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Cultivar, sowing density, or time of emission: What influences mortality and performance of wheat tillers the most?

Cultivar, densidade de semeadura ou momento da emissão: o que influencia mais a mortalidade e desempenho de perfilhos de trigo?

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ABSTRACT

The emission and survival of wheat tillers can be influenced by several factors. This study aimes to evaluate the influence of sowing density, tillering potential, and temporal order of emission on the survival, and performance of individual tillers by contrasting the tillering potential of wheat cultivars. The experiment design consisted of a randomized block design with four replications, in a 2×4 factorial scheme, consisting of two wheat cultivars (*TBIO Toruk and TBIO Sossego*) and four sowing densities (208, 312, 416, and 500 viable seeds m^{-2}). Tillers were identified weekly, according to the temporal order of emission, for four consecutive weeks. The study evaluated emission, survival, and productive performance of all tillers, in addition to plant height, peduncle length, stem diameter, fresh weight, and presence of grains. The overall mortality of emitted tillers was 24%. A decrease of 73% in emission and 92% in tiller survival was observed over a period of four weeks. The increased sowing density led to a decrease of 43% in emission and 44% in tiller survival. The cultivar *Sossego* presented less tillering potential, but with higher survival rate than *Toruk*. The first two emitted tillers represented 77% of the total emitted tillers. Surviving tillers emitted in the first week were responsible for 40% of the total presence of grains at the end of the wheat cycle.

KEYWORDS: *Triticum aestivum*, tillering potential, time of emission.

RESUMO

A emissão e sobrevivência de perfilhos em trigo depende de diversos fatores. Neste estudo, objetivou-se avaliar a influência da densidade de semeadura, do potencial de perfilhamento e da ordem temporal de emissão de perfilhos, na emissão, na sobrevivência e no desempenho de perfilhos individuais em cultivares de trigo contrastantes quanto ao potencial de perfilhamento. O experimento foi realizado em delineamento de blocos casualizados, com quatro repetições, em esquema fatorial 2x4; sendo duas cultivares de trigo (TBIO Toruk e TBIO Sossego) e quatro densidades de semeadura (208; 312; 416 e 500 sementes aptas m^{-2}). Os perfilhos foram identificados semanalmente, conforme a ordem temporal de emissão durante quatro semanas consecutivas. Foram avaliadas a emissão, a sobrevivência e o desempenho produtivos de todos os perfilhos, além disso, foram avaliadas a altura de plantas, comprimento do pedúnculo, diâmetro de colmo, massa verde e presença de grãos. A mortalidade geral de perfilhos emitidos foi de 24%. Houve um decréscimo de 73% na emissão e 92% na sobrevivência de perfilhos ao longo de quatro semanas. O aumento da densidade de semeadura promoveu decréscimo de 43% na emissão e 44% na sobrevivência de perfilhos. A cultivar Sossego apresentou menor potencial de perfilhamento, mas com sobrevivência superior a Toruk. Os dois primeiros perfilhos emitidos representaram 77% do total de perfilhos emitidos. Perfilhos sobreviventes emitidos na primeira semana foram responsáveis por 40% do total da presença de grãos ao final do ciclo.

PALAVRAS-CHAVE: *Triticum aestivum,* potencial de perfilhamento, época de emissão.

INTRODUCTION

Tillers are lateral branches derived from meristematic cells (buds). They represent a compensation mechanism for empty spaces within a plant community in species of the *Poaceae* family (ALMEIDA et al. 2004). Tiller composition is directly related to grain yield, significantly affecting the structure and quality of a population of wheat plants. Moreover, the construction of a population structure based on productive tillers increases crop yield potential (CAI et al. 2014).

Sowing density is one of the management techniques that can most influence the behavior of wheat tillering and its yield components. The ability of wheat to compensate for the lack or excess of one component through changes in other components is essential to obtaining improved performance. This compensation is dependent on the genotype, environment, and their interaction (HERBERICH et al. 2020, VALÉRIO et al. 2013). However, information on the lack of uniformity and production capacity of tillers in wheat and the lack of effective measures to regulate the population structure has been so far insufficient (CAI et al. 2014). The unevenness of tillers in cereal growing seasons is regulated by endogenous and mainly environmental signals that lead to a decrease in grain yield (CAI et al. 2014).

The time tiller emission occurs is another factor that determines their survival, in addition to promoting a decrease in their production potential. The number of grains per ear and thousand-grain weight unit are among the yield components most affected by the time of emission, which acts independently from the genotype (FIOREZE & RODRIGUES 2012b). However, the genotype tillering potential should be taken into account for the number of plants in the sowing row, as genotypes with low tillering potential express a higher effect on grain yield due to an increase in sowing density (VALÉRIO et al. 2013).

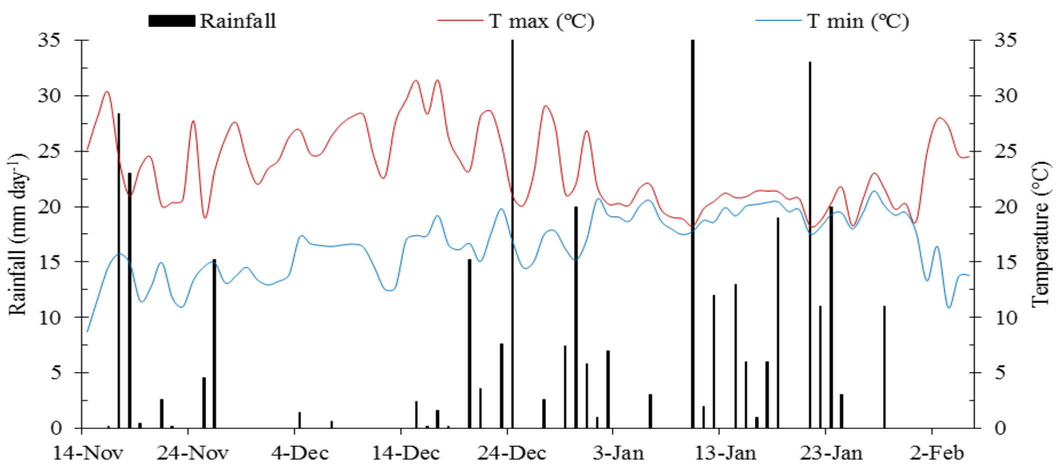
Several authors have shown that the dynamics of tiller emission in plants of the Poaceae family and their survival may be influenced by several factors, such as sowing density (FIOREZE & RODRIGUES 2014), photoperiod insensitivity (OCHAGAVÍA et al. 2017), hormonal and environmental conditions (HERBERICH et al. 2020) genetic factors (MOELLER et al. 2014), time of emission (time factor) (HERBERICH et al. 2020, FIOREZE & RODRIGUES 2012a), among others. However, little information is available on the magnitude and quantification of the intensity of the influence of factors that act on the emission and survival of wheat tillers.

Therefore, this study aimed to evaluate the influence of sowing density, tillering potential, and temporal order of emission on the survival, and performance of individual tillers by contrasting the tillering potential of wheat cultivars.

MATERIAL AND METHODS

Study site and fertilization

The experiment took place in the Spring/Summer of the 2017/2018 growing season on experimental beds containing soil at the experimental area of the Center for Agricultural Sciences of the Santa Catarina State University, located in Lages, State of Santa Catarina, Brazil. This municipality is in the South Plain of Santa Catarina. It presents an average altitude of 930 m, latitude of 27°48′58″ S, longitude of 50°19′34″ W, with mild summers, an average temperature of 15 °C, and annual precipitation of 1500 mm (RADIN et al. 2011). Figure 1 shows the data of maximum and minimum temperature and precipitation during the experimental period.



Source: performed by authors, 2018; from datas of EPAGRI/CIRAM, 2018.

Figure 1. Rainfall, maximum and minimum temperature from sowing to harvest of assay. Lages, SC, 2017/2018 growing season.

The soil of the experimental area is classified as a *Cambisol*. Its chemical analysis showed the following results: organic matter of 4%, P of 15.15 mg dm^{-3}, K of 195 mg dm^{-3}, pH (H_2O) of 6.8, and CEC of

18.5 $cmol_c$ dm^{-3}. Soil pH correction and fertilization were carried out according to the recommendations of the Commission of Soil Chemistry and Fertility of the States of Rio Grande do Sul and Santa Catarina (CQFS-RS/SC 2016) for an expected wheat and triticale grain yield of 5 t ha^{-1}.

Experimental design and methodology

The experiment was conducted according to a randomized block design. Treatments were distributed in a 2×4 factorial scheme with four replications, considering tillers as a third factor. The cultivars TBIO Toruk (high-tillering cultivar) and TBIO Sossego (low-tillering cultivar), released in 2014 and 2016, respectively, were evaluated. The sowing density indicated by the breeder for both cultivars is 300 to 350 plants m^{-2}. Both genotypes were submitted to four sowing densities (208, 312, 416, and 500 viable seeds m^{-2}). The seeds were selected before sowing using a 1.75×20 mm mesh sieve to obtain only seeds larger than 1.75 mm aiming to maximize germination and uniformity in the emergence to obtain the appropriate stand.

Sowing was carried out manually on November 14, 2017, using 50 cm long templates (Figure 2a) manufactured from the values of density per square meter (DSM) and transformed into the linear distance between seeds (LDBS) using the formula LDBS = 50/(DSM/10), considering an inter-row spacing of 20 cm. Thus, LDBS values of 2.4 cm (suboptimal), 1.6 and 1.2 cm (optimal), and 1.0 cm (supra-optimal) were obtained. The seeds were placed one by one in the holes of the templates using tweezers, being then placed on the soil surface in the sowing row. The compartment was opened to deposit the seeds into the sowing rows (Figures 2b and 2c) and the seeds were covered with a 3 cm layer of sieved soil, forming experimental units of four rows of 50 cm in length with inter-row spacings of 20 and 50 cm between plots (Figure 2d).

After seedling emergence, ten plants from the two central rows were randomly selected per experimental unit at the phenological stage 13 to 14 (three to four laminar leaves emerged in the main stem) of the Zadoks growth scale (ZADOKS et al. 1974). These plants were labeled using a colored string, totaling 10 plants per replication, 40 plants per treatment, and 320 total plants evaluated in the experiment (Figure 2e). The tillers of each selected plant were identified once a week from the phenological stage 21 (beginning of tillering and one visible tiller per plant) during four consecutive weeks and taking into account the temporal order of emission, using colored enamels to assign a color to each emitted tiller (Figure 2f). The evaluation of this emission was performed by observation and phenological characterization during the tillering process until reaching stem elongation (from Zadoks code 31).

Weed, insect, and disease management

The pre-sowing weed control was carried out using manual hoes. The post-sowing control was performed throughout the crop cycle based on the identification of weed plants and the respective manual eradication. Disease control was performed through sequential applications of tebuconazole (Folicur® 0.75 L ha^{-1}) based on the observation of plants with the first symptoms of leaf fungal diseases. Insect pests were controlled using sequential applications of imidacloprid + beta-cyfluthrin (Connect® 0.5 L ha^{-1}) on December 14, 2017, January 3, 2018, and January 17, 2018.

The experimental units were maintained under 2×2 cm mesh galvanized metal screens with a wire of 0.2 mm in diameter throughout the growing cycle to prevent bird herbivory.

Evaluated characteristics

The ten plants evaluated per experimental unit were collected separately at the end of the crop cycle and taken to the laboratory. Each tiller previously identified was harvested separately according to order of emission (observation and phenological characterization during the tillering process until reaching stem elongation) within each experimental unit. These tillers were reevaluated and individual measurements were performed in the main stem and respective tiller(s) regarding height, peduncle length, stem diameter, fresh weight, and presence of grains. Emission and survival (ear to ear with at least one grain) were evaluated at the end of the cycle considering the presence and absence of effective tiller(s), respectively. Tillers with the presence of grains were considered viable (effective) and those without grains were considered not viable.

Statistical analysis

Emission and survival means and their respective errors were generated for all evaluated plants, evaluation weeks, tiller, cultivar, and density, obtaining the average decrease rate (ADR) in percentage using the equation $ADR = \frac{\sum Deviations}{n}$, where n is the number of observations. The data regarding the main stem (MS) and first and second tillers (T1 and T2) were submitted to analysis of variance by the F-test ($p<0.05$ and $p<0.01$) considering MS, T1, and T2 as factors and independent from the other factors of variation because they were emitted and survived in all experimental units. The means of the qualitative factor were compared by the Tukey test ($p<0.05$) whereupon significant variances were observed. A regression analysis was performed for the quantitative factor considering 5 and 1% probability of significance for the slope.

Figure 2. Methodology of implantation and conduct of the experiment: templates (a), template accommodation in the row (b), seed deposition in row (c), experimental units (d), plant selection after emergence (e), tillers identification on each wheat plant (f).

RESULTS

Emission, survival, and presence of grains

The 320 plants observed resulted in the emission of 1303 main stem + tillers (MST), with a survival rate of 988 MST and a mortality rate of 24% (Figure 3a). The emission per plant was 4.07 MST (1303/320), while the survival rate per plant reached 3.08 MST (988/320). However, the ratio 1303/288 - where 288 is the product between four replications, two cultivars, four densities, and up to nine observed tillers - generated an overall emission of 4.52 MST (1303/288) and overall survival rate of 3.43 MST (988/288).

All experimental units had the emission of the main stem (MS) and three tillers (T1, T2, and T3) in the first week of evaluation, followed by two new tillers (T4 and T5) in the second week, two tillers (T6 and T7) in the third week, and one tiller (T8) in the fourth week, totaling a maximum emission of eight tillers and the main stem observed in plants at a density of 208 seeds m^{-2}. A reduction in the emission of tillers was observed over the weeks, with stabilization ocurring in the third week of evaluation compared to the second week, demonstrating that the emission interval was lower than seven days, although the decrease in emission was gradual (Figure 3E and Table 1).

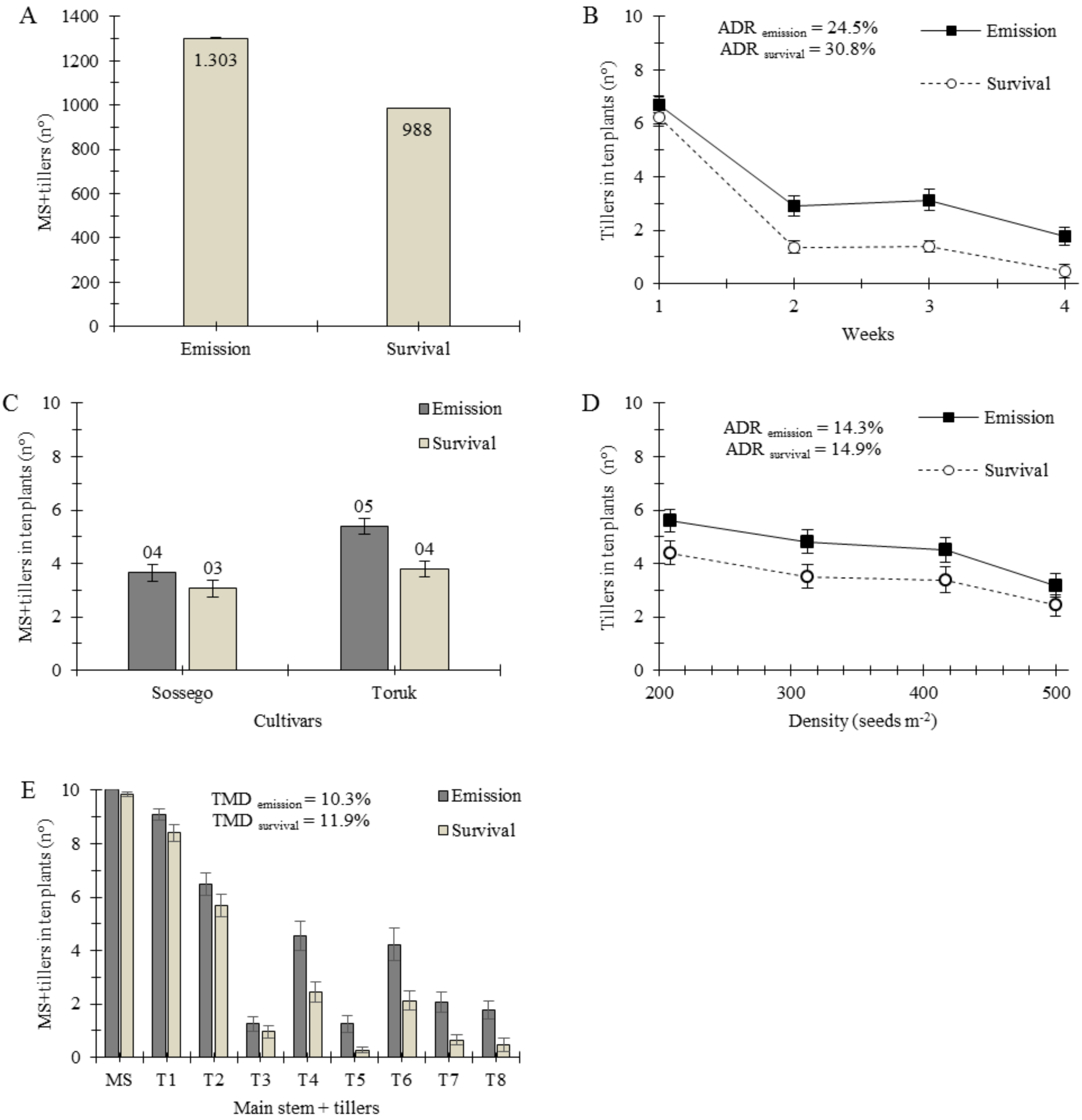


Figure 3. A) Main stem + tillers emission and survival rate (MS+T=MST) of 320 wheat plants on average of two cultivars and four sowing densities. B) Average emission and survival of two cultivars and four sowing densities of MST of 10 wheat plants over four weeks. C) Emission and survival on average of four sowing densities of MST of 10 wheat plants of two wheat cultivars. D) Average emission and survival of two cultivars of MST of 10 wheat plants submitted to four sowing densities. E) Emission and average survival of main stem (MS), first tiller (T1), eighth tiller (T8) of 10 wheat plants. Bars are the standard error of the mean. Lages, SC, 2017/2018 growing season.

The total decrease was 73% in the emission and 92% in tiller survival over the four weeks with an average decrease rate (ADR) of 24.5% of tiller emission (Figure 3B). The average emission over the four weeks was 0.67, 0.29, 0.31, and 0.18 tillers/plant/week, respectively, including the main stems in the first week, while the survival rate presented means of 0.62, 0.14, 0.14, and 0.05 tillers/plant/week, respectively (Figure 3B). These values resulted in a mortality rate of only 8% for the first three emitted tillers, including the main stem, while tillers emitted between the second and third weeks reached a mortality rate of around 50%. Moreover, tillers emitted in the fourth week presented a mortality rate of 74%. The reduction in tiller survival pointed to an ADR of 30.8%, demonstrating that tillers emitted late contribute less to the total number of tillers at the end of the cycle (Figure 3B).

The cultivar *Sossego* presented an overall average emission of 3.7 MST, while the cultivar *Toruk* showed an average of 5.4 MST, showing a tillering potential of around 30% higher than the cultivar *Sossego* (Figure 3C). However, the tiller survival rate of the cultivar *Sossego* was 3.1 MST, which represented a 16% mortality, while the cultivar *Toruk* presented an average survival rate of 3.8 MST and mortality of around 30%, despite its higher tillering potential (Figure 3C). However, the cultivar *Toruk* remained with a final number of tillers of around 20% higher than the cultivar *Sossego* at the end of the cycle. Thus, the cultivar *Toruk* showed the highest genetic potential for tillering.

An inverse relationship was observed between the increase in sowing density and tiller emission and survival. An increase of 292 seeds m^{-2} promoted a 43% reduction in tiller emission and a 44% reduction in tiller survival. Sowing densities of 208, 312, 416, and 500 seeds m^{-2} provided an average emission of 5.6, 4.8, 4.5, and 3.2 MST, respectively (Figure 3D). The decreasing character showed an ADR of 14.4% in tiller emission, with an increase of plant numbers in the sowing row (Figure 3D). Tiller survival presented a similar behavior, with averages of 4.4, 3.5, 3.4, and 2.4 MST (Figure 3D), leading to an ADR of 14.9% in tiller survival due to an increase in sowing density.

The temporal order of emission of tillers led to a decreasing trend for their emission and survival. The emission and survival of individual tillers presented a total decrease of 82 and 95%, respectively. The emission showed an ADR of 10.3%, while survival presented an ADR of 11.9% (Figure 3F). The main stem had a mortality rate of 1.5%, whereas the mortality of the eighth emitted tiller reached around 73%, which represented an average of only 0.5 tillers per plant in the total of experimental units. The main stem and the first two tillers were the only culms that survived in all experimental units, regardless of the sowing density, representing 77% of the total emitted tillers of the 320 plants initially identified.

The evaluation of grains present in the main stems and surviving tillers (Table 1) showed that the surviving tillers emitted in the first week were responsible for 40% of the total presence of grains at the end of the cycle. The tillers emitted in the second week were responsible for only 16% of the presence of total grains, which is directly related to the higher abortion of tillers that week, which reached approximately 46%. An absence of grains in all surviving T7 and a mortality rate of 44% were observed from the third week. The 25% of surviving T8 represented less than 3% of the total presence of grains.

Table 1. Presence and absence of grains in main stem and tillers according to the emission order of two wheat cultivars submitted to four sowing densities. Lages, SC, 2017/2018 growing season.

		Grain presence on main stem or tillers week^{-1}								
		1st week				2nd week		3th week		4th w
Cultivar	Density (Seeds m^{-2})	MS	T1	T2	T3	T4	T5	T6	T7	T8
Sossego	208.3	P	P	P	P	P	P	P	A	A
	312.5	P	P	P	P	P	-	P	-	P
	416.6	P	P	P	-	P	-	-	-	A
	500	P	P	P	-	P	-	-	-	-
Toruk	208.3	P	P	P	P	P	P	P	A	P
	312.5	P	P	P	P	P	P	P	A	-
	416.6	P	P	P	P	P	P	P	A	-
	500	P	P	P	-	P	-	P	A	-

"P" grain presence; "A" grain absence; "-" tiller absence.

Discriminatory analysis of emission and survival in the morphometric characters and MS, T1, and T2 weight.

A significant effect was observed in the interaction between tillers and cultivars and between tillers and sowing density for the emission and survival of the main stem + two first tillers, demonstrating that genotype and density act differently, but interfere with tillering (Table 2). Emission and survival of MS, T1, and T2 showed similar behavior. Both cultivars had a gradual decrease in emission and survival according to the order of emission of tillers, but the decrease in emission was significant from T1 for the cultivar *Sossego* and only from T2 for the cultivar *Toruk,* which showed an emission 26% higher than the cultivar *Sossego* for this tiller (Figure 4A). Moreover, the survival rate presented similar behavior, but the cultivar *Toruk* presented a significance from T1 (Figure 4B).

Table 2. Summary of analysis of variance in emission (EMI), tillers survival (SUR), height (PH), peduncle length (PED), stem diameter (SD) and main stem fresh weight (FW) and two first tillers emitted in two wheat cultivars submitted to four sowing densities. Lages, SC, 2017/2018 growing season.

SOV	Mean square					
	EMI	SUR	PH	PED	SD	FW
Block	2.03	2.18	45.7	4.56	0.09	2.37
Tiller (T)	105.59	142.57	146.94*	3.1	0.41	80.17*
Cultivar (C)	12.76	10.66	7274.07*	926.53*	1.22	86.88*
Density (D)	18.95	27.62	74.04*	21.6*	0.62*	67.53*
T x C	9.76*	13.26*	14.91	0.22	0.12*	6.48
T x D	6.49*	8.61*	19.83	1.38	0.05	4.49
T x C x D	0.19	0.71	17.95	1.91	0.05	0.37
Error	1.07	1.64	19.14	3.07	0.03	3.17
CV (%) =	12.15	16.06	8.27	18.87	7.72	27.01
General average	8.53	7.97	52.89	9.28	2.36	6.6

* and **: significative by F test to 5 and 1%, respectively. CV: coefficient of variation. SOV: source of variation

The interaction between tiller × density showed that MS and T1 had stability in their emission and survival at densities up to 416.6 seeds m^{-2}, while T2 presented a decrease in emission compared to those previously emitted in all densities, markedly at densities higher than 500 seeds m^{-2}. This behavior is shown in the box plot with data of the upper limit, third quartile, second quartile, first quartile, and lower limit (Figure 4C and 4D), which presented a higher range of variation, especially at the high sowing densities for the emission and survival of the second tiller in each plant. The regression analysis showed no relationship between the emission and survival of MS and the increase in density, while the emission and survival of T1 and T2 had a behavior of stimulating the emission, with a point of maximum technical efficiency of T1 (Xmax = 311.7; Ymax = 9.97) and T2 (Xmax = 247.7; Ymax = 7.83) (Figure 4E), with these density values similar to what is recommended. The point of maximum technical efficiency or ideal density for T1 (Xmax = 301.2; Ymax = 9.56) and P2 survival (Xmax = 253.0; Ymax = 7.10) (Figure 4F). Low- and high-tillering cultivars showed similar behavior for these characteristics.

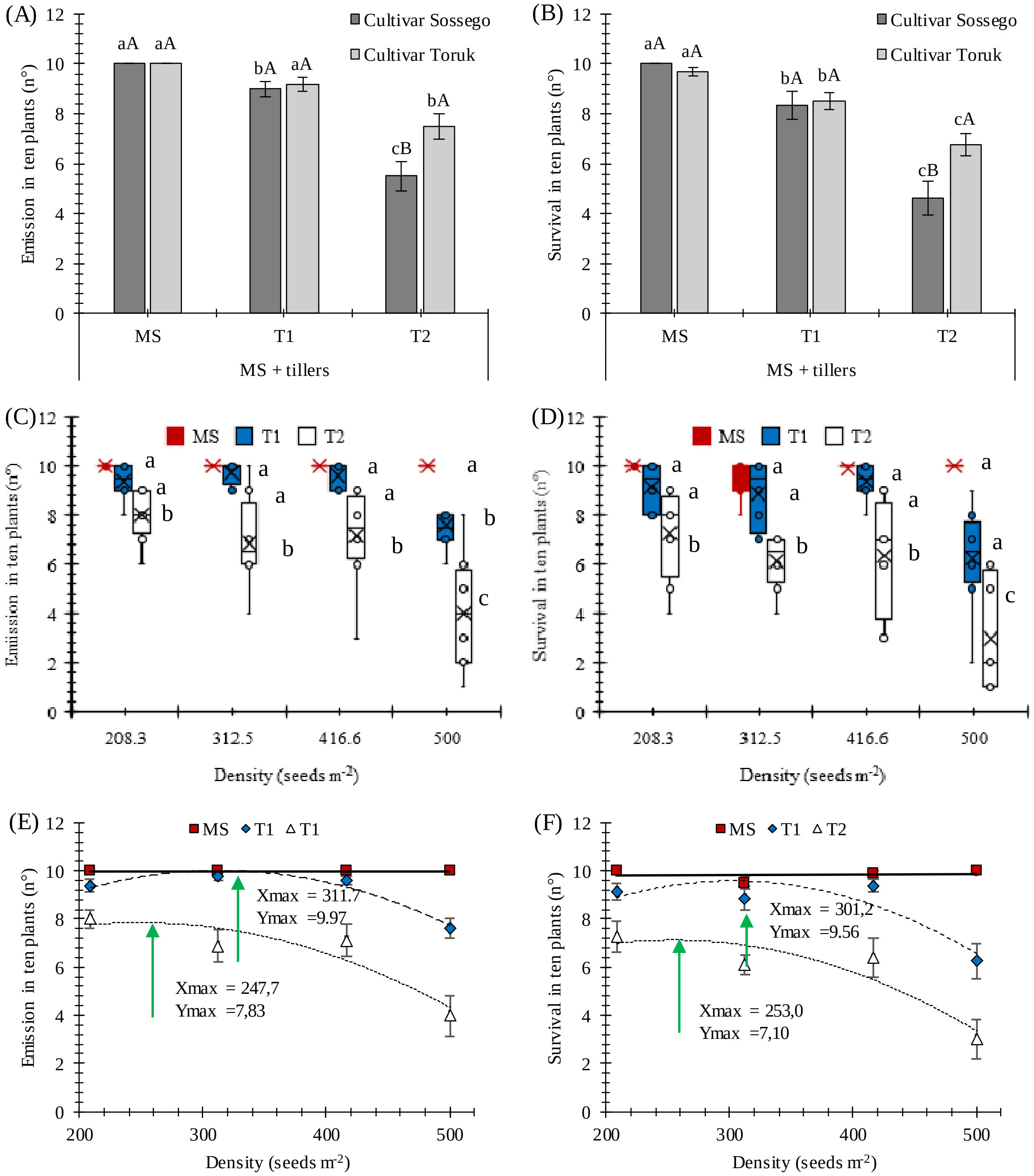
Plant height was affected by the main effect of the three factors (tillering, cultivar, and density). The main stem showed an average height of 52.3 cm, followed by 52.0 and 51.3 cm for T1 and T2, respectively (Figure 5A). The cultivar *Sossego* had an average height between MS, T1, and T2 of 61.6, while the cultivar *Toruk* presented 44.2 cm (Figure 5B).

An inverse relationship was observed between the increase in sowing density and the average height of MS, T1, and T2. A decreasing linear regression with a significant slope was adjusted (Figure 5B). The highest height (54.9 cm) was observed at the density of 208 seeds m^{-2}, regardless of the cultivar, with a decreasing tendency of up to 51.2 cm at the density of 500 seeds m^{-2}. There was a reduction of approximately 1.3 cm in height for each increase of 10 seeds m^{-2}, in the average of these two cultivars.

Peduncle length was affected by cultivar and density. The cultivar *Sossego* differed significantly from *Toruk*, with average values of 12.4 and 6.1 cm, respectively (Figure 5C). This characteristic showed a decrease, with a linear adjustment with a significant slope as a function of the increase in sowing density (Figure 5D). The coefficient of determination was low (47.4%), suggesting a higher range of variation between the internodes of MS, T1 and T2.

The interaction tiller × cultivar showed that the cultivars differed significantly regarding to the stem diameters of MS, T1, and T2. The cultivar *Sossego* decreased from T1, while the cultivar *Toruk* showed a decrease at T1, followed by an increase in diameter at T2 (Figure 5E).

Stem diameter was dependent on the sowing density and the interaction between tiller × cultivar (Table 2). The increase in sowing density provided a decrease in stem diameter with a decreasing linear adjustment and significant slope at 1% probability. The largest stem diameter (2.54 mm) was obtained at the lowest density, with a gradual decrease to 2.15 mm at 500 seeds m^{-2} (Figure 5F).



Means followed by the same letter between tiller and capital letter between cultivars do not differ by Tukey tests (P=0.05). Vertical Bars are the standard error of the mean (A, B, E and F).

Figure 4. A) Emission and B) survival of main stem (MS), first tiller (T1) and second tiller (T2) of two wheat cultivars, averaging four sowing densities. Emission (C) and Survival (D) with their upper limit, third quartile, second quartile, first quartile, lower limit, internal x is the mean marker, - median marker, ° internal points marker (n = 8), in average of two wheat cultivars submitted to four sowing densities. Regressions of Emission (E) for Y_{MS}=10; $Y_{T1}=3.567873+0.041115x-0.000066x^2$; $R^2=0.9378$; $Y_{T2}=4.399578+0.027739x-0.000056x^2$; $R^2=0.8402$; and Survival (F) Y_{MS}=10; $Y_{T1}=2.479044+0.046987x-0.000078x^2$; $R^2=0.7975$; $Y_{T2}=3.07182+0.031882x-0.000063x^2$; $R^2=0.8436$, in the average of two wheat cultivars in four sowing densities. E) Regression of Emission and F) survival of MS, T1 and T2 in the average of two wheat cultivars submitted to four sowing densities. Lages, SC, 2017/2018 growing season.

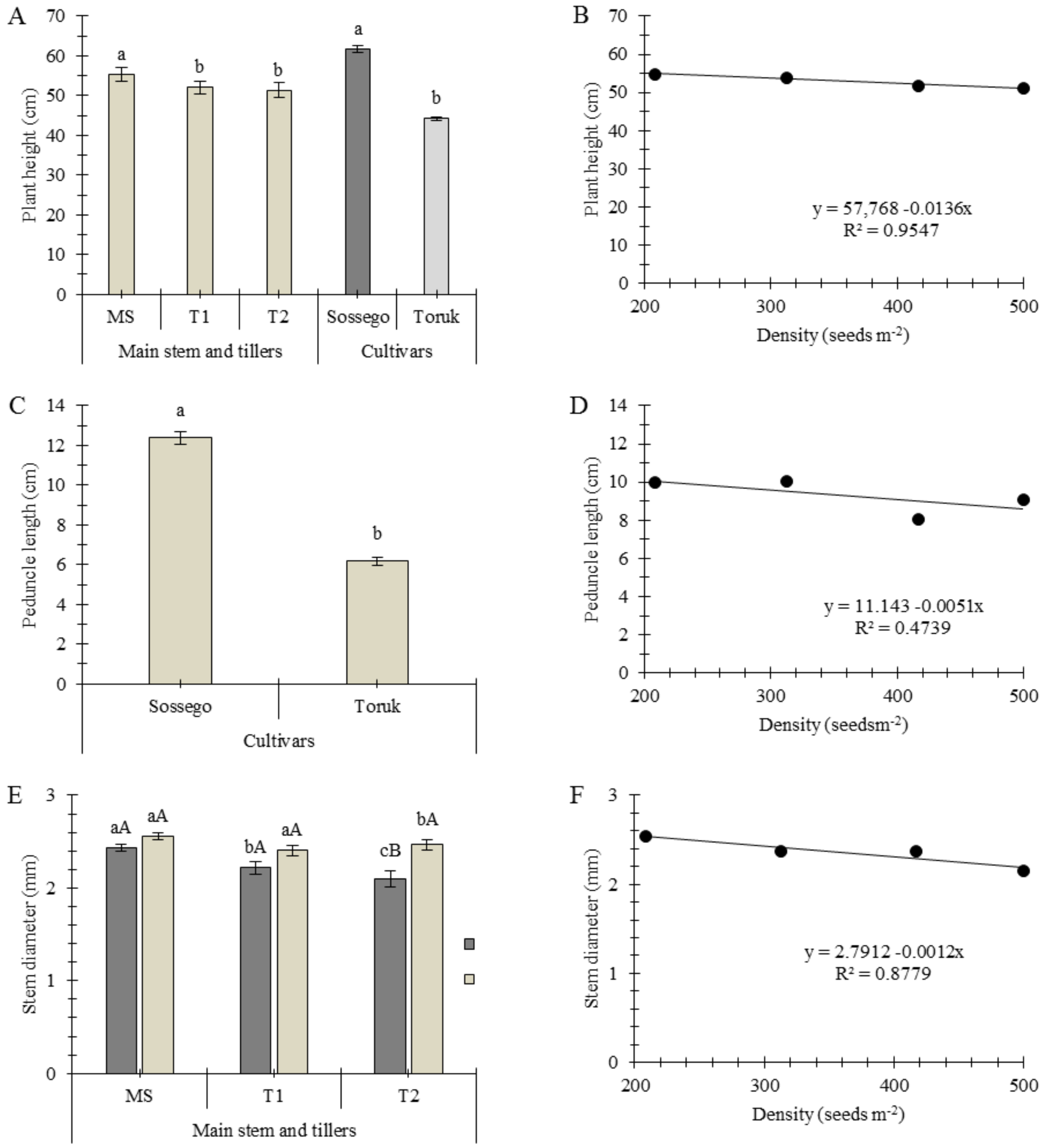
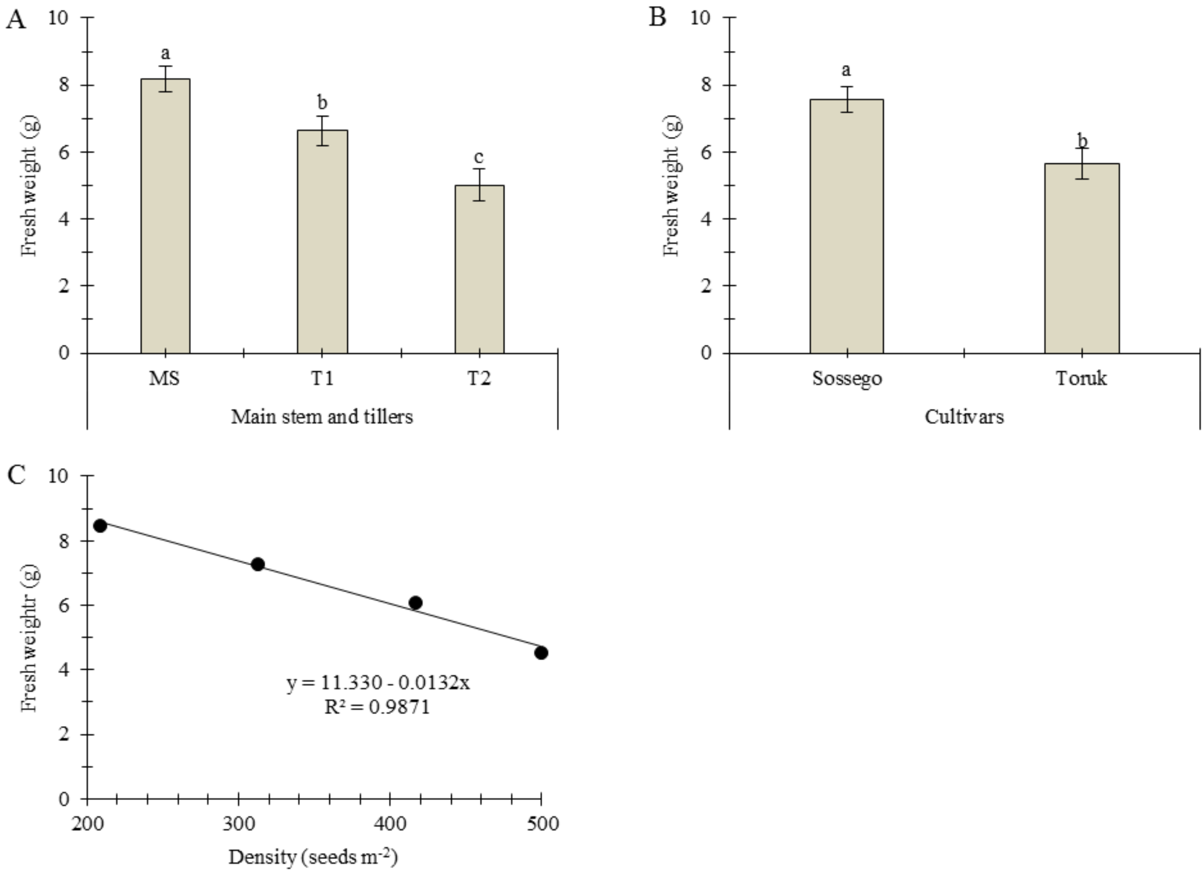


Figure 5. A) Average height of the main stem (MS), first tiller (T1) and second tiller (T2) of wheat and average height of two wheat cultivars. B) Average height of CP, P1 and P2 emitted from wheat plants submitted to four sowing densities. C) Peduncle length of two wheat cultivars, averaging four sowing densities. D) Length of stem CP, P1 and P2 emitted from wheat plants submitted to four sowing densities. E) Stem diameter in the average CP, P1 and P2 emitted from wheat plants submitted to four sowing densities. F) Diameter of CP, P1 and P2 of two wheat cultivars. Vertical bars are the standard error of the mean. Lages, SC, 2017/2018 growing season.

The fresh weight of MS, T1, and T2 were affected by the effects of the individual tiller, cultivar, and density (Table 2). A gradual decrease was observed with the temporal emission of tillers, with MS having an average weight of 8.2 g, followed by 6.6 and 5.0 g for T1 and T2, respectively (Figure 6A). The cultivar Sossego stood out significantly, with an average fresh weight of 7.6 g, while the cultivar Toruk reached a value of 5.6 g (Figure 6B).

A decrease in fresh weight was observed as the sowing density increased, with a linear adjustment, significant slope, and high coefficient of determination (98.7%). The density of 208 viable seeds m^{-2} provided an average fresh weight of 8.5 g of MS, T1, and T2, with a gradual decrease to 4.6 g at the density of 500 seeds m^{-2} (Figure 6C). This represents a decrease of 1.3 g per stem for every 100 seeds added per m^2 of cultivation, regardless of whether the main stem was evaluated or T1 and T2.



Means followed by the same letter between tiller and capital letter between cultivars do not differ by Tukey tests (P=0.05). Vertical Bars are the standard error of the mean. **: significative to 1% (P<0.01).

Figure 6. A) Fresh weight of main stem (MS), first tiller (T1) and second tiller (T2) on the average of two wheat cultivars and four sowing densities. B) Fresh weight of wheat plants on the average of four sowing densities as function of cultivars. C) Fresh weight of wheat plants, on the average of two cultivars, as function of four sowing densities. Vertical bars are the standard error of the mean. Lages, SC, 2017/2018 growing season.

DISCUSSION

Emission and survival of the main stem and first and second tillers in the presence of grains in the ear

Not all the emitted tillers survived until the end of the cycle. This growth pattern was evidenced in the emission and total survival of the evaluated plants, which may reduce the productive potential of the crop. WHALEY et al. (2000) reported that a balance in the growth rate between the tiller and main stem is necessary for survival to be possible. According to ZEKERIYA (2002), this phenological asynchrony induces tillers to not produce grains, which was observed in the third tiller. Self-thinning also occurs due to intraspecific competition between plants and/or between plants and their tillers (SBRISSIA & SILVA 2008). SANGOI (2009) observed that tillers could be considered stress agents in maize because they compete for resources with the main stem during the vegetative phase, which would make them drain photoassimilates left over from producing grains in the main stem. However, the absence of grains (Table 1) was predominantly dependent on tiller mortality. The surviving tillers with the absence of grains represented only 9% of the total presence of grains. This fact would evidence that the tillers that succumbed could have become a source for the survivors, demonstrating that the hierarchical behavior of tillers within the same botanical species is different due to the genetic improvement of each cultivar.

Tillers are considered sinks when they survive until the end of the cycle and do not produce grains. This behavior occurred only in the seventh emitted tiller. Therefore, this evidence shows that tillers would act more as a source and less as a sink up to the sixth emitted tiller. FIOREZE & RODRIGUES (2012b) also reported that tillers emitted late have low productive potential due to their low viability, which is considered by HERBERICH et al. (2020) as a self-thinning tiller, corroborating with this study since tillers emitted after the third week showed no grains. However, the source/sink transition is not abrupt and can be slow and gradual. Thus, tillers can be a sink-source-sink, but in different proportions, depending on the time the evaluation is carried out.

FIOREZE & RODRIGUES (2012b) pointed out that the timing of tiller emission is decisive for their survival, which corroborates with this study. A decrease in survival reached 92% as the weeks of emission evaluation advanced, and 95% when comparing the ends of individual tillers. The aforementioned author showed that higher tiller vigor determines its survival and must be related to lower energy expenditure in the production of a high number of tillers. Therefore, the lower the tiller potential, the higher its survival rate. This hypothesis is closely associated with the results obtained in this study, which showed a reduced tillering potential for the *Sossego* cultivar compared to the *Toruk* cultivar. The *Sossego* cultivar had a higher survival rate, with a mortality rate of only 16%, while the *Toruk* cultivar reached a 30% mortality rate. Moreover, VALÉRIO et al. (2013) also showed this balance, as they reported that cultivars with reduced tillering potential responded positively to grain yield due to increased sowing density. Therefore, there is a higher rate of self-thinning for tillers in high-tillering cultivars and lesser self-thinning of tillers in low-tillering cultivars.

Tiller emission response in wheat cultivars has high variability due to variations in sowing density (VALÉRIO et al. 2008). However, a high tiller emission does not guarantee a high yield, as this relationship is dependent on several biotic or abiotic factors, since the behavior of individualized tillers observed in this study demonstrated an evident decrease in performance in the presence of grains, according to the temporal order of their appearance. The decrease in tiller emission and survival of approximately 44% due to an increase in sowing density was also observed by FIOREZE & RODRIGUES (2014). This is an expected behavior due to intraspecific competition between plants, which becomes highly present with an increase in the number of plants in the sowing row. However, the dynamics of tiller abortion can vary mainly under environmental stress conditions (ELHANI et al. 2007) or depending on cultivar tillering capacity, as demonstrated in the present study (Table 1).

Contribution of emission, survival, morphometric characters, and MS, T1, and T2 weight to the production process

The statistical analysis, based on the interaction tiller × cultivar, confirmed what was proposed by VALÉRIO et al. (2013), who observed a similar tillering emission among cultivars, but with a decrease in survival for the cultivar *Toruk*, with the highest tillering potential. The condition for tiller survival is that its growth rate is similar to that of the main stem (WOBETO 1994). In this context, the results observed in the interaction tiller × density show a high association with this fact, as the lowest densities presented an elongation in the tillering period (208 seeds m^{-2}) and the survival rate was higher, while the highest densities (500 seeds m^{-2}) presented a shorter tiller duration, leading to less emission, mainly in the second tiller, with consequently less survival of the emitted tillers (Figures 4CDEF).

SANGOI (2000) observed greater apical dominance under high population densities, with a trend for plants to etiolate due to changes in their architecture in search of a higher incidence of solar radiation. However, the highest heights in this study were observed at densities with the lowest number of plants in the sowing row. Such behavior may be related to a higher concentration of metabolites mainly due to low competition among the plants. In addition, the overall average of densities included *Toruk* plants, which had the highest abortion of tillers, thus contributing as a source to translocate more photoassimilates to MS, T1, and T2. This same behavior can be extended to the stem diameter, which is a reflection of the competition between plants. The peduncle is the structure that most contributes to the growth in height (ESPÍNDULA et al. 2010), corroborating with the results obtained in the present study, which showed a similar behavior among cultivars, although decreases inversely to the increase in population.

The yield of a crop is dependent on its growth and distribution of dry and fresh matter throughout the plant organs, as well as the transport of metabolites, which is driven by a source-sink system associated with higher mass production (DUARTE & PEIL 2010). In this context, the increase in population can lead to a reduced tiller emission rate (ALMEIDA & MUNDSTOCK 2001, HERBERICH et al. 2020), which was also observed in this study due to competition between plants. FIOREZE & RODRIGUES (2014) attributed the reduction in tiller dry matter to an increase in density, as a small number of tillers would result in lower total dry matter per plant. However, the decreasing behavior of the tiller fresh weight observed in this study is related to the small size due to the temporal order of emission, which is related to the morphometric characters of height and peduncle length. Also, MS, T1, and T2 presented similar means of survival within densities, corroborating the relevance of the tiller's timing of emission even for their weight. Thus, the early emissions of tillers led to the similar fresh weight values for MS, T1, and T2, showing the synchrony between these plant structures, as the emission of T1, T2, and some T3 occurred in the first week of evaluation (Table 1).

FISCHER et al. (2019) observed that the responses of grain yield reflect the high wheat plasticity mainly conferred by tillering, also being reasonably well explained by the notion that the maximum yield requires interception of solar radiation close to the total light availability from the emergence of the flag leaf (stage 37) to the beginning of mass accumulation in the grains (stage 75). In order to accomplish this goal, it is necessary to maintain green leaves efficiently through solar radiation, a fact achieved at low densities. This time interval between stages 37 (flag leaf emission) and 75 (milky grain) may have some compensation if there is a delay in flowering, increasing the timing factor and helping with compensation. FENG et al. (2017) described a superior balance in the internal balance of photoassimilates under lower plant density, especially during the stem elongation stage, promoting higher vertical root development. This increases the root system efficiency in absorbing water and nutrients, enhancing the survival of tillers that will be effective in contributing to grain yield.

CONCLUSION

The timing of tiller emission is the factor that most affects tiller mortality, followed by an increase in sowing density and the intrinsic tillering potential of the cultivar, with tillers that are emitted late having high mortality rates.

The timing at which emission occurs is the factor that most affects the performance of wheat tillers and their absence of grains. In this sense, late tillers present a high absence of grains, which is more associated with early tiller mortality. The high-tillering cultivar (*Toruk*) presented more self-thinning of tillers than to the low-tillering cultivar (*Sossego*).

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