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Agronomic feasibility of wheat and triticale cultivars in the semiarid of Minas Gerais State, Brazil

Viabilidade agronômica de cultivares de trigo e triticale na região semiárida do Estado de Minas Gerais, Brasil

Adson Santos[1]; Carlos Albuquerque[2]; Franklin Sousa[1]; Raphael Siqueira[1]; Fernando Rocha[2]*; Adriano Custodio[3]

Highlights

Wheat and triticale grains can be produced in the semiarid region of Minas Gerais.
Cultivars and sowing times can provide higher yields compared to traditional regions.
Sowing time and cultivar can affect the industrial quality of wheat grains.

Abstract

The production of winter cereals is becoming increasingly important in Brazil, largely due to advanced techniques that enable considerable qualitative and quantitative gains. This is due to plant breeding under different soil and climate conditions combined with proper management. The present study aims to assess the agronomic feasibility of growing wheat and triticale cultivars with two sowing times in the semiarid region of northern Minas Gerais State, Brazil. The experiment was conducted in 2018 at the Instituto de Ciências Agrárias (Institute of Agricultural Sciences) of Universidade Federal de Minas Gerais, Montes Claros campus. A randomized block design was used, with four replications and an 8 × 2 factorial arrangement consisting of eight genotypes (six wheat and two triticale cultivars) and two sowing times (April 21 and May 12, 2018). The irrigated production of wheat and triticale was agronomically feasible in the semi-arid region of Minas Gerais state and sowing time affected the main agronomic traits of interest of winter cereals. However, it is essential to study the economic feasibility of the crop. Sowing in April was the most indicated for wheat and triticale, with IPR Potyporã, IPR 144 and IPR 111 as the recommended cultivars.

Key words: Agronomic traits. *Triticum. aestivum* L. X *Triticosecale wittimack*. Winter cereals.

[1] Students of the Graduate Course in Agronomy at Instituto de Ciências Agrárias, Universidade Federal de Minas Gerais, ICA/UFMG, Montes Claros, MG, Brazil. E-mail: ads_on@live.com; frankklin.psousa@hotmail.com; raphael_m_siqueira@hotmail.com
[2] Profs. Drs., of the Postgraduate Program in Vegetable Production, ICA/UFMG, Montes Claros, MG, Brazil. E-mail: carlosjuliano@ufmg.com; rochafs@ufmg.br
[3] Researcher, Instituto de Desenvolvimento Rural do Paraná, IDR-Paraná, PR, Brazil. E-mail: custodio@iapar.br
* Author for correspondence

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Resumo

A produção brasileira de cereais de inverno está ganhando cada vez mais importância, principalmente pelo uso de técnicas avançadas, o que permite um ganho qualitativo e quantitativo considerável. Isso ocorre em função do melhoramento genético nas diferentes condições edafoclimáticas associado ao manejo adequado dessas plantas. Assim, esse trabalho objetivou avaliar a viabilidade agronômica de cultivares de trigo e triticale em duas épocas de semeadura na região semiárida do estado de Minas Gerais, Brasil. O experimento foi conduzido no delineamento de blocos casualizados com quatro repetições, em arranjo fatorial 8 × 2, composto por oito genótipos (6 cultivares de trigo e 2 cultivares de triticale) e duas épocas de semeadura (21 de abril e 12 de maio de 2018). A produção irrigada de trigo e triticale no semiárido mineiro foi agronomicamente viável, e a época de semeadura afetou as principais características de interesse agronômico dos cereais de inverno. Porém, é fundamental estudar a viabilidade econômica para a indicação da cultura. A semeadura em abril foi a mais indicada para trigo e triticale, nesse caso, recomenda-se o uso das cultivares IPR Potyporã, IPR 144 e IPR 111.
Palavras-chave: Características agronômicas. Cereais de inverno. *Triticum. aestivum* L. X *Triticosecale wittimack.*

Introduction

In recent years, the cultivated area and yield of wheat (*Triticum. aestivum* L.) and triticale (X. *Triticosecale wittimack*) have increased significantly in Minas Gerais state, Brazil. Producers in the Alto Paranaíba, Triângulo Mineiro and northwestern regions of the state have adopted these crops, and a combination of research initiatives and technical support by the government, industry and farmers has seen them expand from traditional growing regions to the central and southern areas of the state (Secretaria de Estado de Agricultura, Pecuária e Abastecimento [SEAPA], 2017).

Minas Gerais depends on foreign exports of winter cereals for human consumption and animal feed. Demand is greater in the northern region of the state due to its warm, dry semiarid climate. Large irrigated areas promoted by the federal government, associated with the water potential of artesian wells in the region have encouraged grain production projects in non-traditional areas as viable alternatives to succession planting systems.

Triticale was synthesized through interspecific hybridization between wheat and rye (*Secale cereale* L.) to combine the baking characteristics and high grain yields of wheat with the rusticity of pest and disease-tolerant rye, resulting in a plant with lower production costs. For some triticale cultivars, yield can exceed 7 Mg ha^{-1} without supplementary irrigation, surpassing crops such as wheat and corn. Triticale produces higher grain yields than other cereals, particularly under less favorable conditions, and can be grown in areas subject to intensive exploitation and/or adverse soil and climate conditions (Dumbravă et al., 2014).

In 2019, average national yields for wheat and triticale were 2,640 and 2,800 kg ha^{-1}, respectively (Companhia Nacional de Abastecimento [CONAB], 2020). The increase in dryland farming and late sowing in months with low rainfall rates in the Cerrado of Minas Gerais have limited yield gains (SEAPA, 2017). Rezende et al. (2020) obtained similar grain yield in the Cerrado and semiarid of Minas Gerais.

In wheat production systems in semiarid regions, it is common consensus that supplementary irrigation is a key factor to achieve good crop yields. In Pakistan, a study with different plant arrangements submitted to five supplementary irrigation depths obtained a grain yield of 5,294 kg ha^{-1} (Kakar & Iqbal, 2015). Djaman et al. (2018) demonstrated the feasibility of growing this winter cereal in the semiarid region of New Mexico, USA, with grain yield ranging from 1,843 to 7,085 kg ha^{-1}. The authors found that the choice of cultivar and sowing time were essential to the feasibility of winter cereal in the region (Djaman et al., 2018).

Given the global importance of winter cereals for human consumption and animal feed, research aims to increase grain yield in different agricultural production and technological management environments (Dumbravă et al., 2014; Coelho et al., 2016; Dumbravă et al., 2016; Djaman et al., 2018). Significant cereal yield increases have been achieved via breeding programs with commercial cultivars, more efficient fertilizer use and more effective insect pest and disease control. However, in Minas Gerais, research on the feasibility of growing winter cereals in the semiarid are scarce. As such, it is vital to understand the agronomic behavior of different genotypes and growing seasons to implement new regional grain production systems. Additionally, selecting the ideal cultivar and sowing time is fundamental in establishing production systems. Thus, the present study aimed to assess the agronomic feasibility of growing wheat and triticale cultivars under two sowing times in the semiarid region of Montes Claros, Minas Gerais state.

Material and Methods

The study was conducted in the municipality of Montes Claros in northern Minas Gerais state, Brazil (16° 41′ 34″S I43° 50′ 41″W and altitude of 639 m), in one growing season (2018) with two sowing times favorable to winter cereals, namely April 21 [season 1] and May 12 [season 2]). The times were chosen based on Condé et al. (2013) and Empresa Brasileira de Pesquisa Agropecuária [EMBRAPA] (2019), who recommend sowing between April 1 and June 15 for irrigated wheat in Minas Gerais. The semiarid region in the present study has a tropical climate classified as Aw according to the Köppen climate classification system (Jacomine, 1979), with a dry winter and wet summer. Average temperature and rainfall during the study were recorded over ten-day periods (Figure 1).

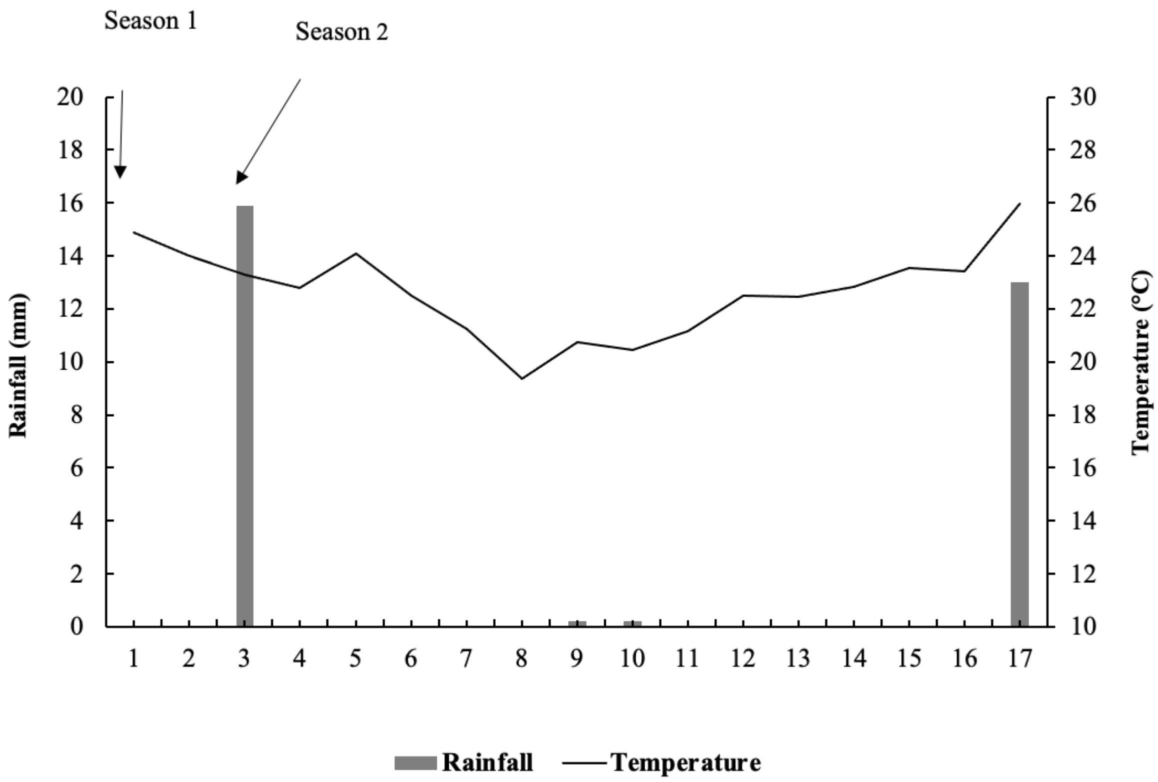

Figure 1. Average temperature and rainfall during winter cereal cultivation in the semiarid region of Montes Claros, Minas Gerais state. Average data over ten-day periods between 04/21/2018 and 07/10/2018.
Source: Instituto Nacional de Meteorologia [INMET] (2021).

The soil is classified as Typic Eutrophic Red-Yellow Argisol according to the Brazilian Soil Classification System and Hapludult (best approximation) under USDA Soil Taxonomy (Santos et al., 2013). Soil texture in the 0-25 cm soil layer is 26% sand, 40% silt and 34% clay. Wheat plants were grown conventionally (plowing and harrowing), but with complementary sprinkler irrigation every two days until field capacity. Fertilization was performed in line with soil chemical analysis and crop requirements (Franco & Evangelista, 2018), using 400 kg ha^{-1} of NPK 04-30-10 at sowing and 300 kg ha^{-1} of NPK 20-00-20 as top dressing 22 days after emergence (DAE) in the tilling stage. Insect control was performed at 15 DAE using 25 ml ha^{-1} of deltamethrin. No fungicide was used.

The present study used six wheat (IPR Catuara, IPR Panaty, IPR Potyporã, IPR Taquari, IPR 144 and PR 85) and two triticale cultivars (IPR Aymoré and IPR 111) from the Instituto de Desenvolvimento Rural do Paraná (Paraná Rural Development Institute - IDR-PR), selected based on the indication of K.A. Arruda (personal communication).

A randomized block design was used, with an 8 × 2 factorial arrangement consisting of eight genotypes (six wheat and two triticale cultivars), two sowing times (April 21 and May 12), and four repetitions. The experimental treatments resulted in 64 experimental units. Each experimental plot had twelve 6-meter-long lines, spaced 17 cm apart, totaling 12.24 m^2 per plot. Cultivation density was 330 viable seeds m^{-2}.

The agronomic traits evaluated were number of days from sowing to heading, number of days from sowing to harvesting, plant height (cm), lodging (%), spike length (cm), number of grains per spike, number of spikelets per spike, hectoliter weight (kg hL^{-1}), grain yield (kg ha^{-1}) and 1000-grain weight (g).

The plants were assessed daily to determine the number of days from sowing to heading and harvesting. Complete exposure of the spike in 50% of the plants was considered heading and physiological maturity (dry plants) the harvesting point. Plant height was measured at harvesting from the ground to the base of the spike in ten plants per plot study area. The number of lodged plants was obtained by the percentage of damaged or broken plants forming an angle smaller than 20° in relation to the soil. Morphometric characterization of the spikes (spike length, grains per spike, spikelets per spike, grains per spikelet) was carried out at harvesting in 10 physiologically mature spikes per plot. Harvest was performed manually using sickles. The study area for harvesting consisted of four linear meters of the six central rows in each plot, totaling 4.08 m² per plot. The moisture content of the grain samples was standardized to 13% for determination of the following parameters: hectoliter weight, grain yield and 1000-grain weight. Moisture content and hectoliter weight were determined using a Gehaka G650i moisture meter.

The data obtained were initially submitted to additivity and normality of errors testing, followed by individual analysis of variance (ANOVA) by season. Next, homogeneity of variances was analyzed by Hartley's test (Gomes, 1990), followed by pooled ANOVA for the two seasons. Significant means were compared using the Scott-Knott test (Scott & Knott, 1974) at 5% significance. ANOVA and the Scott-Knott test were performed with Sisvar software® (Ferreira, 2020).

Results and Discussion

Analysis of the number of days from sowing to heading and to harvesting indicated a significant effect for the cultivar ($p \leq 0.01$), sowing time ($p \leq 0.01$) and sowing time × cultivar interaction ($p \leq 0.01$) (Table 1). Overall, wheat plants reached heading 68 days after sowing and harvesting at 128 days.

Heading occurred later for the second sowing time in all the wheat cultivars. The same was observed for harvesting in most cultivars except IPR Panaty, which was not affected by sowing time, justifying the interaction observed in variance analysis (Table 1).

Since irrigation was performed, the results obtained for number of days from sowing to heading and to harvesting can be explained by the temperature during the experiment rather than water deficit. (Figure 1). Temperature has a considerable influence on the wheat cycle, since the plants start accumulating heat depending on how much the average daily temperature exceeds the basal temperature required by the plant (Noreto et al., 2015).

Table 1

Days from sowing to heading and from sowing to harvest in winter cereal cultivars under two sowing times in the semiarid region of Montes Claros, Minas Gerais state

Cultivar	Species	Heading		Harvest	
		Growing season		Growing season	
		April 21	May 12	April 21	May 12
IPR 144	Wheat	62.25 aB	80.00 aA	122.50 bB	129.50 cA
IPR 85	Wheat	57.50 bB	77.25 bA	122.25 bB	131.00 cA
IPR Catuara	Wheat	58.00 bB	76.50 bA	122.50 bB	132.50 cA
IPR Panaty	Wheat	62.50 aB	77.75 bA	124.50 bA	127.00 cA
IPR Potyporã	Wheat	60.75 aB	78.75 bA	120.25 bB	128.75 cA
IPR Taquari	Wheat	58.50 bB	76.50 bA	122.75 bB	135.75 bA
IPR 111	triticale	60.50 aB	82.25 aA	135.25 aB	143.25 aA
IPR Aymoré	triticale	44.00 cB	67.75 CA	114.50 cB	129.75 cA
P - Value	Cultivars	0.01		0.01	
	Growing season	0.01		0.01	
	Cultivars x Growing season	0.01		0.01	
CV (%)		2.51		1.82	

CV (%): Coefficient of variation. Means followed by the same lowercase letter in the column and uppercase in the row do not differ according to the Scott-Knott test at 5% significance.

The experiments were implemented on 04/21/2018 (Season 1) and 12/05/2018 (Season 2). Analysis of the average temperature and rainfall in this study (Figure 1) associated with heading in the plants suggests that the sowing time in the first season resulted in higher heat accumulation during the vegetative stage (before spikelet emergence), which could explain the greater precocity observed in this phenological stage.

Regardless of the season, days to heading was shorter for the IPR Aymoré triticale cultivar, indicating precocity. On the other hand, heading occurred later for IPR111 (triticale) and the wheat cultivars IPR144, IPR Panaty and IPR Potyporã at the first sowing time. In the second season, IPR111 and IPR 144 were classified as late cultivars (Table 1).

For the first sowing time, harvesting indicated by physiological maturity occurred earlier for IPR Aymoré than IPR 111, also differing from the wheat cultivars. For the second sowing time, the earliest cultivars were IPR Aymoré and five wheat cultivars, and the latest IPR 111 (Table 1).

Cultivar only exhibited a significant effect on plant height ($p \leq 0.01$) (Table 2), whereas for plant lodging, cultivar ($p \leq 0.01$), sowing time ($p \leq 0.01$) and sowing time x cultivar interaction showed a significant effect ($p \leq 0.05$).

Plant height is typically constant in wheat crops grown under rainfall and temperature conditions that favor growth and development (Silva et al., 2018). Thus, it can be inferred that supplementary irrigation prevented water deficit during the experiment and the difference between the cultivars was due to genetic and non-environmental components. Wheat requires about 430 mm during its crop cycle (Borém & Scheeren, 2015).

Table 2
Plant height and lodging in winter cereal cultivars under two sowing times in the semiarid region of Montes Claros, Minas Gerais state

Cultivar	Species	Plant height (cm)		Lodging (%)	
		Growing season		Growing season	
		April 21	May 12	April 21	May 12
IPR 144	Wheat	95.43 b	94.20 b	6.25 cA	6.25 cA
IPR 85	Wheat	81.75 b	86.45 b	93.25 aA	31.75 bB
IPR Catuara	Wheat	83.10 b	90.15 b	83.75 aA	40.50 bB
IPR Panaty	Wheat	88.70 b	84.70 b	64.50 aA	32.75 bB
IPR Potyporã	Wheat	89.23 b	85.80 b	36.25 bA	7.00 cA
IPR Taquari	Wheat	89.03 b	86.95 b	35.00 bA	33.75 bA
IPR 111	triticale	103.28 a	106.25 a	17.50 bB	52.50 bA
IPR Aymoré	triticale	103.03 a	109.95 a	76.25 aA	88.25 aA
P - Value	Cultivars	0.01		0.01	
	Growing season	ns		0.01	
	Cultivars x Growing season	ns		0.05	
CV (%)		9.61		7.62	

CV (%) coefficient of variation. Means followed by the same lowercase letter in the column and uppercase in the row do not differ according to the Scott-Knott test at 5% significance.

In regard to lodging, the wheat cultivars IPR85, IPR Catuara, IPR Panaty and triticale IPR Aymore displayed greater losses in the first season (Table 2). In the second season, the greatest lodging was observed for IPR Aymore, followed by IPR85, IPR Catuara, IPR Panaty, IPR Taquari and IPR 111. It is important to note that most cultivars exhibited more than 30% lodging regardless of sowing time. For both sowing times, IPR 144 showed superior agronomic performance for all the traits assessed.

Spike length, number of grains per spike, spikelets per spike and grains per spikelet were not affected by cultivar, season and sowing time x cultivar interaction (data not shown). The mean values obtained were 10.63 cm for length (CV: 14.20 %); 45.55 grains per spike (CV: 18.68 %); 21.55 spikelets per spike (CV: 10.22 %); and 2.12 grains per spike (CV: 17.02 %).

Hectoliter weight and 1000-grain weight were only affected by cultivar and sowing time ($p \leq 0.01$), with respective coefficients of variation of 2.56 and 7.64% (Table 3).

According to wheat classification based on test weight (Ministério da Agricultura, Pecuária e Abastecimento [MAPA], 2021), values greater than 78 kg hL^{-1} can be classified as Type I and typically used for breadmaking, while wheat with a hectoliter weight of 75 to 78 kg hL^{-1} is classified as Type II and used only for cookies, precluding breadmaking. Values from 72 to 75 kg hL^{-1} are categorized as Type III, suited to the manufacture of standard cookies; and below 72 kg hL^{-1} as 'Out of Type' and used for animal feed (MAPA, 2021). This classification is restricted to *T. aestivum* and *T. durum.* As such, it can be inferred that IPR Catuara, IPR 85 and IPR Potyporã (the last only for the first season) could be used for breadmaking. IPR 111 (triticale) sown in the second season and IPR Panaty (wheat) in the first are recommended for animal feed ('out of type'), while the second triticale cultivar (IPR Aymoré) and IPR Panaty and IPR Taquari wheats were classified as Type III, and the remaining wheats as Type II.

Table 3
Hectoliter weight (HW) and 1000-grain weight (1000GW) of winter cereal cultivars under two sowing times in the semiarid region of Montes Claros, Minas Gerais state

Cultivar	Species	HW (kg hL^{-1})		1000GW (g)	
		Crop season		Growing season	
		April 21	May 12	April 21	May 12
IPR Catuara	Wheat	79.46 aA	79.27 aA	45.63 aA	40.15 aB
IPR Taquari	Wheat	77.69 aA	73.74 cB	38.92 bA	34.04 bB
IPR 144	Wheat	77.66 aA	76.19 bA	40.41 bA	31.05 bB
IPR 85	Wheat	78.56 aA	78.99 aA	44.01 aA	39.99 aB
IPR Panaty	Wheat	71.46 bA	73.02 cA	41.95 bA	35.64 bB
IPR Potyporã	Wheat	78.45 aA	76.68 bA	47.32 aA	35.83 aB
IPR Aymoré	triticale	74.84 bA	74.03 cA	46.37 aA	43.91 aB
IPR111	triticale	73.44 bA	65.46 dB	40.18 bA	31.46 bB
P - Value	Cultivars	0.01		0.01	
	Growing season	0.01		0.01	
	Cultivars x Growing season	0.01		0.01	
CV (%)		2.56		7.64	

CV (%) coefficient of variation. Means followed by the same lowercase letter in the column and uppercase in the row do not differ according to the Scott-Knott test at 5% significance.

In a recent study in the Cerrado and semiarid regions of Minas Gerais using the BRS 264 and BRS 394 cultivars developed by the Brazilian Agricultural Research Association (EMBRAPA), Rezende et al. (2020) reported average hectoliter weights of 78.81 and 72.03 kg ha^{-1} in the municipalities of Uberlândia and Montes Claros, respectively. This underscores the importance of further research to identify the best commercial genetic materials available on the market ideally suited to individual wheat farming regions in Minas Gerais state.

Grain yield was affected by cultivar, sowing time and cultivar x season interaction ($p \leq 0.01$), with a coefficient of variation of 13.43% (Table 4). For the first sowing time (April), superior cultivars were those that produced more than 3000 kg ha^{-1} (IPR Potyporã, IPR 144 and IPR 111) (Table 4), whereas the most promising cultivars for the second sowing time (May) obtained a grain yield greater than 2070 kg ha-1 (IPR Taquari, IPR Panaty and IPR Aymoré). Analysis of cultivar x season interaction demonstrated that environmental variation had little influence on the behavior of IPR85, IPR Catuara, IPR Taquari and IPR Aymore, which remained constant.

According to Condé et al. (2013), wheat grown under irrigated conditions in Minas Gerais require altitudes greater than 500 m, with sowing recommended from April 1 to May 31. The same authors reported that cultivars with a longer cycle or those more susceptible to preharvest sprouting should be sown in April. As such, the conditions in the present study were suitable for wheat cultivation since the altitude of the experimental area is 639 m.

When irrigated, wheat and triticale genotypes are suitable for cultivation in semiarid regions, provided appropriate sowing times are used. According to Agricultural Climate Risk Zoning (ZARC), these cereals can be cultivated from the first ten-day period in April to the first ten-day period in June, regardless of soil type and cycle (EMBRAPA, 2019).

Table 4
Yield (kg ha^{-1}) of winter cereal cultivars under two sowing times in the semiarid region of Montes Claros, Minas Gerais state

Cultivar	Species	Growing season	
		April 21	May 12
IPR 144	Wheat	3103.99 aA	1755.34 bB
IPR 85	Wheat	1823.17 cA	1836.10 bA
IPR Catuara	Wheat	2133.89 cA	1711.81 bA
IPR Panaty	Wheat	2641.55 bA	2074.67 aB
IPR Potyporã	Wheat	3133.88 aA	1862.84 bB
IPR Taquari	Wheat	2557.88 bA	2513.86 aA
IPR 111	triticale	3009.30 aA	1253.56 cB
IPR Aymoré	triticale	2034.67 cA	2211.59 aA
P - Value	Cultivars	0.01	
	Growing season	0.01	
	Cultivars x Growing season	0.01	
CV (%)		13.43	

CV (%): Coefficient of variation. Means followed by the same lowercase letter in the column and uppercase in the row do not differ according to the Scott-Knott test at 5% significance.

The literature reports that late planting in April in the Cerrado of Minas Gerais favors higher yields (Condé et al., 2013) due to lower temperatures in the vital wheat development period, which partially corroborates the results obtained in our study. Coelho et al. (2016) evaluated different wheat cultivars sown from March to May in the Cerrado region of Patos de Minas and obtained higher yields for sowing in late May due to the lower incidence of wheat blast disease (*Pyricularia oryzae* Cavara), which can drastically reduce yield in March. This demonstrates once again the importance of conducting new studies in different mesoregions of Minas Gerais.

In 2019, the cultivated area for wheat in the Midwestern Brazil was 150,000 hectares, using both irrigated (between May and September, with favorable temperature conditions) and rainfed systems, with crops exposed to thermal and water stress and sowing times from March to April (Torres et al., 2022). Although an irrigated system was adopted in the present study, the most productive wheat cultivars for the first sowing time exceeded the average yield obtained in traditional wheat-producing states such as Paraná (2341,00 kg ha^{-1}) and Rio Grande do Sul (2200,00 kg ha^{-1}), as well as in the Cerrado of Minas Gerais (2678 kg ha^{-1}) (CONAB, 2017). Rezende et al. (2020) studied cultivars with different genetic bases sown in June in Montes Claros and reported yields of up to 2520 kg ha^{-1}. Compared with the average national yield of 2500 kg ha^{-1}, wheat yields are higher under irrigation, reaching 5000 to 7000 kg ha^{-1}, and lower in rainfed conditions (Torres et al., 2022).

Thermal stress from high temperatures can reduce the number of grains in the flowering stage and their individual weight during endosperm development. When temperature at the onset of grain filling from 5 to 12 days after anthesis is greater than the maximum temperature required by the cultivar, the potential weight of the grain declines (Stratonovitch & Semenov, 2015). Wheat is sensitive to extreme temperatures during the reproductive stage (Alghabari et al., 2014; Vara Prasad & Djanaguiraman, 2014). Moreover, thermal stress alone can reduce wheat yield by up to 30%, with drought stress due to water deficit potentially responsible for an additional 20% loss, which did not occur in our study due to supplementary irrigation (Asseng et al., 2011).

In the present study, temperature may have influenced the agronomic behavior of the cultivars and the interaction between sowing times and cultivars. According to Taiz and Zeiger (2017), this is because temperature can affect the biochemical reactions of photosynthesis, leading to reduced production. The optimal temperature for wheat and triticale development ranges from 18 to 24 °C, with temperatures higher than 30 °C resulting in significant losses in grain yield and quality (Ribeiro et al., 2012).

Conclusion

Irrigated wheat and triticale production are agronomically feasible in the semiarid region of Minas Gerais state and sowing time affected the main agronomic traits of interest for winter cereals. However, it is essential to study the economic feasibility of the crop. Sowing in April was the most indicated for wheat and triticale, with IPR Potyporã, IPR 144 and IPR 111 as the recommended cultivars.

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References

Alghabari, F., Lukac, M., Jones, H. E., & Gooding, M. J. (2014). Effect of *Rht* alleles on the tolerance of wheat grain set to high temperature and drought stress during booting and anthesis. *Journal of Agronomy and Crop Science, 200*(1), 36-45. doi: 10.1111/jac.12038

Asseng, S., Foster, I., & Turner, N. C. (2011). The impact of temperature variability on wheat yields. *Global Change Biology, 17*(2), 997-1012. doi: 10.1111/j.1365-2486.2010.02262.x

Borém, A., & Scheeren, P. L. (2015). *Trigo: do plantio à colheita.* Editora UFV.

Coelho, M. A. O., Torres, G. A. M., Cecon, P. R., & Santana, F. M. (2016). Sowing date reduces the incidence of wheat blast disease. *Pesquisa Agropecuária Brasileira, 51*(5), 631-637. doi: 10.1590/s0100-204x2016 000500025

Companhia Nacional de Abastecimento (2017). *Acompanhamento da safra brasileira de grãos* (v. 4, Safra 2017/18-Segundo levantamento). https://www.conab.gov.br/info-agro/safras/graos

Companhia Nacional de Abastecimento (2020). *Acompanhamento da safra brasileira de grãos* (v. 7, Safra 2019/20-Quinto levantamento). https://www.conab.gov.br/info-agro/safras/graos

Condé, A. B. T., Moresco, E. R., Martins, F. A. D., & Andrade, A. T. (2013). Trigo irrigado: potencialidades. *Informe Agropecuário, 34*(274), 7-18. https://www.epamig.br/download/informe-agropecuario-274-trigo-tropical-2013/?wpdmdl=4374&refresh=63b85afa45eec1673026298

Djaman, K., O'neill, M., Owen, C., Smeal, D., West, M., Begay, D., Allen, S., Koudahe, K., Irmak, S., & Lombard, K. (2018). Long-term winter wheat (*Triticum aestivum* L.) seasonal irrigation amount, evapotranspiration, yield, and water productivity under semiarid climate. *Agronomy, 8*(96), 1-16. doi: 10. 3390/agronomy8060096

Dumbravă, M., Băşa, A. G., Ion, V., Epure, L. I., Dincă, N., & Ştefan, D. (2014). Results regarding yield and yield components at different triticale varieties. Scientific Papers. Series A. *Agronomy, 57*, 174-179. http://agronomyjournal.usamv.ro/pdf/2014/art31.pdf

Dumbravă, M., Ion, V., Epure, L. I., Băşa, A. G., Epure, L. I., Ion, N., & Duşa, E. M. (2016). Grain yield and yield components at triticale under different technological conditions. *Agriculture and Agricultural Science Procedia, 10*, 94-103. doi: 10. 1016/j.aaspro.2016.09.023

Empresa Brasileira de Pesquisa Agropecuária (2019). *Aplicativo Zarc - Plantio certo.* https://www.embrapa.br/busca-de-solucoes-tecnologicas/-/produto-servico/6516/aplicativo-zarc---plantio-certo

Ferreira, D. F. (2020). SISVAR: a computer analysis system to fixed effects split plot type designs. *Revista Brasileira de Biometria, 37*(4), 529-535. doi: 10.28951/rbb.v37i4.450

Franco, F. A., & Evangelista, A. (2018). Informações técnicas para trigo e triticale-safra 2018. *Anais da Reunião da Comissão Brasileira de Pesquisa de Trigo e Triticale,* Cascavel, PR, Brasil, 11.

Gomes, P, F (1990), *Curso de estatística experimental.* (13a ed.), Piracicaba.

Instituto Nacional de Meteorologia (2021). BDMEP - *Banco de dados meteorológicos para ensino e pesquisa.* http://www.inmet.gov.br/projetos/rede/pesquisa/

Jacomine, P. K. T. (1979). *Conceituação sumária de classes de solos e critérios para subdividí-las.* EMBRAPA.

Kakar, K. M., & Lqbal, A. S. (2015). Effect of irrigation levels and bed-system of planting on seed fill duration, seed growth rate, yield and yield components of spring wheat (*Triticum aestivum*) under semiarid condition. *Pure Applied Biology, 4*(4), 511-521. doi: 10.19045/bspab.2015.44009

Ministério da Agricultura, Pecuária e Abastecimento. MAPA. (2021). Instrução Normativa Nº 38, de 30 de novembro de 2010. http://sistemasweb.agricultura.gov.br/sislegis/action/detalhaAto.do?method= visualizarAtoPortalMapa&chave=358389789

Noreto, L. M., Klosowski, E. S., Tsutsumi, C. Y., Costa, A. C. T., & Franco, F. A. (2015). Growing degree-day sum and crop growth cycle duration for wheat cultivars at different sowing dates. *African Journal of Agricultural Research, 10*(3), 119-124. doi: 10.586/AJAR2013.7809

Rezende, G. F., Sampaio, M. V., Machado, B. Q. V., Lima, D. T., Perdomo, D. N., Celoto, F. J., Albuquerque, C. J. B., Silva, E. J. M., Oliveira, R. S., & Pereira, H. S. (2020). Effect of silicon on aphid populations and wheat yield in Minas Gerais, Brazil. *Semina: Ciências Agrárias, 41*(6), 2481-2494. doi: 10.5433/ 1679-0359.2020v41n6p2481

Ribeiro, A., Pimente, A. J. B., Souza, M. A., Carvalho, J. R. A. S., & Fonseca, W. B. (2012). Estresse por altas temperaturas em trigo: impacto no desenvolvimento e mecanismos de tolerância. *Current Agricultural Science and Technology, 18*(2), 133-142. doi: 10.18539/cast.v18i2.2502

Santos, H. G. dos, Jacomine, P. K. T., Anjos, L. H. C. dos, Almeida, J. A. de, Araujo, J. C. de, Fº., Oliveira, J. B. de, & Cunha, T. J. F. (2013). *Sistema brasileiro de classificação de solos* (3a ed.). EMBRAPA. https://livimagens.sct.embrapa.br/amostras/00053080.pdf

Scott, A. J., & Knott, M. (1974). A cluster analysis method for grouping means in the analysis of variance. *Biometrics, 30*(3), 507-512. https://www.ime.usp.br/~abe/lista/pdfXz71qDkDx1.pdf

Secretaria de Estado de Agricultura, Pecuária e Abastecimento (2017). *Projeções do agronegócio: Minas Gerais 2017 a 2027.* http://www.agricultura.mg.gov.br/index.php/x2014-09-23-01-07-23/projecoes-do-agronegocio

Silva, E. R., Oliveira, J. N., Rubio, C. P., Lyra, G. A., & Steiner, F. (2018). Épocas de semeadura do trigo para a região centro-sul mato-grossense. *Revista de Agricultura Neotropical, 5*(1), 23-27. doi: 10.32404/rean.v5i1.1762

Stratonovitch, P., & Semenov, M. A. (2015). Heat tolerance around flowering in wheat identified as a key trait for increased yield potential in Europe under climate change. *Journal of Experimental Botany, 66*(12), 3599-3609. doi: 10.1093/jxb/erv070

Taiz, L., & Zeiger, E. (2017). *Fisiologia vegetal.* Artmed.

Torres, G. A. M., Ferreira, J. R., Binneck, E., Maciel, J. L. N., & Consoli, L. (2022). Blast disease and wheat production in Brazil. *Pesquisa Agropecuária Brasileira, 57*, e02487. doi: 10.1590/S1678-3921.pab2022.v57.02487

Vara Prasad, P. V., & Djanaguiraman, M. (2014). Response of floret fertility and individual grain weight of wheat to high temperature stress: sensitive stages and thresholds for temperature and duration. *Functional Plant Biology, 41*(12), 1261-1269. doi: 10.1071/FP14061