Original Research Article

Agronomic Performance of Wheat Cultivars Under Different Sowing Densities in Southern Brazil

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ABSTRACT

Sowing density is one of the management techniques that most influence wheat crops. This management practice may affect the plant productive behavior, leading to changes in tillers growth, and also interferes with the plant architecture by influencing solar radiation uptake by the plant canopy, the production components and grain yield. This work aimed to assess the agronomic performance of two wheat cultivars (low tillering and high tillering) under influence of four sowing densities. The experiment was conducted in field conditions from July to November 2017. The experimental design consisted of randomized blocks with split-plots and five replicates. The factors consisted of two wheat cultivars in main plot (TBIO Sossego and TBIO Toruk), subjected to four different sowing densities as sub-plots (208; 312; 416 and 500 viable seeds m^{-2}). Morphological characteristics, relative chlorophyll content, NDVI, production components and grain yield were evaluated. Among the assessed traits, only the stem diameter was affected by sowing density. The highest plant height, peduncle lengthand flag leaf length were found in cultivar Sossego, whereas the largest stem diameter was observed in cultivar Toruk. Relative chlorophyll content and NDVI were higher in cultivar Sossego. The agronomic performance of the cultivar Sossego was higher and exceeded the grain yield of Toruk at 673 kg ha^{-1}. Suboptimal sowing densities promote a decrease in the productive performance of wheat and under conditions of rainfall limitation and genetic potential of reduced tillering while sowing densities above the recommended ones are more efficient.

Keywords: Triticum aestivum; tillering; crop management.

1. INTRODUCTION

Maximization of wheat production has been of vital importance to Brazil from the point of view of self-sufficiency in cereal grains production [1]. The country is the fourth consumer of cereal grains in the world with per capita consumption of 53 kg year^{-1}. However, Brazilian production of grains is around six million tons, not sufficient to meet the domestic demand. Most of the country's total demand is imported, making Brazil the second largest importer of wheat and its byproducts in 2012, with average annual imports of six million tons during the 2005 decade [2].

Wheat yield potential is a characteristic controlled by complex and quantitative mechanisms, since the direct and indirect physiological interferences triggered by the gene expression that affect final grains yield are controlled by various genes of small individual effect [3]. It was further concluded that in addition to the gene effect, the yield components may respond differently to different environmental conditions [4]. In this context, an optimal use of the cropland and field conditions are strategies that aim to increase grain yields, so that the interaction of wheat genotypes with different environmental conditions and crop management would be beneficial [1]. Among the crop management methods that most influence the crop outcomes is sowing density, which has a direct influence on tillers growth and effectiveness, but the tillering capacity is associated with environmental factors and the tillering potential of wheat genotypes [4]. There is a great diversity in the genotypes tillering pattern, which makes more difficult to decide on the most appropriate sowing density for each cultivar. Furthermore, this characteristic may have a direct influence on yield components. So, knowledge on the compensatory effect of yield components as a function of wheat tillering is crucial when technical management recommendations aiming to approximate grain yield to the potential yield of each cultivar [5] are considered. As a rule, the low productivity of Brazilian wheat crops is associated with a small number of fertile tillers in final grains production [6].

Currently, in the microregion 1 (cold and humid) in southern Brazil, sowing density ranges from 250 to 400 of viable seeds per square meter, considering the cultivars cycle, dual purpose cropping (grazing and grains harvesting) and sowing time. However, this technical recommendation of the Brazilian Commission of Wheat and Triticale Research (*Comissão Brasileira de Pesquisa de Trigo e Triticale*) [7] does not consider different tillering behaviors (tillers emergence and survival), the components of each cultivar yield and different cultivation environments, which indicates lack of information for more precise technical recommendations.

In Brazil, one of the requirements to register a cultivar in the National Cultivars Registration is to demonstrate its cultivation and use value through tests conducted according to pre-established criteria. According to the Ministry of Agriculture and Food Supply [8], Cultivation and Use Value refers to the intrinsic combined value of the cultivar’s agronomic properties and its use in agricultural, industrial, commercial and/or consumption activities. Thus, data on grain yields, its behavior against pests and diseases, regions of adaptation and other factors that indicate the cultivar’s marketable importance must be recorded.

Currently, occurrence of diseases in wheat crops is caused by pathogens of different characteristics, and the genetic improvement of resistant or tolerant cultivars is the most effective way to reduce economic losses [9]. Therefore, genotypes with different behaviors have been frequently launched in triticale growing regions, which make that decisions on the most suitable management methods for each cultivar lack clarity. Thus, this work aimed to assess the agronomic performance of two wheat cultivars held in the private domain and recently launched, under the influence of suboptimal, optimal and supraoptimal sowing densities.

2. MATERIAL AND METHODS

2.1 Site of assay

The experiment was conducted from July to November 2017 in the agricultural and livestock experimental area of the Federal University of Santa Catarina, in the municipality of Curitibanos, state of Santa Catarina, Brazil. The city is located at an altitude of 987 m between geographic coordinates 27º16’44” S latitude and 50°34’57” W longitude, with an annual mean temperature of 16.5 °C and annual precipitation around 1500 mm [10]. The soil is classified as Cambissolo Haplico with typical clay texture (550g kg^{-1} of clay). Figure 1 shows the maximum and minimum temperatures and precipitation rates during the experiment.

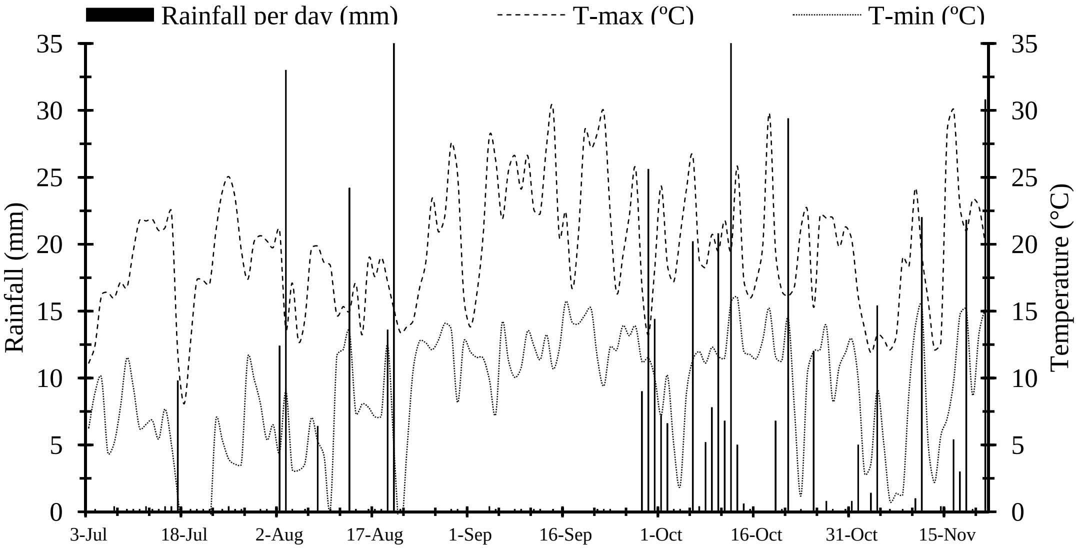

Fig. 1. The rainfall, maximum and minimum temperatures from sowing to harvest of two wheat cultivars. Curitibanos, State of Santa Catarina, 2017 growing season. Source: Agroclimatic report EPAGRI/CIRAM.

2.2 Experimental design and management pratices

The experiments were conducted in a randomized blocks design with split-plots and five replicates. The cultivars TBIO Toruk (high tillering) and TBIO Sossego (low tillering), launched in 2014 and 2016, respectively, were assessed in the main plot. The planting density indicated for both cultivars, according to the breeder, is 300 and 330 plants m^{-2}, respectively. Both genotypes were subjected to four sowing densities of viable seeds m^{-2} in sub-plots, namely: 208 (suboptimal); 312 and 416 (optimal) and 500 (supraoptimal). Prior to sowing, a germination test was conducted in laboratory for both cultivars to obtain the germination rate to adjust the number of seeds for each plant density. Before implementing the experiment, soil was sampled at 0-20 cm depth, and the soil test indicated the following results: organic matter = 3.3%; P= 13.1 mg dm^{-3}; K= 74 mg dm^{-3}; pH (H_2O) 6.7; CEC = 20.5 cmolc dm^{-3}. Correction of pH and fertilization were performed according to the recommendations of the Commission of Soil Chemistry and Fertility (*Comissão de Química e Fertilidade do Solo)* [11] for wheat crops for estimated grain yields of 5 tons ha^{-1}.

Sowing was performed on July 03, 2017 using a seed drill (Embrapa-Semeato, model Sêmina) under no-till system. Each experimental unit consisted of five rows with 5 meters in length, spaced 0.2 m between rows and 0.5 m between plots. It was considered three central rows with four linear meters, disregarding two side rows and 0.5 m at the end of each row.

2.3 Weeds, diseases and pests managements

Weeds control was made ten days prior to the implementation of the experiment with pre sowing application of glyphosate (Roundup® 3 L ha^{-1}), and application of paraquat (Gramoxone® 1.5 L ha^{-1}) soon after sowing. Postemergence control was made with applications of iodosulfuron-methyl (Hussar® 100 g ha^{-1}) on Aug. 28, 2017 when weeds had

2-4 leaves, and with clodinafop-propargyl (Topik® 0.2 L ha^{-1}) on Sept. 04, 2017, when weeds exhibited 1-2 leaves. All herbicides were applied sequentially as its recommended dose for the weed development and species.

Diseases control was performed with sequential applications of propiconazole (Tilt® 0.5 L ha^{-1}) on Sept. 04, 2017, when the first symptoms of leaf fungal diseases were visible on the plant, and tebuconazole (Folicur® 0.75 L ha-1) was applied on Oct. 03, 2017. Pest control was performed with sequential applications of beta-cyfluthrin + imidacloprid (Connect® 0.5 L ha^{-1}) on Aug. 28 and Oct. 03, 2017.

2.4 Evaluated traits

Relative chlorophyll content (RCC) and the normalized difference vegetation index (NDVI) were determined on field at the growth stage 59 (end of ear formation) of the Zadoks growth scale [12] by reading the leaf blade of flag leaf and the leaf bellow of flag leaf (leaf^{-1}) of ten plants at each experimental unit using a portable chlorophyll meter (Falker, model Clorofilog CFL 1030), and NDVI was measured with a portable sensor (PlantPen NDVI-300). The peduncle length (PL), plant height (PH), flag leaf length (FLL), stem diameter (SD), number of grains per ear (NGE), number of spikelets per ear (NSE), number of grains per spikelet (NGS) were quantified by harvesting all plants in 30 cm rows of each experimental unit. From this sample, a subsample of 15 stems was randomly collected, among the stems and tillers, and measuring PL, PH and FLL using a graduated ruler, and SD with a pachymeter, and the number of total spikelets on 15 stems were counted. Finally, after manual threshing, the Number of Total Grains from 15 stems (NTG15) were obtained. The morphometric traits and NSE were obtained from the average of 15 stems. The NGE and NGS were obtained from NGE=NTG15/15 and NGS=NSS/NGE ratios. The considered area was harvested manually on Nov. 21, 2017. After harvesting, the harvest index (HI) was obtained, which corresponds to the ratio of grain yield dry weight (GY) to plant total dry weight (TDW); therefore, HI=GY/TDW X 100. The hectoliter weight (HW) was determined using a DallaMolle scale with results expressed in kg hL^{-1}. The Thousand grain weight (TGW) was obtained by the average of 8 x 100 grains as following the method described on the Rules for Seeds Analysis [13]. The percentage of grains with size larger than 1.75 mm (G>1.75), subsample of 250g of grains from each experimental unit was sieved at a 1.75 x 20 mm mesh sieve.

Grain yield (GY) was determined by harvesting the considered area of each experimental unit following the wheat tracks. Yield was estimated in kg ha^{-1}, adjusted to 13% moisture standard. The adjusted weight was obtained by the following equation: production from each plot * [(100-RM)/(100-13)], where RM is the real moisture of the grains at the harvesting time, and 13 is the moisture standard. This real moisture was obtained by drying the grains in oven at 65 °C to constant weight, starting from an initial wet weight of 100g impurities-free grains. The moisture content expressed on a wet basis was determined by the following equation: M%=[100 * (GW-GD)/GW], where GW = grains wet weight, GD= grains dry weight.

2.5 Statistical Analysis

Data were subjected to analysis of variance by F test (*P* = 0.05). When significant variances were found, the means of the qualitative factor were compared using theTukey probability test (*P* = 0.05). Regression analysis was applied for the quantitative factor. Pearson's correlation was measured between all variables in the overall mean of all experimental units and for each sowing density.

3. RESULTS

3.1 Morphometric and physiological traits

There was a significant effect of the cultivars on the morphometric variables (Table 1). The longest peduncle length, plants height and flag leaf length were found for the cultivar Sossego, whereas the greatest stem diameter was found for cultivar Toruk.

Cultivar Sossego exhibited the longest mean length of peduncle, measuring 29.11 cm in the comparison with cultivar Toruk, which exhibited a peduncle length of 20.28 cm (Figure 2a). When the mean sowing densities for this same dependent variable were compared, the variation between the extreme values was 0.6 cm only, which generated a nonsignificant angular coefficient for this factor, corroborating the low variance value (Table 1), showing that the population density had little influence on the plants' peduncle length. The plant height of cultivar Sossego was 19.75 cm higher than the Toruk cultivar, and the flag leaf length of Sossego cultivar was 2.83 cm higher than the Toruk cultivar (Figure 2b and 2c).

Relative chlorophyll content (RCC) and NDVI were affected only by the cultivar factor (Table 1). The RCC of cultivar Sossego was about 12% higher than cultivar Toruk at the reading time (Figure 3a), while cultivar Sossego exhibited 0.25 units of NDVI higher in the mean values of its experimental units (Figure 3b).

Regarding the stem diameter, cultivar Toruk had a mean diameter of 3.03 mm in its experimental units, while cultivar Sossego had a mean stem diameter of 2.90 mm (Figure 2d). The sowing density factor affected the stem diameter with 10% significance probability level. The mean sowing densities in the experimental units indicated adjustment for the quadratic function with significant parameters (Figure 2e). The largest stem diameter was found in the suboptimal density, showing a downward behavior for sowing densities close to the optimal density, from which an upward behavior is observed.

Table 1. Summary of the analysis of variance, mean square and significance for plant height (PH), stem diameter (SD), penduncle length (PL), flag leaf length (FLL), relative chlorophyll content (RCC) and normalized difference vegetation index (NDVI) of wheat.

SOV	PH	SD	PL	FLL	RCC	NDVI
Block	24.55	0.01	3.48	2.68	35.96	0.58*
Cultivar (C)	3901.41**	0.15*	779.45**	80.56**	365.23**	0.65*
Error 1	3.50	0.01	2.42	2.25	17.62	0.06
Density (D)	7.70	0.05	0.80	1.55	12.29	0.32
C × D	5.30	0.02	1.71	0.70	20.37	0.20
Error 2	19.29	0.02	3.78	2.48	12.06	0.25
CV (%)[1]	2.69	4.71	6.31	9.56	8.53	3.71
CV (%)[2]	6.31	5.28	7.88	10.02	7.05	7.02
Main	69.56	2.97	24.69	15.71	49.23	7.13

** and **: significative by F-test F at 5 and 1%, respectively. [1] coeficient of variation for main plot; [2] coeficient of variation for split plot. SOV, source of variation.*

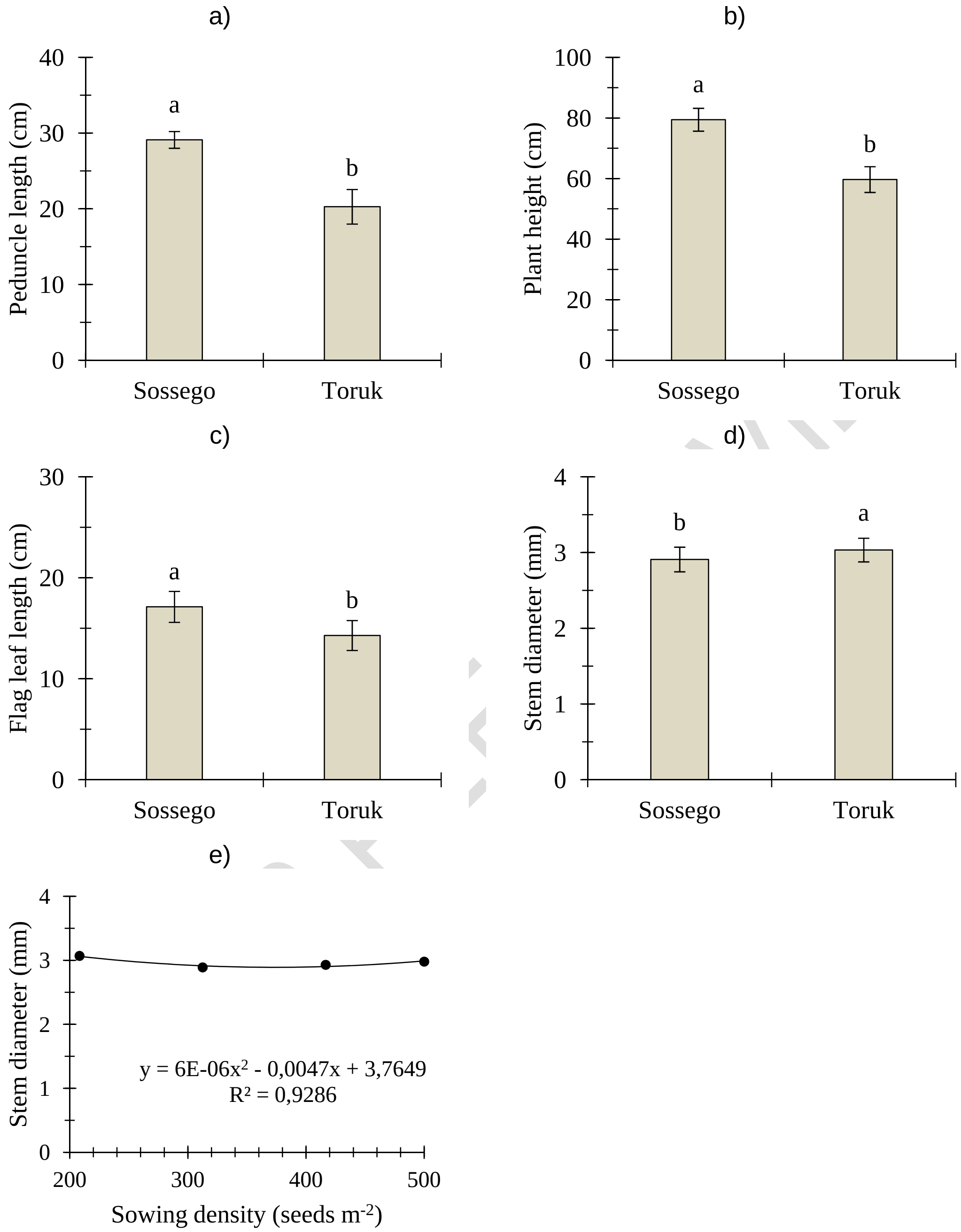

Fig. 2. Single effect of wheat peduncle length (a), plant height (b), flag leaf length (c), stem diameter (d) of two wheat cultivars; "Toruk" and "Sossego" and stem diameter as function of four sowing densities (e). Curitibanos, Brazil, 2017 growing season. Vertical bars are standard deviation of mean.

3.2 Productive and qualitative characteristics of grains

The factor levels under study did not have a significant effect on the yield components, harvest index and grains size larger than 1.75 mm. However, there was a significant variance between the means of the cultivars for grains yield and hectoliter weight (Table 2), and a significant angular coefficient was obtained with a significance probability level of 10% for sowing densities with adjustment of the increasing linear function in grains yield (Figure 3d).

The cultivar Sossego obtained grain yield of 4527 kg ha^{-1} and cultivar Toruk obtained 3853.61 kg ha^{-1} (Figure 3c). The significant coefficient showed that the increase in sowing density promoted an estimated increase of 193 kg ha^{-1} in grain yield (Figure 3e). However, a higher number of seeds would be needed to estimate the point of maximum yield under the same conditions. The mean value of the cultivars grown at the suboptimal density was 480 kg ha^{-1} lower than the overall mean of the experiment, which aggravates when compared to a density of 312 seeds m^{-2}. The highest grain yield was achieved at density of 312 seeds m^{-2}, where a decrease of 715 kg ha^{-1} was found, while the mean value of the experimental units with supraoptimal density was 205 kg ha^{-1} higher than the overall mean, and a decrease of only 28 kg ha^{-1} was observed when compared to a density of 312 seeds m^{-2}. This fact indicates that densities below the recommended values may be important from the point of view of productive potential. Such relationship is still clear when the mean values of the two cultivars grown with suboptimal density are observed, in which a decrease over 900 kg ha^{-1} of Toruk grains compared to Sossego. Cultivar Sossego, although showing more potential, had its GY reduced to more than 500 kg ha^{-1} as density was reduced from 312 to 208 seeds m^{-2}.

HW was dependent on the cultivar factor (Table 2). Cultivar Sossego exhibited a mean value in its experimental units of 79.63 kg hL^{-1} while for cultivar Toruk a mean value of 77.47 kg hL^{-1} was observed (Figure 3d).

Table 2. Summary of the analysis of variance, mean square and significance for grain yield (GY) thousand grain weight (TGW), number of spikelets per spike (NSS), number of grains per spike (NGS), number of grains per spikelet (NGSS), harvest index (HI), sieve grains higher than 1,75mm (G>1.75) and hectoliter weight (HW) of wheat.

SOV	GY	TGW	NSS	NGS	NGSS	HI	G>1,75	HW
Block	1637188.61	3.76	1.83*	12.93	0.00	10.20	3.59	0.25
Cultivar (C)	4535067.59*	36.29	1.49	2.40	0.00	72.19	14.73	46.31*
Error 1	372550.59	5.50	0.25	2.97	0.00	31.79	3.48	3.42
Density (D)	1100480.09*	3.59	3.28	35.46	0.03	82.40	9.12	3.45
C × D	149080.09	4.19	1.41	31.61	0.07	4.20	7.99	0.79
Error 2	538458.88	3.52	1.13	14.09	0.03	31.70	4.73	2.79
CV (%)^{1}	14.57	6.01	3.48	5.83	4.79	13.26	1.91	2.36
CV (%)^{2}	17.51	4.80	7.40	12.68	9.71	13.24	2.22	2.13
Main	4190.32	39.06	14.40	29.59	2.05	42.51	97.86	78.55

** and **: significative by F-test F at 5 and 1%, respectively. ^{1} coeficient of variation for main plot; ^{2} coeficient of variation for split plot. SOV, source of variation.*

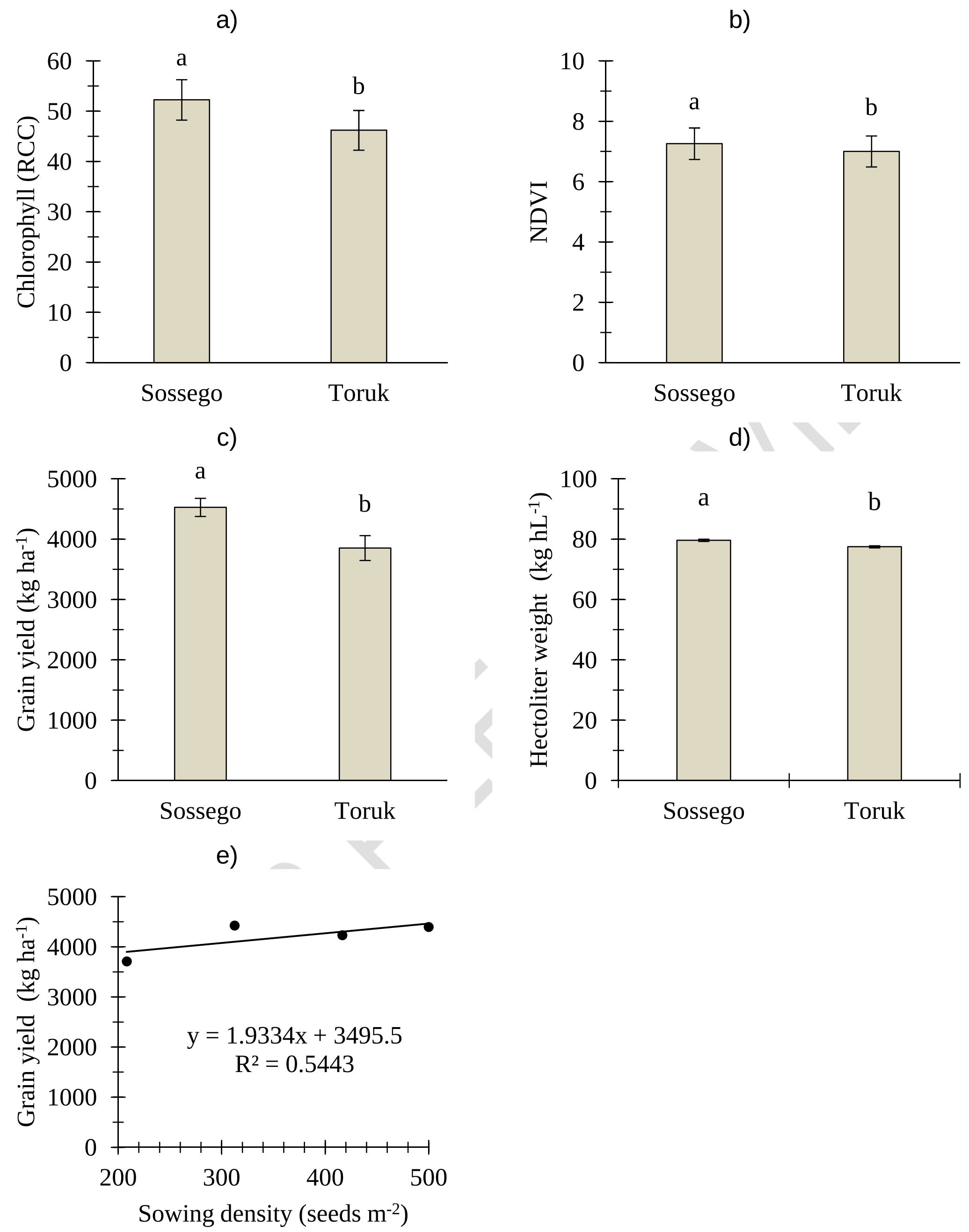

Fig. 3. Single effect of wheat relative chlorophyll content (a), normalized difference vegetation index (NDVI) (b), grain yield (c), hectoliter weight (d) of two wheat cultivars; "Toruk" and "Sossego" and grain yield as function of four sowing densities (e). Curitibanos, Brazil, 2017 growing season. Vertical bars are standard deviation of mean.

4. DISCUSSION

4.1 Morphometric and physiological characters

It has been mentioned that the peduncle is the structure that contributes most to plant height growth; however, for plants height it was found that when the cultivars were compared for different sowing densities, there was more variability in the differences between the cultivars for this variable, but which did not extrapolate the MSD (minimum significant difference). Thus, this fact indicates that sowing density may result in a higher contribution to internodes on the stem base than to the peduncle length in the composition of the total height of wheat plants. The peduncle length and plant height are traits that are indicated to assist in the indirect selection of genotypes, since they can diminish the risk of lodging by increasing the plant resistance to this phenomenon [14]. In this study, there was no occurrence of strong winds and prolonged periods of rain, especially during the reproductive period, which minimizes lodging occurrences. Rainfall during the growing period was of 477.8 mm, but there was a poor distribution of rainfall with long periods of low precipitation, which contributed to the soil dryness (Figure 1) and, as a consequence, the plants grew less.

The flag leaf length (FLL) in this study corroborates with other findings [15], who worked with an increased number of wheat plants in the cultivation line and found that the flag leaf length was not affected by sowing density. However, these authors reported a decrease in the flag leaf dry matter accumulation. It was reported that the senescence of wheat tiller is a gradual process in which the stoppage of leaf extension precedes the gradual senescence of the leaves [16]. Therefore, decreases and / or stagnation in FLL may be indicative that certain tillers will not become effective, succumbing to the course of the cycle.

Grains development is dependent on carbohydrate accumulation in the stems during the pre-anthesis stage and afterwards. In post-anthesis, this dependence lies on the carbon assimilation rate, which is associated with the flag leaf [15]. Because the flag leaf is the youngest leaf, it is photosynthetically more active and does not have its growth constrained by self-shading; therefore, it is physiologically more important than other leaves. This assertion corroborates with other findings and infers that the genetic improvement prioritized genotypes with more upright leaves since they can adapt to greater plant densities per area, which contributes to solar radiation absorption efficiency [17]. Therefore, high densities of plants with compact architecture may contribute to a higher efficiency of natural resources and potentiate grains yield. It was reaffirmed the importance of leaves at the upper portion of the stem and recognizes that the pre-anthesis reserve accumulation is an important source of carbon for grains filling under water stress or phytopathological stress [18]. Such assertion has a direct relation with the behaviour observed in the cultivars of this study, which clearly showed that a higher plant stature, as identified in the morphological traits of cultivar Sossego, and the water deficit that was imposed to the experiment, especially during the early stages of the experiment, influenced final grain yield.

An increased sowing density causes more competition between plants in the cultivation line and affects tillering adversely. Thus, the behaviour of the stem diameter is a clear reflection of competition. When spacing between the cultivation lines is enlarged, thus enhancing the tillering potential, there is more area for nutrients uptake, whereas with increased densities and reduced nutrients uptake, there is an upward behaviour reflected on the stem diameter due to a lower tillering potential. The plants have the capacity to use the nutrient reserves stored on the stems for grains filling in conditions of limited carbohydrate sources [19]. Thus, by observing other morphometric traits, it can be seen that cultivar Toruk exhibited a lower height, which indicates that this characteristic may have culminated in a lower performance.

Furthermore, in addition to the peduncle and plants height, the stem diameter is a characteristic that must be considered with regard to plants lodging resistance, since such resistance is a function of the tissues thickening level at the base of the plant and inversely proportional to its height [20]. However, cultivar Toruk showed to be more stable for this variable, considering that the deviations in all densities in relation to the cultivar overall mean were lower when compared to cultivar Sossego.

Relative chlorophyll content may be an indicator of sunlight energy conversion into chemical energy, i.e., of photo-assimilates accumulation [21]. For wheat cultivation, NDVI can be a reference on biophysical characteristics (total fresh mass, leaf dry mass and leaf area index) with more correlation in the post-anthesis stages, besides representing the duration of the photosynthesis activity during the cycle and being correlated with grains yield [22]. Indirectly, this index can also be correlated with nutritional status, diseases infestation and leaf senescence from chloroses, also being an effective tool in nitrogen fertilization at a variable rate [23].

The two portable meters used in this study express measures based on absorbance and reflectance correlations. In the case of this study, since the measures were read at the same day in all experimental units, although the breeder of both cultivars classify them as medium-cycle cultivars, cultivar Toruk clearly showed a cycle advance at the time, since its leaves had already turned yellow, therefore with lower chlorophyll and NDVI levels. Genotypes that require a lower accumulated heat sum remain less time in the field, as they complete their cycle more quickly [24]. However, mention that the cycle may be longer when plants suffer water stress and, as a consequence, the accumulated heat sum is higher when compared to a cycle without restrictions [25]. Considering that both cultivars are of medium cycle, the RCC and NDVI analysis suggests that these cultivars have different accumulated heat sums and/or respond differently to temporary water deficit, considering that at the third phase of the initial cycle both cultivars experimented low rainfalls (Figure 1).

4.2 Productive and qualitative characteristics of grains

The upward behaviour in grains yield with increased sowing density was not observed by other findings [26]. These authors observed a decreasing GY relationship with an increasing number of plants in the cultivation line. According to these authors, the adverse response to individual components as a function of an increased number of plants derives from dry matter accumulation in the pre-anthesis stage, due to interspecific competition between plants, and the accumulation of dry matter is one of the factors that contribute to GY. However, the authors used complementary irrigation, which may have contributed to more accumulation of dry matter at lower densities and full irrigation is the best management practices for better growth and to attain maximum grain yield [27]. However, it was observed that the dry mass accumulation during late stages (flowering to maturity) was more stable under water-saving management conditions [28].

In the case of this study, in which cultivation was under natural rain conditions, there was a long period of low precipitation rates, particularly during the pre-anthesis phase (Figure 1), and this fact caused a reduction in biomass accumulation, making that the compensation of this factor was achieved by the greater number of plants in the crop line. This situation can also be observed in the HI, where in the average of the experimental units of 208 seeds m^{-2} there was a decrease of HI when compared to the other sowing density conditions. This behaviour was also observed in corn . It was reported that there was an increase in yield due to the increase in plant density in the crop year with water restriction, making the contribution of tillers to yield decrease [29]. Also, the long period of water deficit may have caused a higher tillers mortality, particularly of those that emerged late, in addition to the fact that wheat cultivars with reduced tillering potential stand out in conditions where water is a limiting factor [30], like observed to cultivar Sossego. It was founded that in water deficit conditions, there is a reduced number of effective tillers due to low emergence or early abortion of the tillers and reports that such reduction may result from the plant need to diminish the leaf area, increasing senescence and causing the tillers death [31]. Reductions in grain yield due to low densities can be attenuated due to the regular distribution of rainfall, which reduces the role of tillering as a compensatory trait to yield [32]. It was also concluded that genotypes with low tillering potential express more effect on grains yield as a function of increased sowing density, which was also observed in cultivar Sossego, which has less tillering potential than Toruk and exceeded the grains yield of the latter [4].

The hectoliter weight (HW) is correlated with the grain size and protein content and that higher grains weight makes that higher HW values be achieved [33]. Moreover, since HW is a weight to volume ratio, this may be also an indirect indicator of milling yield, and due the fact that it correlates positively with protein content, grains lots of wheat with lower HW may produce flour with lower breadmaking quality. From this perspective, it was found that the TGW of cultivar Sossego reached 38.1 g whereas Toruk reached 40.0 g, and when productivity is considered, Sossego showed highest grain yield. Since the NGS averages were practically the same, this suggests that the grains of cultivar Sossego may have a higher bulk density compared to Toruk, and that this cultivar has smaller grain sizes, as reported by TGW, which culminates in a larger specific surface area, contributing to higher HW. A lower bulk density may also result in less flour yield per ton of processed wheat, which, consequently, requires a greater storage volume. According to Normative Instruction 38/2010, which sets technical regulation for wheat in Brazil [34], HW is a requirement that classifies wheat types for flour, and the minimum HWs for wheat types 1, 2 and 3 are 78, 75 and 72, respectively. Thus, since cultivar Toruk was at the threshold of legislation for type 1, only cultivar Sossego fell into this category, although both are appropriate for milling aiming flour for bread.

4.3 Correlation study

Pearson correlation between all variables in the overall average of all experimental units and for each sowing density (Table 3) was tested to check for general and specific relations between the variables as a function of plants population, particularly the contributions of each variable on grain yield. It was found that in fact the morphometric traits had a higher correlation coefficient with yield, especially at suboptimal density, whereas on the overall mean of plants populations this effect diminished. This key trait favoured the accumulation of dry matter, contributing to a higher sink/source ratio for the grains, given that the suboptimal density caused the greater amount of tillers death, leading to a greater dependence of the main stem on grain yield and, consequently, a lower phenotypic plasticity as a result of the decreased plants population.

Stress situation in wheat crops may cause changes in the redistribution of photosynthates and the sink/source balance, and changes in these patterns may lead to a compensation or yield losses [35]. From this perspective, what was found in this study is that the higher degree of positive linear association between the morphometric variables and grain yield suggests that there was a greater remobilization of stem assimilates to the grains, especially at lower densities. This fact is also clear from the perspective of cultivars, in which cultivar Sossego exhibited a higher stature compared to cultivar Toruk, which also led to a greater dry mass accumulation with an effect on final grain yield.

In addition to this fact, the greater tillering potential of cultivar Toruk associated with water deficit, resulted in tillers abortion, which are more sensitive regarding the main stems, with a positive impact on the productive performance of this cultivar. Thus, supraoptimal density eventually promoted a compensation due to the deleterious effects of water deficit on the overall densities average. Supraoptimal densities contribute to maximizing the yield potential of low-tillering cultivars, while suboptimal densities maximize the yield potential of high-tillering cultivars [4]. What was found in this study is that this relation can be affected by abiotic factors (low rainfall), contributing to reduce the yield potential of cultivar Toruk (high tillering) at suboptimal plant density.

It was confirmed this interaction between environment and sowing density regarding wheat grain yields and highlights the importance of having an optimal stand and the need for recommendations based on a period of more than a year and for specific sites [4]. In production systems that do not have irrigation, this fact becomes even clearer, considering that the water deficit imposed on the initial of the cycle altered the grain yield dynamics as result of sowing density in this study. Furthermore, drought stress in preharvest caused decrease (16,3%) on grain yield [36].

Table 3. Pearson correlation among the studied variables of wheat grain yield (GY), a thousand grains weight (TGW), number of spikelets per spike (NSS), number of grains per spike (NGS), number of grains per spikelets (NGSS), harvest index (HI), grains higher than 1.75 mm (G>1.75), hectoliter weight (HW), peduncle length (PL), plant height (PH), flag leaf length (FLL), stem diameter (SD), relative chlorophyll content (RCC) and normalized difference vegetation index (NDVI) among all experimental traits and within four seeding densities.

All experimental traits (all densities)														
	GY	TGW	NSS	NGS	NGSS	HI	G>1.75	HW	PL	PH	FLL	SD	RCC	NDVI
GY	1													
TGW	0,50*	1												
NSS	0,61*	0,59*	1											
NGS	0,54*	0,62*	0,90*	1										
NGSS	0,58*	0,71*	0,80*	0,88*	1									
HI	0,50*	0,64*	0,40*	0,35*	0,50*	1								
G>1.75	0,59*	0,36*	$0,25^{ns}$	$0,27^{ns}$	0,32*	0,41*	1							
HW	0,74*	$0,21^{ns}$	0,55*	0,47*	0,50*	0,41*	0,43*	1						
PL	0,64*	$-0,15^{ns}$	0,42*	0,33*	$0,24^{ns}$	$0,00^{ns}$	0,47*	0,76*	1					
PH	0,64*	$-0,17^{ns}$	0,41*	0,32*	$0,25^{ns}$	$0,02^{ns}$	0,44*	0,75*	0,98*	1				
FLL	0,74*	$0,14^{ns}$	0,64*	0,50*	0,47*	$0,21^{ns}$	0,49*	0,79*	0,87*	0,85*	1			
SD	$0,28^{ns}$	0,67*	0,66*	0,78*	0,79*	0,53*	$0,14^{ns}$	0,34*	$-0,10^{ns}$	$-0,10^{ns}$	$0,18^{ns}$	1		
RCC	0,67*	$0,08^{ns}$	0,48*	0,35*	0,31*	0,36*	0,56*	0,72*	0,75*	0,75*	0,79*	$0,17^{ns}$	1	
NDVI	0,73*	0,42*	0,46*	0,34*	0,40*	0,58*	0,59*	0,67*	0,48*	0,46*	0,60*	0,36*	0,79*	1
208 seeds/m^2														
	GY	TGW	NSS	NGS	NGSS	HI	G>1.75	HW	PL	PH	FLL	SD	RCC	NDVI
GY	1													
TGW	0,70*	1												
NSS	0,94*	0,68*	1											
NGS	0,92*	0,63*	0,94*	1										
NGSS	0,87*	0,90*	0,89*	0,80*	1									
HI	$0,47^{ns}$	0,88*	$0,57^{ns}$	0,52ns	0,81*	1								
G>1.75	0,80*	0,68*	0,68*	0,81*	0,69*	$0,47^{ns}$	1							
HW	0,96*	0,71*	0,98*	0,95*	0,86*	$0,53^{ns}$	0,77*	1						
PL	0,88*	$0,31^{ns}$	0,83*	0,89*	$0,58^{ns}$	$0,12^{ns}$	0,72*	0,86*	1					
PH	0,87*	$0,28^{ns}$	0,83*	0,88*	$0,57^{ns}$	$0,10^{ns}$	0,68*	0,84*	1,00*	1				
FLL	0,92*	$0,57^{ns}$	0,90*	0,94*	0,71*	$0,37^{ns}$	0,75*	0,94*	0,88*	0,87*	1			
SD	$0,41^{ns}$	0,84*	$0,54^{ns}$	$0,44^{ns}$	0,66*	0,79*	$0,43^{ns}$	$0,55^{ns}$	$0,07^{ns}$	$0,05^{ns}$	$0,42^{ns}$	1		
RCC	0,75*	0,72*	0,83*	0,80*	0,72*	$0,57^{ns}$	0,75*	0,86*	$0,61^{ns}$	$0,59^{ns}$	0,80*	0,79*	1	
NDVI	0,65*	0,72*	0,78*	0,69*	0,70*	$0,60^{ns}$	$0,59^{ns}$	0,80*	$0,47^{ns}$	$0,45^{ns}$	0,69*	0,87*	0,97*	1
312 seeds/m^2														
	GY	TGW	NSS	NGS	NGSS	HI	G>1.75	HW	PL	PH	FLL	SD	RCC	NDVI
GY	1													
TGW	0,61	1												
NSS	0,98*	$0,55^{ns}$	1											
NGS	0,97*	0,66*	0,94*	1										
NGSS	0,91*	0,83*	0,85*	0,89*	1									

HI	0,65*	0,85*	0,66*	0,72*	0,74*	1								
G>1.75	0,90*	0,80*	0,87*	0,91*	0,91*	0,83*	1							
HW	0,81*	0,33^{ns}	0,84*	0,75*	0,73*	0,43^{ns}	0,59^{ns}	1						
PL	0,61*	-0,22^{ns}	0,65*	0,50^{ns}	0,29^{ns}	-0,07^{ns}	0,30^{ns}	0,58^{ns}	1					
PH	0,55^{ns}	-0,30^{ns}	0,58^{ns}	0,43^{ns}	0,23^{ns}	-0,17^{ns}	0,23^{ns}	0,59^{ns}	0,98*	1				
FLL	0,78*	0,15^{ns}	0,82*	0,63*	0,57^{ns}	0,20^{ns}	0,54^{ns}	0,72*	0,87*	0,82*	1			
SD	0,66*	0,77*	0,65*	0,72*	0,78*	0,87*	0,72*	0,67*	-0,07^{ns}	-0,12^{ns}	0,19^{ns}	1		
RCC	0,67*	-0,13^{ns}	0,69*	0,59^{ns}	0,36^{ns}	0,07^{ns}	0,41^{ns}	0,57^{ns}	0,97*	0,93*	0,85*	0,02^{ns}	1	
NDVI	0,86*	0,13^{ns}	0,87*	0,80*	0,60^{ns}	0,29^{ns}	0,64*	0,76*	0,90*	0,87*	0,86*	0,31^{ns}	0,92*	1

416 seeds/m^2

	GY	TGW	NSS	NGS	NGSS	HI	G>1.75	HW	PL	PH	FLL	SD	RCC	NDVI
GY	1													
TGW	0,30^{ns}	1												
NSS	0,68*	0,74*	1											
NGS	0,30^{ns}	0,90*	0,75*	1										
NGSS	0,35^{ns}	0,96*	0,79*	0,93*	1									
HI	0,57^{ns}	0,70*	0,90*	0,75*	0,74*	1								
G>1.75	0,88*	0,39^{ns}	0,84*	0,43^{ns}	0,44^{ns}	0,75*	1							
HW	0,81*	-0,05^{ns}	0,37^{ns}	-0,16^{ns}	-0,09^{ns}	0,35^{ns}	0,71*	1						
PL	0,66*	-0,43^{ns}	0,11^{ns}	-0,47^{ns}	-0,41^{ns}	0,09^{ns}	0,55^{ns}	0,91*	1					
PH	0,75*	-0,32^{ns}	0,30^{ns}	-0,28^{ns}	-0,27^{ns}	0,26^{ns}	0,70*	0,89*	0,96*	1				
FLL	0,71*	-0,17^{ns}	0,45^{ns}	-0,20^{ns}	-0,11^{ns}	0,37^{ns}	0,70*	0,82*	0,87*	0,91*	1			
SD	0,08^{ns}	0,87*	0,58^{ns}	0,95*	0,85*	0,67*	0,22^{ns}	-0,27^{ns}	-0,60^{ns}	-0,45^{ns}	-0,39	1		
RCC	0,77*	-0,27^{ns}	0,39^{ns}	-0,21^{ns}	-0,18^{ns}	0,28^{ns}	0,73*	0,80*	0,90*	0,97*	0,94*	-0,42^{ns}	1	
NDVI	0,90*	0,33^{ns}	0,60^{ns}	0,19^{ns}	0,29^{ns}	0,54^{ns}	0,81*	0,91*	0,69*	0,70*	0,69*	0,04^{ns}	0,65*	1

500 seeds/m^2

	GY	TGW	NSS	NGS	NGSS	HY	G>1.75	HW	PL	PH	FLL	SD	RCC	NDVI
GY	1													
TGW	0,57^{ns}	1												
NSS	0,89*	0,73*	1											
NGS	0,94*	0,67*	0,94*	1										
NGSS	0,93*	0,57^{ns}	0,87*	0,95*	1									
HI	0,53^{ns}	0,88*	0,78*	0,67*	0,54^{ns}	1								
G>1.75	0,92*	0,40^{ns}	0,72*	0,86*	0,89*	0,36^{ns}	1							
HW	0,78*	0,32^{ns}	0,62*	0,76*	0,84*	0,38^{ns}	0,70*	1						
PL	0,62*	-0,18^{ns}	0,26^{ns}	0,49^{ns}	0,62*	-0,21^{ns}	0,69*	0,78*	1					
PH	0,56^{ns}	-0,23^{ns}	0,21^{ns}	0,42^{ns}	0,56^{ns}	-0,22^{ns}	0,62*	0,79*	0,99*	1				
FLL	0,87*	0,20^{ns}	0,62*	0,78*	0,89*	0,15^{ns}	0,88*	0,87*	0,90*	0,86*	1			
SD	0,77*	0,81*	0,91*	0,86*	0,79*	0,89*	0,67*	0,58^{ns}	0,11^{ns}	0,08^{ns}	0,48^{ns}	1		
RCC	0,72*	0,11^{ns}	0,53^{ns}	0,62*	0,68*	0,28^{ns}	0,66*	0,88*	0,78*	0,81*	0,80*	0,41^{ns}	1	
NDVI	0,77*	0,80*	0,92*	0,84*	0,73*	0,92*	0,62*	0,52^{ns}	0,08^{ns}	0,04^{ns}	0,44^{ns}	0,91*	0,51^{ns}	1

Color key

<0,59	0,6 - 0,69	0,7 - 0,79	0,8 - 0,89	0,9 – 1

4. CONCLUSION

Cultivar Sossego exhibited a better agronomic performance compared to cultivar Toruk independent of sowing density.

Sowing density affects the stem diameter and causes a decrease of this structure, a result of the plants competition into row particularly on tillerest cultivar as Toruk.

Suboptimal sowing densities affect the productive performance of wheat cultivars and, under conditions where rainfall is a limiting factor, reduced tillering potential and supraoptimal sowing densities are more efficient and needed to achieve highest grain yield. Further research can be given to wheat plant grown under stressed-factors such drought or heat stress when plant densities are changed on basis to low or higher tillering potential.

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