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Yield performance of oat cultivars in response to sowing dates and densities

Desempenho produtivo de cultivares de aveia em resposta a épocas e densidades de semeadura

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Highlights

Grain yield varies according to sowing dates and densities.
The first sowing date favored the grain yield of both cultivars.
For the IPR Artemis cultivar, late sowing results in more lodging of plants.

Abstract

Adjustment of seeding density oriented by genotype and conditions of the growing environment may favor growth, development and yield performance of the oat crop. This study aimed to evaluate the growth, lodging, yield components, and grain yield of oat cultivars grown at different sowing dates and densities. Two independent experiments were conducted at two sowing dates (May 5 and June 24) in Londrina-PR under a randomized block design in a 4 × 2 factorial scheme, with four replications. Treatments consisted of four sowing densities (180, 240, 300, and 360 viable seeds m^{-2}) and two cultivars (IPR Afrodite and IPR Artemis). Plant height, number of panicles.m^{-2}, number of spikelets per panicle, number of grains per spikelet, number of grains per panicle, thousand-grain weight, plant lodging, and grain yield were evaluated. The data were submitted to the analysis of joint variance for sowing dates, separately for the cultivars. The averages of sowing dates were compared by the F test and densities submitted to polynomial regression analysis up to 2nd degree, at 5% probability. The first sowing date favors most yield components and grain yield of the cultivars IPR Afrodite and IPR Artemis. In contrast, the number of panicles m^{-2} was reduced during this growing season for both cultivars. The late sowing date for the IPR Artemis cultivar resulted in a high percentage of lodging at all evaluated densities. However, this phenomenon is more intense at higher sowing densities during the first sowing date. Yield components and grain yield varied according to sowing dates and densities and the cultivar. The highest grain yield of the cultivar IPR Afrodite at the first sowing date was achieved with a lower sowing density than in the later date. However, the highest grain yield of the IPR Artemis cultivar was achieved at density of 280 viable seeds m^{-2}, regardless of the growing season.

Key words: *Avena sativa* L. Growing environments. Management techniques. Plasticity. Productivity.

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Resumo

O ajuste da densidade de semeadura orientado pelo genótipo e pelas condições do ambiente de cultivo pode favorecer o crescimento, o desenvolvimento e o desempenho produtivo na cultura da aveia branca. Neste sentido, objetivou-se avaliar o crescimento, o acamamento, os componentes de rendimento e a produtividade de grãos de cultivares de aveia branca granífera cultivadas em diferentes épocas e densidades de semeadura. Dois experimentos independentes, conduzidos em duas épocas de semeadura (05/05 e 24/06), foram realizados em Londrina-PR, em delineamento experimental de blocos casualizados em esquema fatorial 4 x 2, com quatro repetições. Os tratamentos constaram de quatro densidades de semeadura (180, 240, 300 e 360 sementes viáveis m^{-2}) e duas cultivares (IPR Afrodite e IPR Artemis). Foram avaliados: altura de plantas, número de panículas m^{-2}, número de espiguetas por panícula, número grãos por espigueta, número de grãos por panícula, massa de mil grãos, acamamento de plantas e produtividade de grãos. Os dados foram submetidos à análise de variância conjunta para épocas de semeadura, separadamente para as cultivares. As médias de épocas foram comparadas pelo teste F e de densidades submetidas à análise de regressão polinomial até 2° grau, a 5% de probabilidade. A primeira época de semeadura favorece a maioria dos componentes de rendimento e a produtividade de grãos das cultivares IPR Afrodite e IPR Artemis, com exceção do número de panículas m^{-2}, que é reduzido nesta época de cultivo para ambas as cultivares. Para a cultivar IPR Artemis, a semeadura tardia resulta em maior acamamento de plantas em todas as densidades avaliadas, entretanto, na época 1, este fenômeno apresenta maior intensidade nas maiores densidades de semeadura. Os componentes de rendimento e a produtividade de grãos variam de acordo com as épocas e densidades de semeadura e a cultivar utilizada. A maior produtividade de grãos da cultivar IPR Afrodite, na primeira época de semeadura, é obtida com menor densidade de semeadura do que na época mais tardia. Já o maior rendimento de grãos da cultivar IPR Artemis é alcançado na densidade de 280 sementes viáveis m^{-2}, independentemente da época de cultivo.

Palavras-chave: *Avena sativa* L.. Ambientes de cultivo. Técnicas de manejo. Plasticidade. Produtividade.

Introduction

The increase in the grain yield potential of the white oat crop, achieved by genetic breeding programs in southern Brazil, has considerably modified the productive scenario of this species. In recent years, it has been possible to verify high productivities resulting from the release of new cultivars adapted to different Brazilian growing environments and technical management incorporated into the production system (Lângaro & Carvalho, 2014).

Sowing density stands out among the various growing techniques that have been adopted and improved to maximize the yield potential of the oat crop (Ceccon, Grassi, & Bicudo, 2004). This practice interferes with the ability of plants to use resources of the environment, which are variable according to the region or growing season, in addition to causing morphophysiological changes in plants (Zagonel, Venancio, & Kunz, 2002), which may significantly affect the growth and final crop yield.

The general indication of sowing density for oat is 200 to 300 viable seeds m^{-2}, with an interrow spacing from 0.17 to 0.20 m (Lângaro & Carvalho, 2014). However, oat cultivars have shown significant changes in their architecture by reducing height and leaf area, besides a high resistance to lodging and good adaptation to different environmental conditions (Hawerroth et al., 2015). These characteristics can alter the response of cultivars to the plant population, requiring specific recommendations for each group of cultivar according to the growing environment (site or sowing date).

In addition to density, another management technique that assists substantially in altering yield components and increasing grain yield is the sowing date in a given growing site. According to Amorim, Hamawaki, Sousa, Lana and Hamawaki (2011), the sowing date can be defined as a set of environmental factors that react with each other and interact with the plant, causing variations in productivity and grain quality, besides affecting other agronomic characteristics of plants.

The proper choice of sowing date allows the different phenological stages of the crop to occur at times when weather elements are the most favorable for plants, which positively affects growth, yield, and quality of grains (Caron et al., 2017). According to Silva et al. (2011), it is essential to provide specific recommendations of the best sowing date and density for the various genotypes available on the market in Brazil, where a large number of cultivars are differentiated by the cycle, potential of tiller emission, and ability to adapt to climate and soil conditions. It allows the expression of their maximum genotypic potential.

Thus, sowing date and density, associated with the choice of cultivars adapted to the region of production, have been management strategies to obtain high productivities (Freitas, Hamawaki, Bueno, & Marques, 2010).

In this sense, this study aimed to evaluate the growth, lodging, yield components, and grain yield oat cultivars grown at different sowing dates and densities.

Material and Methods

Two independent experiments were conducted at two sowing dates (May 5 and June 24) in Londrina-PR on a eutroferric Red Latosol at the Experimental Station of the Agronomic Institute of Paraná (IAPAR), located at 23°23′ S and 51°11′ W, with an altitude of 610 m. The regional climate is Cfa, according to the Köppen classification, described as humid subtropical with hot summers, infrequent frosts, and a tendency of rainfall concentration during the summer, but without a defined dry season. Rainfall and temperature data were obtained from the records of IAPAR weather stations (Figure 1).

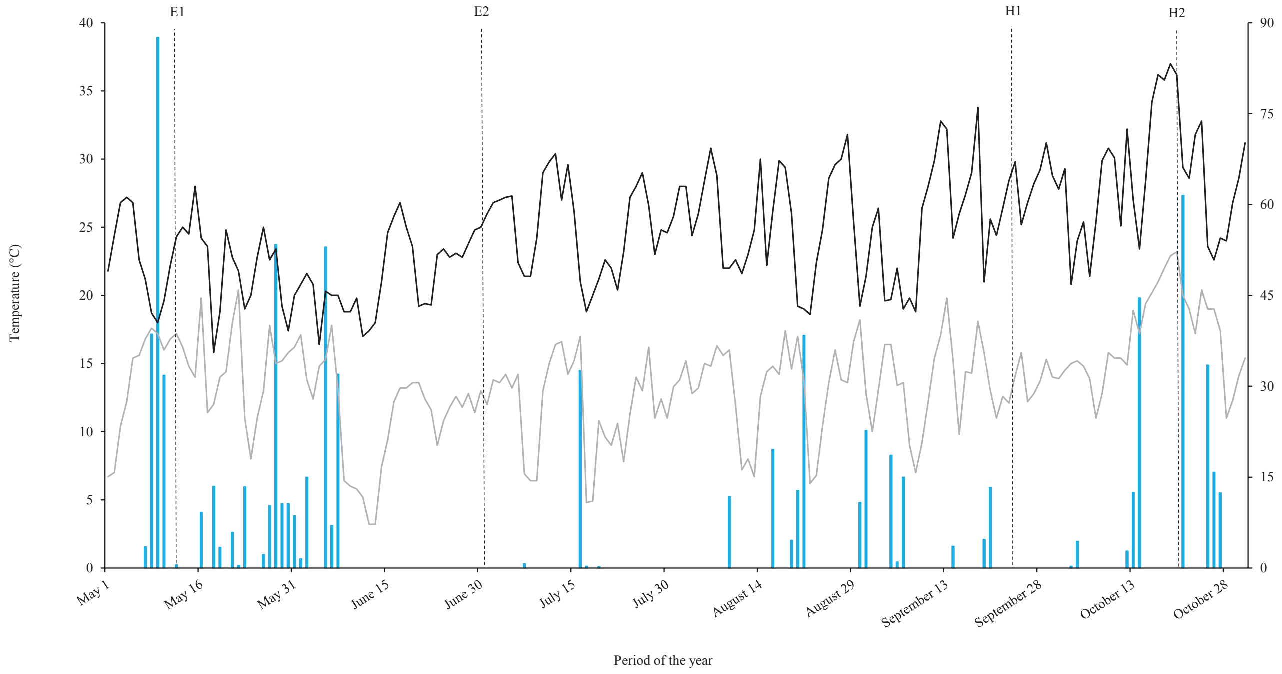

Figure 1. Daily data of maximum and minimum temperatures and rainfall for the conduction period of experiments. E1: emergence of sowing date 1 (May 13), E2: emergence of sowing date 2 (July 1), H1: harvest of sowing date 1 (September 23), and H2: harvest of sowing date 2 (October 21).

Soil chemical characteristics were determined at depths of 0–10 and 10–20 cm before setting up the experiment. The depth of 0–10 cm presented a pH ($CaCl_2$) of 4.80, H+Al^{3+} of 5.76 $cmol_c$ dm^{-3}, Ca_2+ of 4.42 $cmol_c$ dm^{-3}, Mg^{2+} of 1.56 $cmol_c$ dm^{-3}, K^+ of 0.35 $cmol_c$ dm^{-3}, P of 36.3 mg dm^{-3}, and organic matter of 19.09 g dm^{-3}. On the other hand, the depth of 10–20 cm showed a pH ($CaCl_2$) of 4.90, H+Al^{3+} of 5.76 $cmol_c$ dm^{-3}, Ca^{2+} of 4.57 $cmol_c$ dm^{-3}, Mg^{2+} of 1.52 $cmol_c$ dm^{-3}, K^+ of 0.27 $cmol_c$ dm^{-3}, P of 15.1 mg dm^{-3}, and organic matter of 16.59 g dm^{-3}.

Experiments were conducted using the cultivars IPR Afrodite (medium cycle, moderate resistance to lodging, medium height, and released in 2012 by IAPAR) and IPR Artemis (medium cycle, moderate resistance to lodging, medium height, and released in 2016 by IAPAR). A randomized block design in a 4 × 2 factorial arrangement, with four replications, was used in both experiments and sowing dates. Treatments consisted of four sowing densities (180, 240, 300, and 360 viable seeds m^{-2}) and two cultivars (IPR Afrodite and IPR Artemis). Plots were composed of six rows of 5 m in length and interrow spacing of 0.17 m, with a useful area of 5.1 m^2.

The experiments were carried out under a conventional soil management system, in an area previously cultivated with soybean. Base mineral fertilization in the sowing furrow was calculated based on soil chemical characteristics in the experimental area, being constant for all treatments and consisting of 20 kg N ha^{-1}, 60 kg P_2O_5 ha^{-1}, and 20 kg K_2O ha^{-1}, using the formula 10–30–10.

Phytosanitary treatments for disease control and other management practices were carried out as required and taking into account crop recommendations (Lângaro & Carvalho, 2014). Harvest was carried out after the grains reached the harvest maturity, a stage characterized by the hardening of caryopsis, plants with dry aspect, and grains with moisture below 20%. The following evaluations were carried out to determine the agronomic performance:

Plant height: determined by measuring the length of five plants taken at random in the useful area of each experimental plot during the grain-filling period from the soil level to the end of the panicle, with average results expressed in centimeters.

Number of panicles.m^{-2}: determined at harvest by counting the number of panicles in 1.0 m of a row of plants in the useful area of the plots. Subsequently, the number of panicles.m^{-2} was calculated by multiplying the number of panicles.m^{-1} by the interrow spacing (0.17 m).

Number of spikelets per panicle: determined by manually counting ten panicles harvested randomly from each plot.

Number of grains per spikelet: determined by manually counting the spikelet grains from ten panicles harvested randomly from each plot.

Number of grains per panicle: determined by removing the grains from ten panicles harvested randomly from the useful area of the plot. After their total separation, they were manually counted.

Thousand-grain weight: obtained by counting and weighing eight replications of 100 grains per plot. The mean of these values was multiplied by 10 to obtain this variable, which was expressed as grams.

Lodging: obtained through visual observations during the maturation stage of plants using the scale of scores from 0 to 10, in which the score 10 represents 100% of lodged plants, and 0 refers to no lodged plant at the plot.

Grain yield: determined by harvesting grains from plants in the useful area of the plots. After mechanical threshing, the grains were weighed, and the data transformed into kg ha^{-1} at 13% moisture.

The data were subjected to the analysis of normality and homogeneity of errors and, subsequently, to the analysis of joint variance for sowing dates, separately for cultivars. The means of sowing dates were compared by the F-test and those of densities submitted to a polynomial regression analysis up to 2nd degree at 5% probability.

Results and Discussion

Precipitations during the cycle of plants grown at first and second sowing dates were 622.70 and 336.80 mm, respectively (Figure 1). Precipitation volume was below the minimum required by the crop at the late sowing, with a period of more severe water restriction during the vegetative stage. However, precipitation distribution was uneven for both growing seasons, which may have altered the agronomic performance of the evaluated cultivars.

For the cultivar IPR Afrodite the interaction of sowing date and density was significant for the number of spikelets per panicle, number of grains per panicle, thousand-grain weight, and grain yield. Plant height and number of panicles m^{-2} had an isolated effect of sowing dates. No significant effect of sowing dates, densities, and interaction between factors was observed for the number of grains per spikelet and plant lodging.

For the cultivar IPR Artemis the interaction of sowing date and density was significant for thousand-grain weight and plant lodging. An isolated effect of sowing date was observed for plant height, number of panicles m^{-2}, number of spikelets per panicle, number of grains per panicle, and grain yield. An isolated effect of sowing densities was found only for grain yield. No significant effect of sowing dates, densities, and interaction between factors was observed for the number of grains per spikelet.

The plant height of the cultivars IPR Afrodite and IPR Artemis showed a reduction of 12.3 and 14.5% in sowing date 2, respectively (Table 1). This fact may be related to the shortening of the cycle of plants sown in the second date, which resulted in their low growth in response to weather conditions, such as low rainfall, high temperatures, and long days. According to Coffman and Frey (1961), these conditions favor more accelerated vegetative development, anticipating flowering.

Table 1
Mean values of plant height (PH), number of panicles m^{-2} (PAN), number of spikelets per panicle (SP), number of grains per panicle (GP), and grain yield (GY) of two cultivars of white oats as a function of sowing dates (Sowing date 1: May 5; Sowing date 2: June 24)

Sowing dates	Traits				
	IPR Afrodite				
	PH (cm)		PAN		
Sowing date 1	131 A		412 B		
Sowing date 2	115 B		518 A		
CV (%)	8.5		11.4		
	IPR Artemis				
	PH (cm)	PAN	SP	GP	GY (kg ha^{-1})
Sowing date 1	133 A	386 B	45 A	98 A	6811 A
Sowing date 2	113 B	501 A	27 B	59 B	3946 B
CV (%)	7.7	11.5	13.6	15.2	10.2

Means followed by the same letter in the column do not differ from each other by the F-test ($p<0.05$).

The number of panicles m^{-2} of IPR Afrodite and IPR Artemis cultivars presented the best results in the second sowing date (Table 1). The highest values obtained for this variable in the late sowing may be associated with the occurrence of low temperatures and good solar incidence during crop tillering. According to Floss, Caierão, Cunha and Pires (2009), these conditions favor the development and growth of lateral buds, found in the axils of lower leaves of the main stem, which give rise to tillers, affecting the yield component number of panicles per area. According to Castro, Costa and Ferrari (2012), tillering in annual grasses is maximum at 25 °C.

The number of spikelets per panicle of IPR Afrodite cultivar had adjusted to a decreasing linear function with the increased number of seeds m^{-2} in sowing date 1. However, no effect of sowing density was observed for this trait in sowing date 2. Moreover, the first sowing date showed the highest values for the number of spikelets per panicle for all sowing densities (Figure 2).

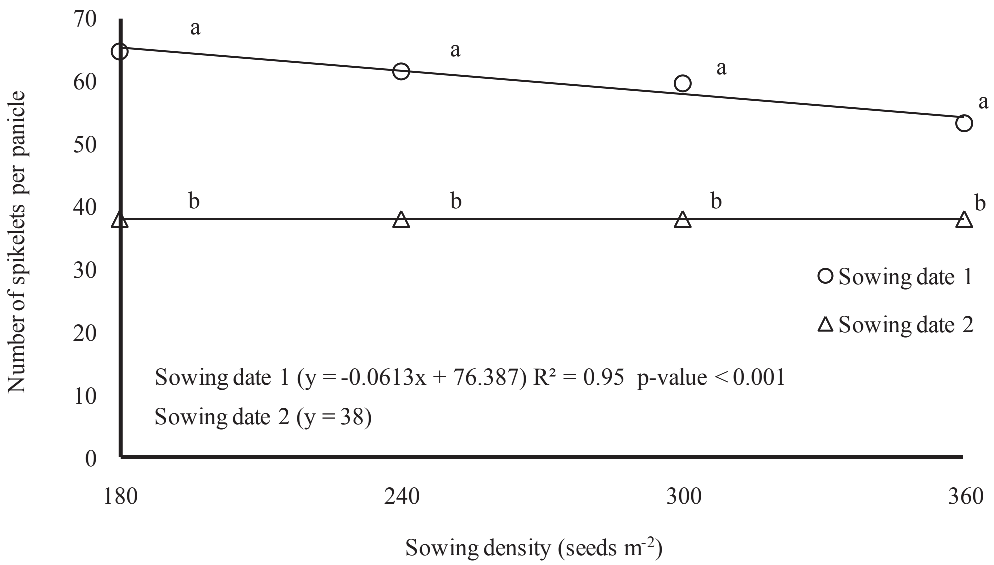

Figure 2. Number of spikelets per panicle of IPR Afrodite cultivar as a function of sowing dates and densities.

The number of spikelets per panicle produced by plants of the IPR Artemis cultivar sown at the first sowing date was higher than the number obtained from plants grown during the late sowing period (Table 1), with no significant effect of sowing density for both sowing dates.

The late sowing for both cultivars resulted in plants with low height and a high number of panicles per area (Table 1) compared to the early sowing, which may have contributed to the reduction in the number of spikelets per panicle due to the low photosynthetic capacity of plants and the competition of fertile tillers for photoassimilates. On the contrary, Ramos et al. (2013) and Venske et al. (2016) worked with wheat and rice, respectively, and found no significant effect of sowing dates for the variable under analysis. However, these divergent responses may be associated with differences in weather conditions between study sites, as well as with the interaction of sowing dates and management.

Sander, Costa and Duarte (2017) evaluated the effect three interrow spacings (13, 17, and 21 cm), four sowing densities (200, 300, 400, and 500 viable seeds m^{-2}), and two agricultural years (2010 and 2011) on the wheat cultivar BRS 208. Also, Fioreze and Rodrigues (2014a) evaluated the effect of applying or not growth retardant and four sowing densities (30, 50, 70, and 90 seeds m^{-1}) on the wheat cultivar IAC 370. These authors verified that the number of spikelets per ear reduced with the increasing sowing density, as found for the present study during the cultivation of oats at the first sowing date. Gross et al. (2012) reported that this fact could be explained by high intraspecific competition for environmental resources due to the high number of seeds per area.

The number of grains per panicle for the IPR Afrodite cultivar in sowing dates 1 and 2 was adjusted to decreasing and increasing linear equations, respectively, in response to an increase in the number of seeds.m^{-2} used during sowing (Figure 3). The first sowing date showed the highest values for this trait at all sowing densities.

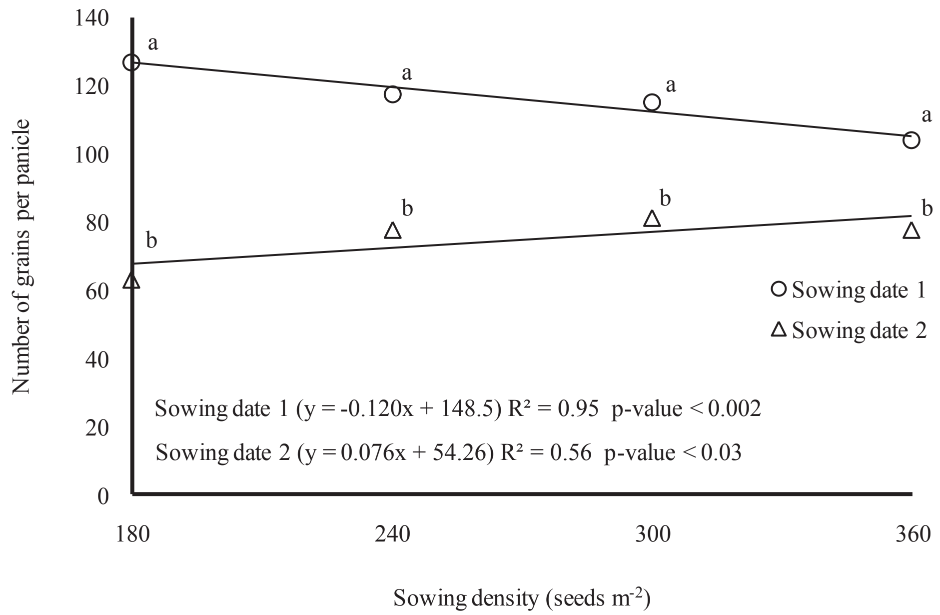

Figure 3. Number of grains per panicle of IPR Afrodite cultivar as a function of sowing dates and densities.

Fioreze and Rodrigues (2014b) evaluated the effect of population density on the wheat crop and found that an increase in sowing density led to a reduction in the number of grains in productive structures. This fact may be associated with the high competition for space, water, light, and nutrients resulting from the high population of plants per unit area due to the increased sowing density.

Akhter et al. (2017) found a similar number of grains per panicle produced by the IPR Afrodite cultivar at the late sowing when evaluating the effect of three sowing densities (100, 120, and 140 kg ha^{-1}) and five wheat varieties (BARI Gom 24, BARI Gom 25, BARI Gom 26, BARI Gom 27, and BARI Gom 28) on yield components and grain yield. These authors observed that an increase in the number of seeds per unit area increased the number of grains per ear. On the other hand, Abati et al. (2017) worked with two levels of seed vigor (high and low), two sowing densities (200 and 400 viable seeds m^{-2}), and two wheat cultivars (BRS Sabiá and CD 150) and found no significant effect of sowing density on the number of grains per ear.

The linear increase in the number of grains per panicle due to an increase in sowing density in sowing date 2 may be related to the fact that the increase in population was followed by a high amount of fertile tillers per area in this treatment (Table 1). It may have favored a high competition between these structures, resulting in senescence of later tillers and reducing competition between panicles for environmental resources/photoassimilates, which led to the formation of a high number of grains per panicle.

Similar to the IPR Afrodite cultivar (Figure 2B), the IPR Artemis cultivar produced the highest number of grains per panicle in sowing date 1 (Table 1). It may have occurred because oat plants produced a low number of panicles.m^{-2} in these treatments (Table 1), which allowed increasing the number of caryopses per panicle due to less competition between plants at early sowing.

Thousand-grain weight of the cultivars IPR Afrodite and IPR Artemis showed no effect on sowing density in sowing date 1. However, it was adjusted to quadratic equations with minimum points at 263.89 and 258.48 seeds m^{-2} for the cultivars IPR Afrodite and IPR Artemis, respectively, in sowing date 2 (Figures 4 and 5).

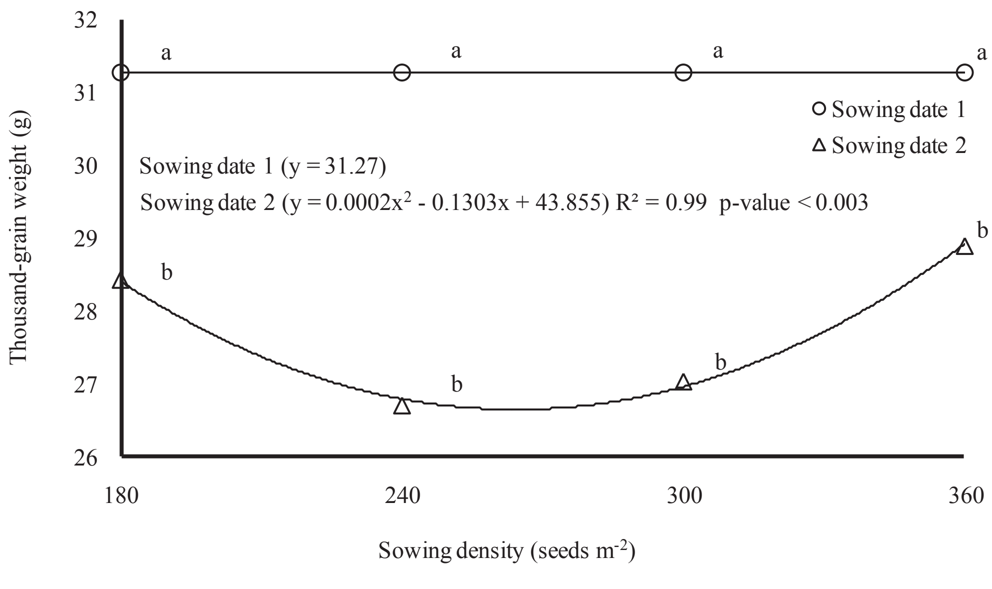

Figure 4. Thousand-grain weight of IPR Afrodite cultivar as a function of sowing dates and densities.

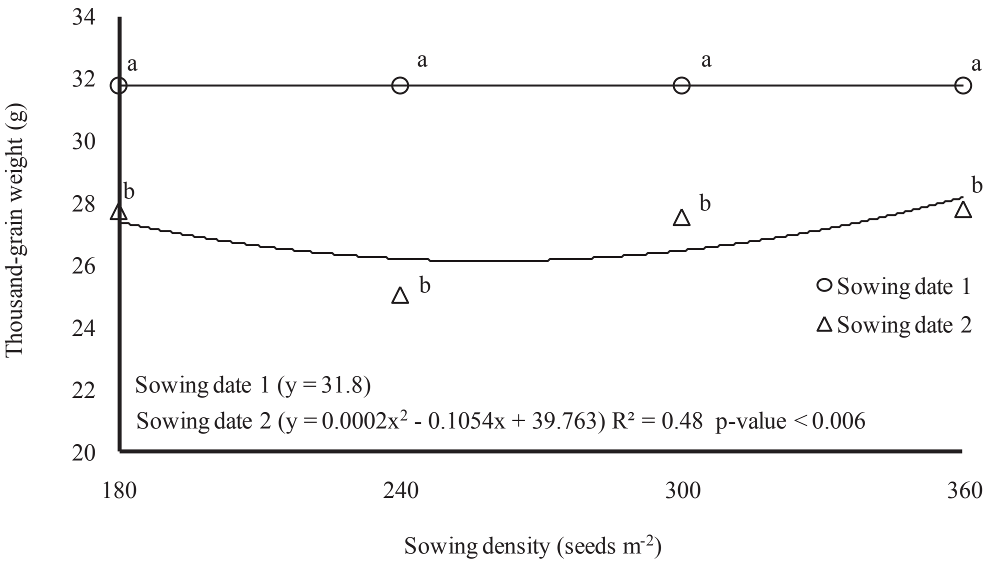

Figure 5. Thousand-grain weight of IPR Artemis cultivar as a function of sowing dates and densities.

The first sowig date resulted in the production of grains with high weight for both cultivars, regardless of the sowing density. It was due to good weather conditions (well-distributed precipitation and milder temperatures) that occurred during the growth and vegetative development of plants grown in sowing date 1, thus allowing them to accumulate more dry matter (organic production), with direct effects on grain weight. Another factor that may be related to the occurrence of a higher thousand-grain weight at the first sowing period is that the plant cycle was longer in this treatment than in the second sowing, extending the grain-filling period.

Tavares, Foloni, Bassoi and Prete (2014) observed results of sowing density similar to those found in the present study for the thousand-grain weight of the cultivars IPR Afrodite and IPR Artemis when evaluating the effect of wheat genotypes (PF 014384, BRS Tangará, and BRS Pardela) grown at different sowing densities (150, 250, 350, and 450 viable seeds m^{-2}) in Londrina-PR and Ponta Grossa-PR in 2009 and 2010 on yield components and grain productivity. They concluded that thousand-grain weight was not influenced by sowing densities in both locations in 2009, but Ponta Grossa and Londrina in 2010 had a quadratic fit for this variable as a function of sowing densities.

Plant lodging at the first sowing date for the IPR Artemis cultivar was fit to an increasing linear equation in response to the increased number of seeds m^{-2} (Figure 6). According to Zagonel et al. (2002), high sowing densities can increase the percentage of lodging due to a series of morphological changes that plants under these conditions are subject to, such as less dry matter accumulation and a reduction in stem diameter, for example.

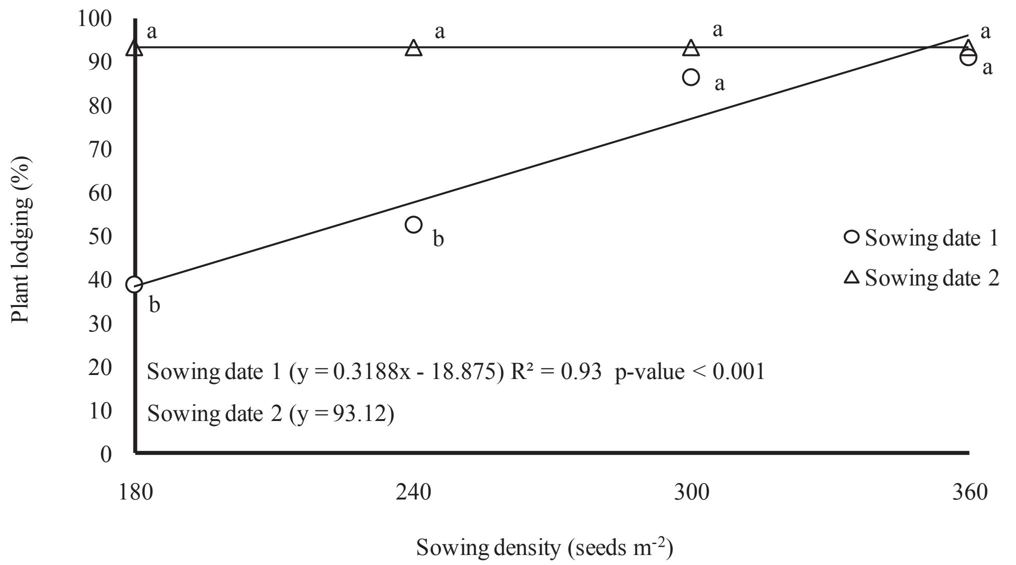

Figure 6. Plant lodging of IPR Artemis cultivar as a function of sowing dates and densities.

Plant lodging at the second sowing date for the cultivar IPR Artemis showed no significant effect of sowing density (Figure 6). Zagonel et al. (2002) observed a similar result when working with three wheat densities (44, 60, and 75 plants m^{-1}), application or not of growth retardant (trinexapac-ethyl), and four topdressing N doses (0, 45, 90, and 135 kg ha^{-1}). These authors also observed no alteration in the percentage of lodged plants due to an increase in the number of seeds m^{-2}.

Figure 6 shows that the highest percentages of lodged plants for sowing densities of 180 and 240 seeds m^{-2} were found at the sowing date 2. On the other hand, densities of 300 and 360 seeds m^{-2} showed no significant difference between sowing dates due to the linear increase in lodging in sowing date 1 in response to density, equating the percentages of lodging between both sowing dates at the highest densities.

Grain yield in sowing date 1 for the IPR Afrodite cultivar showed no response to sowing density. However, this trait was fit in sowing date 2 to an increasing linear equation in response to the increased number of seeds m^{-2} used during sowing (Figure 7). Growing in sowing date 1 resulted in a high oat grain yield for all sowing densities.

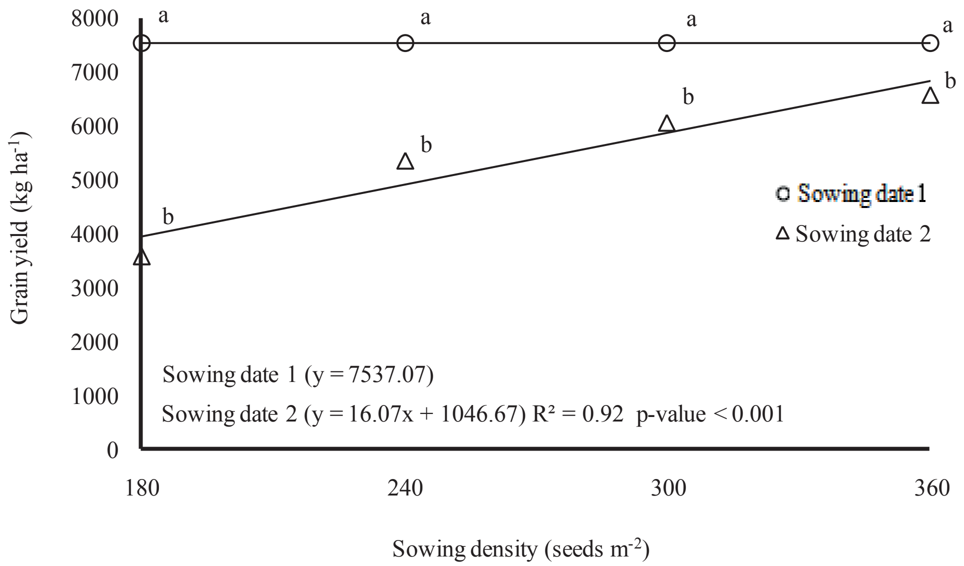

Figure 7. Grain yield of IPR Afrodite cultivar as a function of sowing dates and densities.

Sowing date 1 favored grain yield for the IPR Artemis cultivar (Table 1). Moreover, this trait was adapted to a quadratic equation with a maximum point at 285.81 seeds m^{-2}, regardless of the growing season (Figure 8).

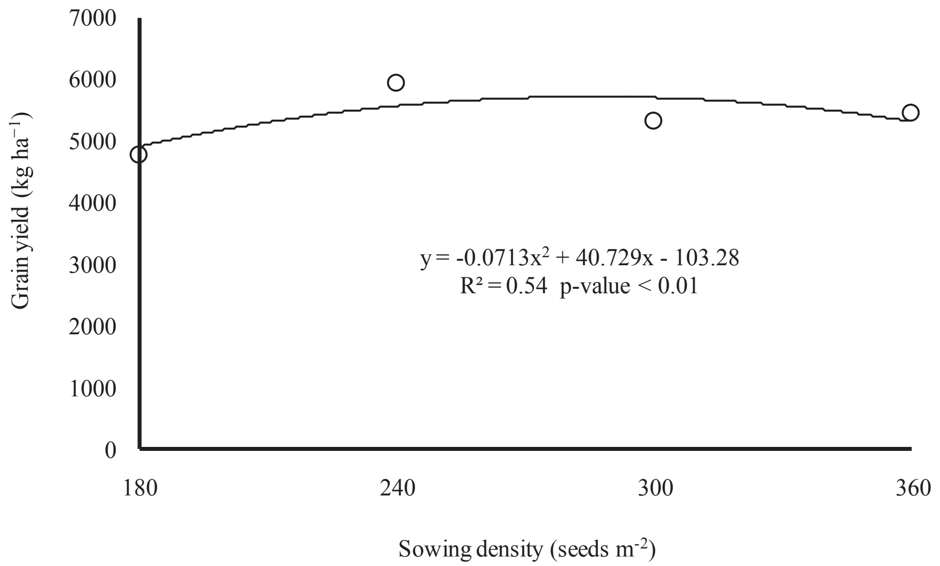

Figure 8. Grain yield of IPR Artemis cultivar as a function of sowing densities.

Both cultivars showed the highest values for grain yield at the first sowing date. Ferrazza, Soares, Martin, Assmasnn and Nicola (2013) found similar results when working with four oat cultivars (FAPA 2, FUNDACEP FAPA 43, IPR 126, and UTF Iguaçu) and four sowing dates (March 11, April 8, May 6, and June 3, 2009) in Pato Branco-PR. They found that the first sowing date provided a high production compared to the others due to the longer vegetative period of plants, indicating that delays in sowing lead to the shortening of the vegetative cycle and, consequently, losses in productivity.

Grain yield results found in the present study may be related to several factors, such as the genetic traits of cultivars and, mainly, weather conditions recorded throughout the plant cycle as a function of the sowing date of oat cultivars. The delay in sowing provided the plants to be submitted to high temperatures and the availability of solar radiation during the growing period. According to Castro et al. (2012), it accelerates the growth and development of oat plants, stimulating plant respiration, as their metabolic processes are more active. These factors decrease the grain yield potential at these seasons, decreasing grain yield.

Another factor that may have contributed to the highest grain yield of the cultivars IPR Afrodite and IPR Artemis at the first sowing date was the highest number of spikelets per panicle (Table 1 and Figure 2), number of grains per panicle (Figure 3 and Table 1), and thousand-grain weight (Figures 4 and 5) at this growing season.

Thus, considering the effects that weather conditions can cause on the morphological development and productivity of oat plants, the adequacy of the sowing date can increase grain yield. Consequently, the diversification of sowing dates can minimize the negative effects of weather conditions on grain yield.

Regarding sowing density, the lack of response from the IPR Afrodite cultivar for grain yield due to an increase in the number of seeds m^{-2} at the first sowing date (Figure 7) can be attributed to the compensatory effect between yield components, as annual winter grasses have a high capacity to compensate for the lack or excess of one component by modifying or adjusting others (Grafius, 1978). This modification, depending on the genotype, environment, and interaction between both, may be enough to maximize the yield potential per unit area. Thus, the same grain yield can be achieved by different paths, making it difficult to establish an optimal combination of components (Tavares et al., 2014). The optimal density level that determines the maximum grain yield may not be directly related only to tiller emission.

Sowing date 2 showed a linear increase in grain productivity with the increased sowing density (Figure 7). Similarly, Tavares et al. (2014) conducted a study with wheat and found that the sowing density of 450 viable seeds m^{-2} resulted in the highest grain yield in 2009. However, these authors found that 150 viable seeds m^{-2} in 2010 was enough to obtain a good grain yield. These results show the differences regarding weather conditions during different years of cultivation and different sowing date at the same place. In this case, inadequate weather conditions can negatively affect the tillering potential and the expression of the compensation potential in yield components by plants, compromising crop grain yield.

The quadratic adjustment of grain yield as a result of an increase in sowing density for the IPR Artemis cultivar (Figure 8) may be related to the plant lodging (Figure 6) verified for this cultivar in response to the increased number of plants per unit area.

Currently, the recommended sowing density for oat is 200 to 300 viable seeds m^{-2} (Lângaro & Carvalho, 2014). Therefore, this recommendation can be considered generalist, disregarding genotypic and environmental variations, as well as the interaction between plant density and management.

The results obtained with the IPR Afrodite cultivar in sowing date 1 (Figure 7) indicate the possibility of using 180 seeds m^{-2} for sowing, reducing the number of seeds in the commercial cultivation, which would assist in reducing production costs. The increased sowing density (up to 360 seeds m^{-2}) of this cultivar at the late sowing could be considered an efficient strategy to increase grain yield.

The results for the IPR Artemis cultivar indicate the possibility of using approximately 280 seeds m^{-2} for sowing (Figure 8) to achieve the highest grain yield, regardless of the sowing date.

Conclusions

The first sowing date favored plant height, number of spikelets per panicle, number of grains per panicle, thousand-grain weight, and grain yield of the cultivars IPR Afrodite and IPR Artemis. In contrast, the number of panicles m^{-2} was reduced during this growing season for both cultivars.

The late sowing date for the IPR Artemis cultivar resulted in a high percentage of lodging at all evaluated densities. However, this phenomenon is more intense at higher sowing densities during the first sowing date.

Yield components and grain yield varied according to sowing dates and densities and the cultivar.

The highest grain yield of the cultivar IPR Afrodite at the first sowing date was achieved with a lower sowing density than in the later date. However, the highest grain yield of the IPR Artemis cultivar was achieved at density of 280 viable seeds m^{-2}, regardless of the growing season.

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