letter within a column do not differ significantly between treatments. Means followed by the same lowercase Greek letter within a column do not differ significantly between periods for the same cultivar. Means followed by the same uppercase Roman letter within a row indicate that cultivars across periods belong to the same group, according to the Scott-Knott test ($p \leq 0.05$)

Table 5. Hectoliter weight (HW) according to the different industrial seed treatments in wheat cultivars TBIO Sossego and ORS 1401 in two different sowing dates in Guarapuava, Paraná state, Brazil

Treatment	June		July	
	TBIO Sossego	ORS 1401	TBIO Sossego	ORS 1401
Imidacloprid	77.25 aAα	75.83 aAα	72.46 aAβ	70.40 aAβ
Thiodicarb	76.63 aAα	70.56 cBα	70.85 aAβ	69.61 aAα
Imidacloprid + Thiodicarb	74.27 aAα	71.11 cBα	69.50 aAβ	70.80 aAα
Pyraclostrobin + (Thiophanate methyl + Fipronil)	74.81 aAα	72.19 cBα	68.21 aAβ	69.05 aAβ
Fluxapyroxad	75.20 aAα	69.96 cBα	72.31 aAβ	70.51 aAα
Fluxapyroxad + Imidacloprid	76.73 aAα	73.93 bBα	70.46 aAβ	68.60 aAβ
Fluxapyroxad + Thiodicarb	74.99 aAα	76.68 aAα	72.93 aAα	70.90 aAβ
Fluxapyroxad + Imidacloprid + Thiodicarb	75.44 aAα	74.48 bAα	70.23 aAβ	69.23 aAβ
Fluxapyroxad + Pyraclostrobin + (Thiophanate methyl + Fipronil)	74.60 aAα	76.90 aAα	69.73 aAβ	68.54 aAβ
Control	75.15 aAα	76.16 aAα	75.10 aAβ	69.45 aAβ

Means followed by the same lowercase Roman letter within a column do not differ significantly between treatments. Means followed by the same lowercase Greek letter within a column do not differ significantly between periods for the same cultivar. Means followed by the same uppercase Roman letter within a row indicate that cultivars across periods belong to the same group, according to the Scott-Knott test ($p \leq 0.05$)

sowing season 1 was planted within the zoning, with ideal temperature conditions for the crop, while season 2 was planted outside the zoning, experiencing a period of high temperatures at the end of the cycle, leading to a decrease in HW. According to the Normative Instruction for wheat classification, the hectoliter weight (HW) equal to or greater than 78 kg hL^{-1} for clean grain at 13% moisture is considered the reference value for high industrial quality wheat.

However, the HW for wheat crops is a genetic factor, a wheat quality trait. Still, it can be harmed by the occurrence of rains during physical maturation, as well as high temperatures, affecting the quality of the grains (Franceschi et al., 2009).

O HW was positively influenced by seed treatments based on Imidacloprid, Pyraclostrobin + (Thiophanate methyl + Fipronil), Fluxapyroxad + Imidacloprid, Fluxapyroxad + Imidacloprid + Thiodicarb, Fluxapyroxad + Pyraclostrobin + (Thiophanate methyl + Fipronil), and Control, in both cultivars evaluated TBIO Sossego and ORS 1401, when sowing occurred in June. Regarding the cultivars in each treatment, there was a difference for the treatments: Thiodicarb, Imidacloprid + Thiodicarb, Pyraclostrobin + (Thiophanate methyl + Fipronil), Fluxapyroxad, and Fluxapyroxad + Imidacloprid which were inferior to the cultivar TBIO Sossego; and concerning season 2, with no difference between the treatments. In season 1, in both cultivars (TBI Sossego and ORS 1401), the treatments Imidacloprid, Fluxapyroxad + Imidacloprid, Fluxapyroxad + Thiodicarb, Fluxapyroxad + Imidacloprid + Thiodicarb), Fluxapyroxad + Pyraclostrobin + (Thiophanate methyl + Fipronil), and the control were superior to the others. Season 1 presented a superior result to season 2 for the treatments. For season 2, the treatments, Imidacloprid, Fluxapyroxad, and Fluxapyroxad + Thiodicarb, were superior, differentiating them from the others for the TBI Sossego cultivar as well as for ORS 1401. Although the HW is an inherent trait of the cultivar, as reported by Franceschi et al. (2009), this factor can be benefited or suspended in the industrial seed treatment (IST) conditions since this technology was innovative in the seed, in some treatments, it is more efficient in this aspect.

The first sowing date showed the best results regarding 1000-grain weight (Table 6), which presented a double significant interaction between cultivar × treatment and cultivar × sowing date. This fact may be related to the plant's grain production, as water stress may have contributed to a smaller number of grains, interfering with photoassimilate distribution in the grains and consequently leading to greater grain weight. The cultivar ORS 1401 did not show significant effects for the treatments in the evaluated trait.

For the cultivar TBIO Sossego, the treatments using Imidacloprid, Fluxapyroxad, Fluxapyroxad + Thiodicarb, and Fluxapyroxad + Imidacloprid + Thiodicarb presented the highest averages compared to the other treatments. The treatment using Thiodicarb showed the lowest average 1000-grain weight. A study carried out applying Tebuconazole, Pyraclostrobin, and Metiram + Pyraclostrobin fungicides in

Table 6. 1000-grain weight (P1000) of two wheat cultivars (TBIO Sossego and ORS 1401) treated with different industrial seed treatments (IST) and evaluated in two different sowing dates in Guarapuava, Paraná state, Brazil

Treatment	TBIO Sossego	ORS 1401
Imidacloprid	28.26 aA	21.39 aB
Thiodicarb	18.08 cA	18.45 aA
Imidacloprid + Thiodicarb	23.58 bA	18.47 aB
Pyraclostrobin + (Thiophanate methyl + Fipronil)	23.09 bA	19.06 aB
Fluxapyroxad	25.56 aA	17.79 aB
Fluxapyroxad + Imidacloprid	22.73 bA	18.81 aB
Fluxapyroxad + Thiodicarb	25.90 aA	21.74 aB
Fluxapyroxad + Imidacloprid + Thiodicarb	28.04 aA	20.15 aB
Fluxapyroxad + Pyraclostrobin + (Thiophanate methyl + Fipronil)	21.83 bA	20.41 aA
Control	20.20 bA	18.85 aA
Season		
June	24.11 A	18.12 B
July	24.07 A	20.91 B

Means followed by the same lowercase letter in the column and uppercase letters in the line belong to the same group by the Scott-Knott test ($p \leq 0.05$)

soybean crops showed the best disease control levels and also the highest 1000-grain weight values (Demant & Maringoni, 2012). Thus, it is clear that the fungicide used in industrial seed treatment can have a positive effect on the 1000-grain weight of wheat.

Nonetheless, the flowering and grain formation stages occurred during periods of rainfall without total water restriction (Figure 1). However, the rainfall levels during these stages are related to wheat grain yield. According to Franceschi et al. (2010), water deficiency or a reduction in water availability during these stages can decrease the number of grains per spike and, consequently, reduce crop yield. The lower water availability in the second sowing date led to a 19% reduction in 1000-grain weight, as 188 mm of rainfall were recorded during the last four ten-day periods (10, 14, 15, and 16) before harvest in the first sowing date, compared to only 75 mm during the same interval (periods 15, 16, 17, and 18) in the second sowing date. This reduction in precipitation negatively affected grain filling, resulting in lower grain weight.

From the weather factors described in Figure 1, a relationship can be observed with all the agronomic traits analyzed. According to Silva et al. (2011), the grain yield potential can be maximized by choosing the appropriate sowing period without increasing the production cost. Therefore, this is a fundamental practice, and sowing recommendations must be followed for each location within the Agricultural Zoning of Climate Risk. However, it is necessary to consider the current local conditions, such as the expected rainfall, to ensure the crop's initial development and plant stand.

In the first sowing date, there was a water deficit after the crop planting (Figure 1), leading to a lower germination index and, consequently, a smaller stand (Table 3). This may explain the difference in grain yield between the sowing dates. In the second sowing date, there is no difference between cultivars; it is remarkable how good the grain yield of the cultivar ORS 1401 is in periods with favorable growth conditions. On the other hand, the cultivar TBIO Sossego is more stable under varying weather conditions, achieving higher grain yield even in unfavorable environments. Thus, it is highlighted that each cultivar exhibits different behavior under different weather conditions (Liu et al., 2018).

According to Macedo & Castro (2011), the use of some active ingredients in industrial seed treatment can increase wheat production. Using Thiamethoxam, Abamectin + Thiamethoxam + Fludioxonil, Fipronil + Thiophanate-methyl + Pyraclostrobin, Imidacloprid + Thiodicarb, Carboxamide, Abamectin, and Metalaxyl-M + Fludioxonil as active ingredients in seed treatment, Cunha et al. (2015) observed beneficial effects in several stages of soybean initial growth and crop development, but no effect on grain yield was observed.

Among the cultivars (Table 7), there were differences between the treatments using Fluxapyroxad and the control for cultivar ORS 1401, differing from those in cultivar TBIO Sossego. In this way, the behavior of the cultivar regarding the treatment can be different at the same sowing date. For the second sowing date, there was no statistical difference between treatments for cultivar TBIO Sossego, but for cultivar ORS 1401, the treatments using Imidacloprid and Fluxapyroxad obtained the best results, differing from all other treatments. In their study, Milosavljević et al. (2019) highlighted the economic return of using the active ingredient Imidacloprid in wheat due to its impact on grain yield, concluding that its use is more beneficial in plots with industrial seed treatment, even though there was no high incidence of pests in the experiment.

The production of the cultivar TBIO Sossego (Table 7) under the treatment using Imidacloprid was inferior compared to the production of the cultivar ORS 1401 under the same treatment. It was also observed that the treatment using Pyraclostrobin (Thiophanate-methyl + Fipronil) for the ORS 1401 cultivar resulted in lower grain yield (Table 7) when compared to the cultivar TBIO Sossego, showing a statistical difference between the treatments within the cultivars. Thus, the variation of treatments within the cultivars was highlighted again.

In the first sowing date (Table 7), the treatment using Fluxapyroxad + Thiodicarb showed the best average (3,930 kg ha^{-1}), differing statistically from the treatments using Imidacloprid, Fluxapyroxad + Imidacloprid + Thiodicarb,

Table 7. Grain yield (GY) of two wheat cultivars (TBIO Sossego and ORS 1401) treated with different industrial seed treatments and evaluated in two sowing dates in Guarapuava, Paraná state, Brazil

Treatment	June	July
Imidacloprid	3359 B	3924 A
Thiodicarb	2887 A	3306 A
Imidacloprid + Thiodicarb	2785 A	3106 A
Pyraclostrobin+(Thiophanate methyl + Fipronil)	3072 A	3140 A
Fluxapyroxad	3049 B	3707 A
Fluxapyroxad + Imidacloprid	3082 B	3648 A
Fluxapyroxad + Thiodicarb	3930 A	3503 A
Fluxapyroxad + Imidacloprid + Thiodicarb	3400 A	3598 A
Fluxapyroxad + Pyraclostrobin + (Thiophanate methyl + Fipronil)	3366 A	3259 A
Control	2663 A	3004 A

Means followed by the same uppercase letter in the line belong to the same group by the Scott-Knott test ($p \leq 0.05$)

and Fluxapyroxad + Pyraclostrobin (Thiophanate-methyl + Fipronil). Finally, the lowest averages were obtained using the following treatments: Thiodicarb, Imidacloprid + Thiodicarb, Pyraclostrobin (Thiophanate-methyl + Fipronil), Fluxapyroxad, Fluxapyroxad + Imidacloprid, and the control.

Therefore, the use of seed treatment, compared to the control, in most cases helps to reduce grain yield losses, and the intensity of this loss can be even greater when the plant experiences a water deficit. It can be stated that using IST with any active ingredient is superior to not using IST. These findings are consistent with laboratory results reported by Hossen et al. (2014), who suggested that seed treatment (ST) can benefit wheat crops by promoting more uniform and productive plants.

According to Freiberg et al. (2017b), the use of wheat seed treatment with Abamectin + Thiamethoxam + Fludioxonil + Mefenoxam + Thiabendazole under adverse water stress conditions resulted in treated seeds showing a grain yield of 57.4% higher than untreated seeds. In this way, as confirmed in the present experiment, the following hypothesis can be confirmed: IST acts as a bioactivator capable of assisting in cases of field stress conditions.

Table 8 shows the non-orthogonal contrasts to compare the different industrial seed treatments in the two wheat cultivars (TBIO Sossego and ORS 1401) and under two sowing dates concerning the evaluated agronomic and morphological traits in Guarapuava, Paraná state, Brazil.

Regarding plant stand (ST), the contrasts I vs. F, CARB vs. NEO, ASSOC vs. NEO + MET, S1 vs. S2, and C1 vs. C2 were significant (Table 8). It is worth mentioning that for I vs. F and S1 vs. S2, the contrasts were negative, whereas for CARB vs. NEO, ASSOC vs. NEO + MET, and C1 vs. C2, the contrasts were positive, indicating numerical superiority. Therefore, using fungicides in IST is superior to using insecticides for the plant stand factor. Moreover, the use of Carboxamide is superior to Neonicotinoid.

Nevertheless, the combination of fungicides and insecticides was superior to the use of Neonicotinoid and oxime methylcarbamate. In a study using insecticides and fungicides for the treatment of soybean seeds, it was concluded that the use of mixtures in IST can benefit seedling emergence in the field (Moraes et al., 2022). For hectoliter weight (HW), only the contrast S1 vs. S2 was significant, showing more than 95% probability and indicating a negative contrast, which suggests the superiority of the first sowing date. Although hectoliter weight is a genetic factor, as observed in previous results, it can be influenced by environmental conditions that cause morphological changes. Experiments treating soybean seeds with Thiamethoxam, Fipronil, and Imidacloprid insecticides showed results similar to the control, with no significant effect of IST on hectoliter weight (Dan et al., 2012).

Regarding the number of tillers per plant (NT), significance was observed at more than 95% probability for the contrasts NEO vs. MET, NEO vs. NEO + MET, and S1 vs. S2, indicating a positive contrast and, thus, superiority. For the contrasts CARB vs. NEO and ASSOC vs. NEO + MET, superiority was indicated by a negative contrast. Therefore, oxime methylcarbamate is superior to the others concerning the number of tillers per plant. Moreover, the sowing dates differed significantly, with the first sowing date showing better results. It was also observed that the use of Neonicotinoid was superior to Carboxamide, and the treatment with Neonicotinoid plus oxime methylcarbamate yielded better results than the treatment with the combination of fungicides and insecticides. According to Macedo & Castro (2011), using insecticides in wheat seed treatment resulted in higher tiller growth. However, Ma et al. (2018) found that tiller growth decreased when wheat was sown outside the recommended period, indicating that this trait is closely linked to the sowing period and its edaphoclimatic conditions.

For 1000-grain weight (P1000), the following contrasts were significant at more than 95% probability: NEO vs. MET, NEO vs. NEO + MET, CARB vs. MET, ASSOC vs. NEO, and C1 vs. C2, indicating positive superiority; and MET vs. NEO + MET, ASSOC vs. NEO + MET, and S1 vs. S2, indicating negative superiority. According to the results, it can be observed that the treatments with active ingredients can positively affect

Table 8. Estimation of significance probability of the contrasts for plant stand (ST), hectoliter weight (HW), number of tillers per plant (NT), 1000-grain weight (P1000), and grain yield (GY) obtained with the different industrial seed treatments of two wheat cultivars (TBIO Sossego and ORS 1401) in two sowing dates

CONTRAST	ST	HW	NT	P1000	GY
CON vs. I	(-) 0.85	(-) 0.75	(-) 0.98	(-) 0.34	(-) 0.01
CON vs. F	(-) 0.12	(-) 0.52	(+) 0.55	(-) 0.32	(-) 0.01
I vs. F	(-) 0.01	(-) 0.63	(+) 0.45	(-) 0.78	(-) 0.30
NEO vs. MET	(-) 0.13	(-) 0.30	(+) 0.01	(+) 0.01	(+) 0.01
NEO vs. NEO + MET	(-) 0.24	(-) 0.70	(+) 0.01	(+) 0.01	(+) 0.01
MET vs. NEO + MET	(+) 0.71	(+) 0.52	(+) 0.67	(-) 0.04	(+) 0.40
CARB vs. NEO	(+) 0.02	(+) 0.39	(-) 0.01	(-) 0.01	(-) 0.14
CARB vs. NEO + MET	(+) 0.26	(+) 0.64	(+) 0.54	(+) 0.63	(+) 0.02
CARB vs. MET	(+) 0.45	(-) 0.86	(+) 0.86	(+) 0.01	(+) 0.12
ASSOC vs. MET	(+) 0.08	(+) 0.97	(-) 0.78	(+) 0.97	(+) 0.37
ASSOC vs. NEO	(+) 0.17	(+) 0.28	(-) 0.47	(+) 0.04	(+) 0.96
ASSOC vs. NEO + MET	(+) 0.04	(+) 0.49	(-) 0.01	(-) 0.01	(+) 0.01
CARB vs. ASSOC	(-) 0.53	(-) 0.83	(+) 0.37	(+) 0.66	(+) 0.13
S1 vs. S2	(-) 0.01	(+) 0.01	(+) 0.01	(-) 0.02	(-) 0.01
C1 vs. C2	(+) 0.03	(+) 0.06	(-) 0.81	(+) 0.01	(+) 0.01
CV %	19.76	6.28	28.58	17.23	15.3

CON (Control); I (Insecticides: Imidacloprid; Thiodicarb; Imidacloprid + Thiodicarb); F (Carboxamide Fungicide: Fluxapyroxad); NEO (Neonicotinoid: Imidacloprid); MET (Oxime Methylcarbamate); CARB (Carboxamide: Fluxapyroxad); ASSOC (Association of Fungicide (F) and Insecticides (I)); C1 (Cultivar TBIO Sossego); C2 (Cultivar ORS 1401); S1 (First Sowing Date) and S2 (Second Sowing Date); (+) Positive: Superiority on the Left of the Contrast; (-) Negative: Superiority on the Right of the Contrast. Significant ($p \leq 0.05$)

the 1000-grain weight. Specifically, the use of certain active ingredients can affect the 1000-grain weight. In their study, Henry et al. (2011) found that using Pyraclostrobin in soybean seed treatment increased the seed weight.

The statistical difference between treatments C1 and C2 evidences the efficiency of the cultivar TBIO Sossego, which was superior to ORS 1401 for 1000-grain weight. Furthermore, the significant contrast between the sowing dates (S1 vs. S2) indicates that the second sowing date (S2) had a higher 1000-grain weight than the first sowing date (S1). For grain yield (PROD), significance was observed for CON vs. I, CON vs. F, and S1 vs. S2, showing superiority on the negative side of the contrast, and for NEO vs. MET; NEO vs. NEO + MET; CARB vs. NEO + MET; ASSOC vs. NEO + MET and C1 vs. C2, showing superiority on the positive side of the contrast.

However, it can be inferred that there was a positive response to the application of fungicides and insecticides, affecting grain yield. Thus, using an active ingredient is superior to its non-use, demonstrating that IST is essential. Non-orthogonal contrasts showed significance between the treatments using NEO and CARB and the combination of fungicides and insecticides, indicating that the active ingredients can influence grain yield. Studies using Thiamethoxam and Pyraclostrobin in IST showed improvements in some physiological parameters of soybean crops, increasing their tolerance to water stress and positively affecting grain yield (Balardin et al., 2011).

The observed significance of contrasts between the cultivars shows that cultivar TBIO Sossego was superior to ORS 1401 concerning all the variables. However, the response of the IST can vary depending on the species and cultivar. Statistical significance was observed between sowing dates; thus, higher grain yield was achieved on the second sowing date. This result can be attributed to the amount of precipitation, which caused stress during the early stages of wheat development, thereby affecting its yield potential. Notably, the second sowing date showed greater grain yield even outside the Agricultural Zoning of Climate Risk (ZARC). At the beginning of the wheat crop, crop establishment is crucial for achieving satisfactory yield results.

Conclusions

1. The neonicotinoid active ingredient in the industrial seed treatment increased the number of tillers, 1000-grain weight, and grain yield.

2. The carboxamide fungicide, either alone or in association, increased plant stand.

3. The industrial seed treatment with fungicides or insecticides increased the grain yield of the evaluated wheat cultivars.

4. The agronomic and morphological traits evaluated were influenced by the sowing dates, with the highest grain yields obtained on the second sowing date (July).

5. The cultivar TBIO Sossego showed higher values for plant stand, 1000-grain weight, and grain yield than the cultivar ORS 1401.

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