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Genetic gain in yield and changes associated with physiological traits in Brazilian wheat during the 20th century

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ABSTRACT

The objective of this study was to characterize physiologically wheat cultivars released in different decades and identify selection criteria for the continued genetic progress in Brazil. Ten cultivars released from 1940 up to 2009 were tested during 2010 and 2011 crop seasons. The following traits were evaluated: grain yield (GY), thousand-kernel weight (TKW), grain number per m^{-2} (GN), plant height (PH), harvest index (HI), above-ground biomass (BIO), relative Chlorophyll content and leaf gas exchanges. The increase in grain yield was 29 kg ha^{-1} yr^{-1} a genetic gain of 0.92%, annually. Grain yield improvement was largely associated with HI (0.94^{**}), number of grains m^{-2} (0.93^{**}), BIO (0.88^{**}) and reduced PH (-0.93^{**}). The post-anthesis Chlorophyll content, stomatal conductance and pre/post-anthesis photosynthetic rate were positively correlated with GY. Genetic gains of Brazilian wheat are mainly related to the increases of HI, GN, and BIO. These improvements were achieved by reducing PH and raising gas exchanges and chlorophyll content.

1. Introduction

The improvements of yield potential in Brazilian wheat cultivars through breeding crop management practices enabled an growth in productivity of 44.9 kg ha^{-1} yr^{-1} between 1940 and 1992 (Rodrigues et al., 2007). Besides, the yield increased from 700 kg ha^{-1} in the 1940s to approximately 2140 kg ha^{-1}, currently (Conab, 2014).

The genetic progress of grain yield in wheat ranged from 0.3% to 1.0% yr^{-1} during the last century (Graybosch and Peterson, 2010). However, it has been reduced in recent decades, mostly due to narrow genetic base and lack of adoption of new breeding techniques. Several studies worldwide have showed that rises in the harvest index (HI), grain number per area, and decreases in plant height are the majors traits associated with genetic gain in wheat (Calderini et al., 1999; Brancourt-Hulmel et al., 2003; De Vita et al., 2007; Giunta et al., 2007). Increasing HI has been allowed better partitioning of assimilates to the grains, resulting in greater grain yield (Foulkes et al., 2011).

The HI of modern wheat cultivars ranges from 0.4 to 0.5 (Reynolds et al., 1999; Brancourt-Hulmel et al., 2003; Sadras and Lawson, 2011), already close to the theoretical maximum of 0.62, which were proposed by Austin et al. (1980). Moreover, HI values higher than 0.5 are very difficult to achieve, especially in unfavorable environments (Fischer and Edmeades, 2010). Once again showing that genetic progress in breeding programs faces difficulties for moving forward. Understanding the changes in yield and linked traits is an essential step for developing new breeding strategies and further improving grain yield. Recent studies also indicate that modern cultivars have been presented large increase in total biomass combined with tolerance to lodging (Sadras and Lawson, 2011; Pedro et al., 2011; Sanchez-Garcia et al., 2013).

The continued genetic improvement of grain yield depends on the work of multidisciplinary teams of researchers who willing to incorporate new technologies to complement the traditional techniques in breeding programs. Numerous studies have reported that grain yield is positively associated with photosynthetic rate (Gutiérrez-Rodríguez et al., 2000; Jiang et al., 2003; Tian et al., 2011) and post-anthesis stomatal conductance (Fischer et al., 1998; Reynolds et al., 2000; Zheng et al., 2011). Consequently, modern high-yield cultivars tend to have higher gas exchange rates compared to older cultivars, according to results observed by several authors (De Vita et al., 2007; Sadras and Lawson, 2011; Xiao et al., 2012).

Likewise, pre/post-anthesis chlorophyll content is also positively associated with photosynthetic rate (Thomas et al., 2005;

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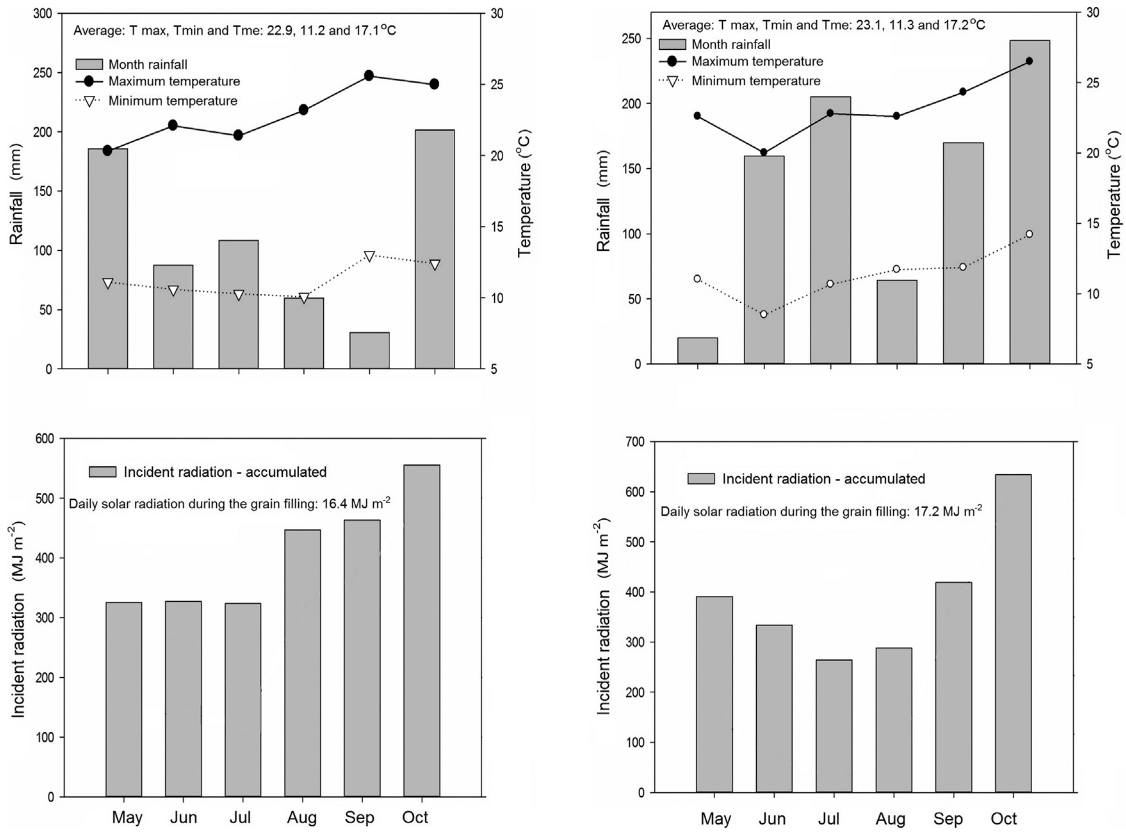

Fig. 1. Meteorological conditions during the each growing seasons. Rainfall and solar radiation in 2010 (A and B) and in 2011 (C and D). Maximum temperature (T_{max}), minimum temperature (T_{min}) and mean temperature (T_{me}).

Zhang et al., 2009), grain yield (Gutiérrez-Rodríguez et al., 2000; Wani et al., 2011) and the release year of cultivars (Sadras and Lawson, 2011). As a result, many studies had suggested that the selection via physiological traits has the potential to improve genetic gains of yield up to 50% in wheat (Fischer, 2007; Flood et al., 2011; Reynolds et al., 2011).

In the current article, we investigated and discussed changes of the physiological and agronomic traits in a set of Brazilian wheat cultivars released between 1940 and 2009.

2. Materials and methods

2.1. Experimental design, cultivars and crop husbandry

The study was performed during the 2010 and 2011 crop seasons in the experimental field of the School of Agronomy at Technological Federal University of Parana (UTFPR), Campus Pato Branco, Paraná State, Brazil (26′10′ S; 52′41′ W), which is located 760 m above the sea level. The soils in this area are Hapludox type.

Ten wheat cultivars released between 1940 and 2009 (Table 1) were sown in third week of June using a randomized block design with three replications. Experimental plots contained 9 rows 5 m long and spaced 0.20 m apart, with seeding density of 350 seeds m^{-2}. The plots were harvester in the second and third week of November.

Base fertilization consisted of 350 kg ha^{-1} of NPK formulation (8-20-20), which represents representing 28 kg of N, 70 kg of P, and 70 kg of K. The soil presented more than 60% of clay and around 4.3% of organic matter, demonstrating a high natural supply of nitrogen. Afterwards, at the full tillering stage – Z 25 (Zadoks et al., 1974), the fertilization was supplemented with 50 kg ha^{-1} of N (urea form, 45% N). Pests, diseases and weed control were managed according the Brazilian technical recommendations for wheat.

Table 1
Cultivars used in the current study.

Cultivars	Year of release	Genealogy
Old		
Frontana	1940	Fronteira/Mentana
Toropi	1965	Frontana/Quaderna A//Petiblanco 8
BR 23	1987	CC/ALD SIB/3/IAS 54-20/COP//CNT8
BRS 179	1999	BR 35/PF 8596/3/PF 772003*2/PF 813//PF 83899
Modern		
BRS 208	2001	CPAC 89118/3/BR 23//CEP19/PF 85490
BRS 220	2003	Embrapa 16/TB 108
BRS Guamirim	2005	Embrapa 27/Buck Nandu/PF 93159
BRS Tangará	2007	BR 23*2/PF 940382
CD 117	2008	PF 87373/OC 938
Quartzo	2009	Ônix/Avante

The weather conditions are shown in Fig. 1. The maximum, minimum and mean temperatures were similar among years during the growing season. The most important difference between years was related to accumulated and distribution of rainfall and solar radiation. The 2011 growing season presented higher values of precipitation than 2010, reaching up to 200 mm accumulated through the whole crop cycle

2.2. Trait measurements

2.2.1. Leaf gas exchange

The following gas exchange readings were measured: photosynthetic rate (P_N), stomatal conductance (g_s), transpiration rate (E) and water use efficiency (WUE) was calculated as the ratio between