Grain yield and baking quality of wheat under different sowing dates

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ABSTRACT. Choosing the right sowing dates can maximize the outcomes of the interaction between genotype and environment, thus increasing grain yield and baking quality of wheat (Triticum aestivum L.). The present study aimed at determining the most appropriate sowing dates that maximize grain yield and baking quality of wheat cultivars. Seven wheat cultivars (BRS 179, BRS Guamirim, BRS Guabiju, BRS Umbu, Safira, CD 105 and CD 115) were evaluated at four sowing dates (the 1st and the 15th of June and July) in two harvesting seasons (2007 and 2008). The study was setup in a completely randomized block design with four repetitions. The effects of the year and sowing date when combined explained 93% of the grain yield variance. In 2007, the CD 105 and Safira cultivars had the highest grain yield (GY) for all sowing dates. Only the BRS Guabiju and Safira cultivars possessed high baking quality for all sowing dates assessed. In 2008, the environmental conditions were favorable for superior GY, but the baking quality was inferior. Considering adapted cultivars and sowing dates, it is possible to maximize grain yield and baking quality of wheat.

Keywords: GGE biplot, baking quality, gluten strength, alveograph.

Produtividade de grãos e qualidade industrial de trigo em diferentes épocas de semeadura

RESUMO. A escolha de épocas de semeadura adequadas pode maximizar o aproveitamento da interação genótipo x ambiente e incrementar a produtividade de grãos e a qualidade industrial de trigo (Triticum aestivum L.). Objetivou-se com o estudo identificar épocas de semeadura adequadas que maximizam a produtividade de grãos e a qualidade industrial de cultivares de trigo. Sete cultivares de trigo (BRS 179, BRS Guamirim, BRS Guabiju, BRS Umbu, Safira, CD 105 e CD 115) foram avaliadas em quatro épocas de semeadura (01 e 15 de junho, 01 e 15 de julho) durante duas safras agrícolas (2007 e 2008). Utilizou-se delineamento em blocos ao acaso com quatro repetições. Os efeitos de ano e épocas de semeadura explicaram 93% da variedade para produtividade de grãos. Em 2007, as cultivares CD 105 e Safira apresentaram a maior produtividade de grãos (GY) em todas as épocas de semeadura. Apenas as cultivares BRS Guabiju e Safira apresentaram elevada qualidade de panificação em qualquer época de semeadura avaliada. Em 2008, as condições ambientais foram favoráveis ao aumento da GY, contudo de menor qualidade industrial. É possível maximizar a GY e a qualidade industrial do trigo com a escolha de cultivares adaptadas e épocas de semeadura mais adequadas.

Palavras-chave: GGE biplot, qualidade industrial, força de glúten, alveografia.

Introduction

Wheat (Triticum aestivum L.) is an important and extensively used cereal in human and animal diets worldwide. In Brazil, a significant amount of wheat is imported not only because this country produces only half of its internal consumption but also because the wheat produced has inferior baking quality in some regions of Brazil. Increases in grain yield (GY) and baking quality are crucial for wheat crop competitiveness. Such increases may be accessible based upon the selection of adapted cultivars and adequate management practices.

In wheat, GY and baking quality are dependent on the environment, genetic factors and the interaction between them (YAN; HOLLAND, 2010; COVENTRY et al., 2011). An adequate sowing date positively impacts the GY (SILVA et al., 2011) and baking quality of wheat, causing better adjustment to the physiology, phenology and environmental conditions (WHEELER et al., 1996; RIBEIRO et al., 2009). In addition, the appropriate sowing date also affects the water, temperature and solar radiation available for the crop.

Wheat GY can be increased by 10 to 80% with management of the sowing date, cultivar and environmental conditions (COVENTRY et al., 2011). Similarly, baking quality is also influenced by sowing date (SINGH et al., 2010). Adverse environmental conditions during anthesis and grain filling are important factors in the baking quality classification of
wheat (Jiang et al., 2009). Each sowing date determines the baking quality pattern of the wheat (Triboi; Triboi-Blondel, 2002; Motzo et al., 2007). However, it is difficult to obtain high GY and baking quality due to a negative association between these characteristics (Blanco et al., 2011).

Thus, the present study aimed at determining the most appropriate sowing dates that maximize grain yield and baking quality of wheat cultivars for the wheat cropping region of central south of the state of Paraná.

**Material and methods**

The experiment was performed in the municipality of Guarapuava (25º33'S and 51º30'W; altitude of 1,095 m) in the State of Paraná, Brazil. According to the Köppen climate classification system, the predominant climate type in this area is Cfb, which represents a humid subtropical climate with a temperate summer (Maack, 1968). The experimental site, which is located at the Value of Culture and Use Region 1 (VCU 1), is a region of interest because of the increased yield potential and the occurrence of severe frost.

The experiment was setup in a completely randomized block design with four repetitions in a factorial scheme. The following three bread wheat cultivars were evaluated: BRS Guamirim (early cycle), BRS Guabiju (mid-cycle) and Safira (mid-cycle). The following four soft wheat cultivars were evaluated: CD 105 (early cycle), CD 115 (mid-cycle), BRS 179 (mid-cycle) and BRS Umbu (late cycle). The cultivars were planted on the 1st and 15th of June (E1 and E2) and on the 1st and 15th of July (E3 and E4) during the 2007 and 2008 harvesting seasons. These cultivars were chosen because they are the most representative of that region.

In Brazil, wheat cultivars are classified according to the Normative Instruction No. 7 of the Ministry of Agriculture, Livestock and Food Supply (Brasil, 2001). The different classes vary according to the alveogramW and falling number (FN) with five classes currently known as follows: soft wheat (W > 50 and FN > 200); bread wheat (W > 180 and FN > 200); improver wheat (W > 300 and FN > 250); wheat for different end uses (W = any and FN < 200); and durum wheat (W = not defined and FN > 250).

The useful area of each plot consisted of six rows (5 m in length with 0.17 m spacing) with a total area of 5.1 m². Initially, a basal amount of 300 kg ha⁻¹ of NPK 08-30-20 was applied. At the early stages of tilling, 40 kg ha⁻¹ of N in the form of urea was applied for fertilization. GY was estimated (kg ha⁻¹) after harvesting the useful area of each plot, and it was corrected to 13% moisture. A thousand kernel weight (TKW) measured in grams (g) was obtained after sampling 250 grains in duplicate. The test weight (TW), which corresponds to the mass of 100 liters of grains (kg L⁻¹), was determined using a Dalle Molle hectoliter weight balance. The genotypes were characterized using the percentage of pre-harvest sprouting (PHS) with 100 grains randomly collected in each plot. After this, the germinated (rupture of pericarp) and non-germinated grains were counted.

For the analysis of baking quality, individual samples of each treatment were mixed and homogenized resulting in a composite sample. The FN was determined in duplicate using a falling number device from Pertem Instruments following method 56-81B of the American Association of Cereal Chemists (AACC, 2000). This test was applied to measure the intensity of the enzymatic activity of the α-amylase enzyme in the grain with the result given in seconds. Low enzymatic activity is associated with elevated values of FN.

The alveogram test (method 54-30A of the AACC, 2000) was performed using a Chopin alveograph. This test refers to the capacity of water absorption by the proteins that comprise gluten and to the capacity to retain carbon dioxide resulting in a quality bread product. Using a manometer, different pressures were recorded, and the alveograph curve was obtained wherein the length, height, and a circumscribed area of the curve represent the extensibility (L), tenacity (P) and W-index (W), respectively.

The analysis of joint variance was conducted considering the year effect as random, and the genotype and sowing date were considered as fixed effects. For comparison of mean values, the R computer program was used, and the Scott-Knott test was applied (5%).

To perform the analysis of association between the baking quality parameter of each cultivar and different sowing dates and the association between quality parameters and cultivars, the GGE Biplot methodology was applied (Yan et al., 2000) using the GGE biplot software analysis (Yan, 2001) where the interpretation of the associations is based on the cosine of the angle between the two vectors to be compared. The interpretation rule is: the association is positive if the angle between the vectors is < 90°; it negative if the angle is > 90°; and
it is null if the angle is about 90º (YAN; TINKER, 2006). The singular value is entirely partitioned into the entry eigenvectors. Singular value partitioning 1 (SVP 1) is needed for accurate comparison among the entries, while SVP 2 is needed for accurate visualization of the relationship among the testers (YAN et al., 2000).

**Results and discussion**

The analysis of variance (ANOVA) showed that the effect of the year (Y), sowing date (D), CxY interaction (cultivar x year) and CxYxD (cultivar x year x sowing date) interaction significantly affected the GY (Table 1). The coefficient of variation was 5.2%, which represented good precision of the experiment. The majority of the variation was due to changes in the environment (year = 87% and sowing date = 6%). These results indicated that proportionally, there was a greater variability in the response between years when compared to the sowing dates and cultivars, which can be explained by irregular precipitation, solar radiation and temperature between years and sowing dates; and the frost effects at booting (Figure 1). According to Jalata (2011), there is a greater effect of the environment as compared to the cultivar in such experiments.

**Table 1.** Mean of grain yield (kg ha⁻¹) of wheat cultivars with different sowing dates and comparison of the effect of sowing date and cultivars in Guarapuava - Paraná State.

| Cultivars    | Year 2007     | Year 2008     |
|--------------|---------------|---------------|
|              | 01 June 15 June 01 July 15 July | 01 June 15 June 01 July 15 July |
| BRS 179      | 4913 bA¹ 5397 bA 5353 bA 5565 aA | 6441 aB 6721 aB 7402 aB 6940 aB |
| BRS Guabiju  | 4723 bA 5442 bA 5183 bA 5082 bA | 5718 bB 5906 bB 6590 aA 6501 aA |
| BRS Guamirim  | 5000 bB 5548 bA 5775 bA 5816 aA | 6190 bB 6330 bB 6739 aA 6864 aA |
| BRS Umbu     | 5006 bA 5470 bA 5249 bA 5336 bA | 6049 bB 6582 aA 6781 aA 6631 aA |
| CD 105       | 5845 aA 6185 aA 6425 aA 6214 aA | 6581 aA 6720 aA 6552 aA 6934 aA |
| CD 115       | 3924 bB 5557 bA 5445 bA 5280 bA | 6237 bB 6828 aA 6995 aA 6773 aA |
| Safira       | 5554 aB 6148 aA 6158 aA 6361 aA | 6560 aA 6567 aA 6988 aA 6843 aA |

¹,²compare means between cultivars and between sowing dates, respectively. Médias seguidas de mesma letra não diferem entre si pelo teste de Scott Knott a 5%. Means followed by same letter do not differ by testing Scott Knott (p < 0.05).

In 2007, the CD 105 and Safira cultivars showed the highest GY in all sowing dates and did not differ from the BRS Guamirim and BRS 179 cultivars in E4 (Table 2). Regarding sowing dates, the CD 115, BRS Guamirim and Safira cultivars showed an inferior GY in E1. In this context, it is important to note that experimental site has a greater occurrence of lower temperatures during anthesis for early sowing dates (GONÇALVES et al., 1998).

The occurrence of severe frost during the early stages compromises vegetative development and tiller emission and survival. Early cycle cultivars, such as the BRS Guamirim cultivar, must be preferentially planted in the month of July to avoid damages caused by frost. In 2008, the GY was not different between sowing dates, with the exception of the Safira and CD 105 cultivars (Table 2).

**Figure 1.** Climate data of rainfall (A), solar radiation (B) and maximum and minimum temperature (C) in Guarapuava-Paraná State for 2007 and 2008 during wheat growth with different sowing dates.
The evaluated cultivars showed different reduction levels of TW as a result of the sowing date effect where the greatest reduction (7%) was observed for the BRS Umbu cultivar. Bordes et al. (2008) also observed different genotype behavior due to environmental variations. In both years, there was a negative association of TW with PHS and TKW (Figures 2 and 3). Moreover, there was an elevated consumption of the grain reserve and elevated respiration with increased PHS and decreased TKW, TW and GY (GUARIENTI et al., 2003), which resulted in reduced baking quality.

Table 4. Baking quality of wheat cultivars with different sowing dates in Guarapuava-Paraná State in 2008.

| Cultivar   | ST | TW | TKW | PHS | FN | W   | P  | L  | P/L |
|------------|----|----|-----|-----|----|-----|----|----|-----|
| BRS 179    | E1 | 81 | 42  | 0.5 | 255| 128| 57 | 79 | 0.72|
|            | E2 | 80 | 39  | 0.4 | 242| 104| 48 | 91 | 0.53|
|            | E3 | 79 | 36  | 0.5 | 274| 89  | 40 | 110| 0.36|
|            | E4 | 80 | 36  | 0.5 | 292| 139 | 68 | 78 | 0.87|
| BRS Guabiju| E2 | 82 | 38  | 0.8 | 363| 103 | 102| 1.01|
|            | E3 | 82 | 37  | 0.2 | 254| 375 | 90 | 132| 0.68|
|            | E4 | 82 | 37  | 0.6 | 279| 245 | 54 | 181| 0.3|
| BRS Guaraní| E3 | 79 | 41  | 0.1 | 313| 319 | 72 | 162| 0.44|
|            | E4 | 82 | 38  | 0.6 | 297| 206 | 73 | 111| 0.66|

The following abbreviations are used: ST, sowing time; TW, test weight (kg hL-1); TKW, thousand kernel weight (g); PHS, pre-harvest sprouting (%); FN, falling number; W, W-index(10−4 J); P, tenacity; L, extensibility (mm); and P/L, tenacity/extensibility ratio.

In 2007, the TKW was superior in sowing dates that maximized the GY (Figure 2; Tables 2 and 4), which indicated a positive association between GY and TKW, except for the CD 115 cultivar (Figure 2). In contrast, TKW was negatively associated with GY in 2008 (Figure 3). The importance of TKW during the formation of GY has been reported in modern cultivars (BORDES et al., 2008).

Wheat with high baking quality must have an elevated W, L and P (BORDES et al., 2008). For the majority of the cultivars, the values of W, P and P/L showed elevated values in E1 and E4 corresponding to contrast, TKW was negatively associated with GY in 2008 (Figure 3). The importance of TKW during the formation of GY has been reported in modern cultivars (BORDES et al., 2008).

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This result corroborated the study by Scheuer et al. (2011), which reported that high $W$ can result in lower $L$. However, the BRS Umbu cultivar had a high level of $L$ in all sowing dates (Figures 2 and 3). A high level of $L$ is associated with a low production of flour (MÓDENES et al., 2009).

Figure 2. Productivity and baking quality performance of wheat cultivars (A, BRS 179; B, BRS Guabiju; C, BRS Guamirim; D, BRS Umbu; E, CD 105; F, CD 115; and G, Safira) with different sowing dates in 2007 following the GGE biplot methodology. The following abbreviations are used: ST, sowing time; TW, test weight (kg hL$^{-1}$); TKW, thousand kernel weight (g); PHS, pre-harvest sprouting (%); FN, falling number; $W$, strength-index ($10^4$ J); $P$, tenacity; $L$, extensibility (mm); and $P/L$, tenacity/extensibility ratio.
Figure 3. Productivity and baking quality performance of wheat cultivars (A, BRS 179; B, BRS Guabiju; C, BRS Guamirim; D, BRS Umbu; E, CD 105; F, CD 115; and G, Safira) with different sowing dates in 2008 following the GGE biplot methodology. The following abbreviations are used: ST, sowing time; TW, test weight (kg hl⁻¹); TKW, thousand kernel weight (g); PHS, pre-harvest sprouting (%); FN, falling number; W, W-index (10⁻⁴ J); P, tenacity; L, extensibility (mm); and P/L, tenacity/extensibility ratio.

There was a negative association between W and GY for the majority of the cultivars (Figures 2 and 3), except for the CD 115 (Figure 2F) and CD 105 (Figure 3E) cultivars. Sowing dates subsequent to June specifically promoted GY and reduced W (Figures 2A, 2C, 2F and 3B). Likewise, an elevated W is associated with greater accumulated amounts of proteins (PINNOW et al., 2013), which demands an elevated consumption of carbohydrates. An increased content of proteins causes a decreased accumulation of starch and, consequently, a reduction in GY (RHARRABTI et al., 2001; SCHMIDT et al., 2009).

There was an increase in W during sowing dates in which the period of grain filling occurred simultaneously to the increase in mean, minimum and maximum temperatures (Figures 1B, 1C and 1D; Tables 4 and 5). Moreover, a low magnitude of W was observed in E1 and E2 for the BRS 179, CD 105 and CD 115 cultivars (Figures 3A, 3E and 3F). In the same way, Moldestad et al. (2011) reported that elevated temperatures between the silking and grain filling stage resulted in increased W. However, a temperature increase during this phase leads to a reduction of TKW and GY (RHARRABTI et al., 2003; LABUSCHAGNE et al., 2009; HURKMAN; WOOD, 2011) and promotes a negative association between W and GY. A lower W in E1 and E2 can be attributed to greater precipitation during the grain filling stage (GARRIDO-LESTACHE et al., 2005) and a higher PHS (Figures 2 and 3).

In the grains, PHS results in the degradation of starch and protein. An elevated PHS was observed in E1 for the BRS Guamirim and BRS Umbu cultivars (Figures 2C and 3D) and in E2 for the CD 105, CD 115 and Safira cultivars (Figures 2 and 3). PHS was closely linked to the occurrence of precipitation during the pre-harvest period. The BRS Guamirim cultivar showed a higher value of PHS (7.6) in E3 (2008) as a result of the rainy season preceding maturation (Figure 3C). The extent of the damage caused by PHS in favorable environmental conditions (prolonged precipitation and elevated temperature) depends
mainly on the genetic factor (GELIN et al., 2006). The BRS Guamirim cultivar showed the highest PHS among all tested cultivars in both years (Tables 3 and 4).

The falling number method is used to quantify the damages caused by PHS. The FN was elevated in sowing performed in E4 (Tables 3 and 4), which indicated a lower PHS (Figures 2 and 3). A low FN is associated with higher enzymatic activity of α-amylase (elevated PHS). Alterations in PHS and FN can affect the baking quality of wheat, particularly the mass volume, which indicates the amount of end-use flour; thus, an increased FN resulted in greater W (Figures 2 and 3).

In 2007, the BRS Guamirim, BRS Guabiju and Safira cultivars showed high values for baking quality (W, TW, FN, P and P/L) and GY (Figure 4). However, sowing of the BRS Guamirim and Safira cultivars during E1 should be avoided because they exhibited a reduction in GY (Table 2) and a P/L greater than 1.2 (Table 3). The P/L ratio is important as it defines bread volume and structure, which should be between 0.5 and 1.2 for most types of bread (SEBASTIANO et al., 2004). Regardless of sowing date, the BRS Guabiju cultivar showed the lowest PHS (0 to 0.1) and the greatest W (426 to 479) and TW (Figure 4). Independent of sowing date, the BRS Guabiju and Safira cultivars showed improver wheat, and the BRS Umbu cultivar showed bread quality. Moreover, the CD 105 and CD 115 cultivars exhibited a bread quality classification for all sowing dates, except in E1, where they produced soft flour. The BRS Guamirim cultivar was categorized as bread quality in E1 and improver baking quality in the remaining sowing dates (Table 3).

In 2008, the GY was higher than in 2007. The results indicated that it was more difficult to associate elevated grain yield with baking quality independent of the sowing date. Nevertheless, the BRS Guabiju cultivar in E3 and E4 and the Safira cultivar in all sowing dates showed high GY and high baking quality (Table 2 and Figure 5).

The BRS Guamirim and BRS 179 cultivars exhibited high GY and baking quality only in the last sowing date (Figure 5).

Figure 4. Association among cultivars with different sowing dates (A, 1st of June; B, 15th of June; C, 1st of July; and D, 15th of July) and the quality parameters in 2007 following the GGE biplot methodology. The following abbreviations are used: ST, sowing time; TW, test weight (kg hL⁻¹); TKW, thousand kernel weight (g); PHS, pre-harvest sprouting (%); FN, falling number; W, W-index (10⁻⁴ J); P, tenacity; L, extensibility (mm); and P/L, tenacity/extensibility ratio.
Therefore, the BRS Guabiju and Safira cultivars stood out in regard to their wide adaptability to the sowing date and years evaluated with elevated productive potential and baking quality to meet the bakery industry needs (Figures 4 and 5). In particular, the BRS Guabiju cultivar was the only cultivar that was categorized as improver wheat, and this result was obtained in E1 and E2. The Safira cultivar showed bread quality, and the remaining cultivars were classified as soft wheat (BRS 179, BRS Umbu, CD 105 and CD 115) (Table 4). Schmidt et al. (2009) observed that the Safira cultivar stood out among 28 tested genotypes with respect to TW, W and FN; thus, they classified the Safira cultivar as improver wheat.

Conclusion

The results indicated that there was a differential response of the cultivars with respect to baking quality and grain yield in response to the evaluated sowing dates. Sowing that occurred in July yielded greater productivity. Sowing in June maximized the baking quality of wheat, and early-cycle cultivars should be avoided at this sowing date. Sowing dates in which the grain filling occurred under elevated temperature positively affected the W and negatively affected grain yield. Adapted genotypes and an adequate sowing date can maximize the productivity and the baking quality of wheat.

Acknowledgements

The first author acknowledges a fellowship granted by CAPES, Brazil.

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Received on February 28, 2012.
Accepted on June 9, 2012.

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