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Genetic progress in Argentine bread wheat varieties released between 1918 and 2011: Changes in physiological and numerical yield components

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A B S T R A C T

The objective of this study is to update the data of genetic progress in bread wheat cultivars released in Argentina from 1918 to 2011 (emphasizing the last 20 years) characterizing different agronomic traits of interest for breeders. Experiments were carried out with a wide range of bread wheat cultivars and conducted under field conditions without nutritional and water restrictions. Yields showed a significant (R^2 = 0.68) tri-linear trend when associated with the cultivar's year of release. Until the 40s, when the first inflection point occurred, the genetic progress in terms of yield was 0.8 kg ha^{-1} yr^{-1} (0.02% yr^{-1}). Between 1940 and 1999, yield genetic progress reached its highest value (51 kg ha^{-1} yr^{-1}; 1.17% yr^{-1}) but changed after 1999 when values became lower compared to the previous period, showing a value of 14 kg ha^{-1} yr^{-1} (0.18% yr^{-1}). Changes in grain yield were mostly explained by increases in harvest index and not by those in above-ground biomass. Plant height showed a negative bi-linear trend with the year of release, reaching an inflexion point well before the introgression of semi-dwarfing genes in commercial cultivars. Grain number increased ca. 63% when modern cultivars were compared to older ones, which explains most of the grain yield changes. In contrast to grain number, no significant differences between old and modern cultivars were found for grain weight, with average values of ca. 30 mg $grain^{-1}$ for all environments explored.

1. Introduction

As a strategy to increase global and/or regional wheat production and considering the inability to increase the planted area on a large scale, efforts should be focused on yield increments per unit area. One of the most important ways to achieve increments in yields genetic gain is associated with the release of new cultivars with higher yield potential (Reynolds et al., 1996; Sinclair et al., 2004; Reynolds et al., 2009).

In Argentina, the grain yield increases were mainly associated with an increase in grain number and by changes in the partitioning of biomass. The first semi-dwarf varieties, derived from crossings involving cultivar Norin 10, were released in the late '70 s and breeders quickly included dwarfing genes from CIMMyT into the breeding programs. By late '90 s more than 95% of Argentine commercial varieties had Rht-B1 and/or Rht-D1 alleles in their background (Appendino et al., 1993). Slafer and Andrade (1989), Slafer et al. (1990) and Calderini et al. (1995, 1997) analyzed the genetic gain in Argentinean bread wheat varieties released from 1920 to 1990 and did not find any significant differences in above-ground biomass at harvest between old and modern cultivars. However, they did find significant differences in harvest index associated to a marked reduction in plant height when old and modern cultivars were compared. These differences in plant height favored biomass partition to spikes, increasing harvest index by ca. 39%.

When the numerical yield component changes were analyzed in Argentina between 1920 and 1990, new cultivars consistently showed a significant increment in grain number per spike compared to the old ones. However, changes in grain weight associated with the year of release showed contradictory results. Calderini et al. (1995) did not find significant temporal trends in grain weight, but they observed different trends in grain weight when analyzing local cultivars released between 1920 and 1990. In cultivars released before the '80s, yield gains were the consequence of an increment in grain number as from late '80s and up to the '90s (last period analyzed in that work) grain weight increments determined yield gain. Similar results were observed by Sadras and Lawson (2011) for Australian wheat cultivars released between 1958 and 2007 who showed that up until the '80 s grain yield increases were attributed to increments in grain number per unit area that was counterbalanced by partial reductions in grain weight. After the´80 s

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the increments in yields were associated with higher grain weight. Conversely to Calderini's et al. (1995) report, Slafer and Andrade (1989) observed lower grain weight in modern cultivars compared to old ones, possibly caused by a greater contribution of grains fixed in distal positions within spikelet's with lower potential grain weight than those placed in basal positions (Miralles and Slafer, 2007). This situation determines a smaller grain weight contribution to grain yield that reduces average weight without necessarily reflecting a reduction of the source needed to complete the growth of the grain (Miralles and Slafer, 2007).

There are no studies analyzing the genetic gain of Argentinian bread wheat cultivars released in the last 25 years. The last studies were published in the mid-'90s considering cultivars released up until 1990 (Calderini et al., 1995, 1997). Other papers, such as Abbate et al. (1998), have only analyzed a narrow time period in terms of year of release for Argentinian cultivars (between 1984 and 1994). During the last 20 years an important number of European cultivars with high yield potential were introduced into the Argentinian breeding programs and crossed with adapted local cultivars (Brieva, 2007). It is important to perform an upgrade of retrospective studies in order to assess the current the genetic gain for wheat in Argentina as well as analyzing other fine tuning traits that are important for breeding purposes as these traits are not commonly measured in genetic progress analyses. The aim of this study is to update the data of genetic progress in bread wheat cultivars released in Argentina during different periods characterizing different agronomic and breeding traits of interest related to physiological and numerical yield components.

2. Materials and methods

2.1. Genetic material and experimental design

Seventeen commercial wheat bread cultivars released in Argentina between 1918 and 2011 were selected according to their relative importance in the area sown to wheat in each period, an indicator which is closely related to the degree of adoption by farmers. Cultivars were grown under field conditions during two consecutive years in three different environments and most of the cultivars were included in all environments (Table 1). The cultivars corresponded to Argentinian breeding programs with the exception of three materials released from 1999 to 2011 which correspond to European introgressions from French Breeding Programs. The experimental design was a completely randomized one with three replications in all environments.

Table 1
Cultivars used in the experiments of genetic progress. The crosses indicate which location (BA and BC correspond to Buenos Aires and Balcarce, respectively) and in which experimental year (13 and 14 correspond to 2013 and 2014, respectively) each variety of wheat was used.

Cultivars	Breeding program	Year of release	Cultivars used		
			BA13	BA14	BC14
38 MA.	Argentinean	1918	X	X	X
Americano 26n	Uruguay	1918	X	X	X
K. Favorito	Argentinean	1920	X	X	X
Eureka FFCC Sur	Argentinean	1936	X	X	X
K. Rendidor	Argentinean	1954	X	X	X
B. Manantial	Argentinean	1964	X	X	X
B. Pucará	Argentinean	1980	X	X	X
B. Ombú	Argentinean	1984			X
B. Poncho	Argentinean	1986		X	X
K. Cacique	Argentinean	1991		X	X
K. Pegaso	Argentinean	1997	X	X	X
Baguette 10	France	1999	X	X	X
BioINTA 3005	Argentinean	2009	X		
ACA 906	Argentinean	2010	X		
K. Gladiador	Argentinean	2010	X	X	X
Baguette 601	Argentinean/France	2011	X	X	X
B. Sy 110	Argentinean/France	2011	X	X	X

2.2. Growing conditions

The experiments were conducted during 2013 and 2014 at (i) the experimental field of the School of Agronomy, University of Buenos Aires (34°35′S, 58°29′O) (BA_{13} and BA_{14}, respectively) and (ii) during 2014 at the experimental field of the company Agrar del Sur S.A. (37°58′S, 58°23O) located in Balcarce, Province of Buenos Aires (BC_{14}). In BA soils are classified as vertic Argiudolls, while Balcarce has a silty soil classified as typical Argiudoll.

Sowings were done mechanically with a 7 rows seeder spaced at 0.175 m in BA14 while in BC14 and in BA13 7 rows were spaced at 0.21 m. Each plot occupied an area of 2.94; 3.06; and 6.12 m^2 (for BA_{13}, BA_{14} and BC_{14}, respectively). Planting dates were June 7 and May 29 for BA_{13} and BA_{14}, respectively and July 23 for BC_{14}. The target density was 280 plants per square meter. In all experiments weeds, pests and diseases were chemically controlled throughout the crop cycle. For weed control Prosulfuron + Triasulfuron + Dicamba (10 g ha^{-1}; 10 g ha^{-1} and 150 cm^3 ha^{-1}, respectively) was applied. For diseases and pests control Azoxistrobin + Isopyrazam (500 cm^3 ha^{-1}) and Lambda cyhalothrin (35 cm^3 ha^{-1}) was applied in DC3.9, respectively.

The BA_{13} and BA_{14} experiments were supplemented with irrigation to avoid water deficiencies, while BC_{14} was conducted under rainfed conditions. However, BC_{14} did not suffer severe water deficiencies due to the accumulated rainfall between July and December, which was ca. 535 mm. All experiments were fertilized at sowing with 80 kg ha^{-1} of di-ammonium phosphate and at tillering 150 kg N ha^{-1} was applied (DC2.5, Zadoks et al., 1974). As soils had no sulphur and potassium deficiencies, the fertilization with phosphorus and nitrogen was made with the objective of avoiding nutritional deficiencies of those elements during the whole cycle.

Mean temperature during the 2013 and 2014 crop cycle was 15.4 and 16.0 °C in BA, respectively, while in Balcarce mean temperature was 15.7 °C. The average incident PAR Radiation values between emergence and physiological maturity was similar in both years in BA (average 1508.7 MJ m^{-2}); and 1410.4 MJ m^{-2} in BC_{14} (Fig. 1).

2.3. Sampling and measurements

Different physiological variables related to biomass and yields were measured and are detailed below:

Phenology: In all experiments flag leaf appearance (DC39) (Zadoks et al., 1974), anthesis time and physiological maturity were recorded (when 50% of plot plants reached that particular stage) for each particular genotype. Physiological maturity was determined visually by the color of the spike peduncle.

Above-ground biomass: Three samples of above-ground biomass were taken at the stages of: (i) initiation of the critical period in coincidence with the flag leaf appearance (DC39), (ii) end of the critical period (10 days post anthesis) and (iii) physiological maturity. All phenological stages were recorded separately for each particular cultivar and the timing of sampling adjusted to cultivar phenology. Samples were obtained from two 0.5- m row sections, away from plot borders and previously sampled areas. Were dried in an oven at 60 °C for 72 h and then weighed. The crop growth rates during the critical period (for each cultivar according to the phenological events described above) were calculated using the biomass difference between samples taken at DC3.9 and 10 days after anthesis (equation 1).

$$CGR\ (g\,m^{-2}\ d^{-1}) = [AGB_{eCP}\ (g\,m^{-2})\ -\ AGB_{iCP}\ (g\,m^{-2})]/D_{eCP\text{-}iCP}\ (days) \quad (1)$$

where CGR is the crop growth rate during the critical period, AGB_{eCP} and AGB_{iCP} correspond to the above-ground biomass at the end and the start of the critical period, respectively, and $D_{eCP\text{-}iCP}$ corresponds to the

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