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Physiological differences in yield related traits between flint and dent Argentinean commercial maize genotypes

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ABSTRACT

Argentina is the worldwide single maize (*Zea mays* L.) exporter of non-GMO flint maize, also called plata maize. This grain is known for high dry-milling yields, the production of large endosperm grits and specific cooking functional properties. But, this special maize has lower yields at farmer fields when compared to regular dent germplasm, and studies describing the physiological characteristics behind this are scarce. Our objective was to understand differences in yield determination mechanisms between flint and dent commercial germplasm for the temperate area. We characterized 31 genotypes (24 dent and 7 flint) growing at five different environments for describing their yield differences, and also described specific physiological traits to unravel the mechanisms behind these yield differences.

Grain yield, KNP, KW, plant growth rate and biomass partitioning around flowering, kernel set efficiency per unit of accumulated ear biomass at flowering and assimilate availability per kernel during flowering all showed significant kernel type (flints vs. dents) effects ($p < 0.05$). And significant genotype differences within each kernel type were evident for all traits ($p < 0.01$). Flint kernel type showed lower yields (ca. 80% of dents) due to reduced KNP and KW. This lower KNP in flints was mostly related to a lower plant growth rate around flowering, although they also showed a reduced biomass partitioning to the ear during this period. Flint genotypes, however, showed higher kernel set efficiency per unit of accumulated ear biomass when compared to dents ($p < 0.01$). Lower KW in flints was related to a reduced assimilate availability per kernel around flowering ($p < 0.01$), both kernel types showed similar assimilate availability per kernel during grain filling ($p > 0.05$). This indicated flint and dent kernel types had the same amount of assimilates to fulfill their early established potential KW. Our results emphasize the importance of the flowering period for understanding yield differences between flints and dents, and biomass accumulation rate during this period was identified as a key trait for increasing flint yields.

1. Introduction

Argentina is a historically consistent maize exporter, and one of the five largest producers of maize worldwide. It is also the single maize exporter of non-GMO flint maize, also called plata maize. Argentine flint maize is well known for high dry-milling yields and the particular quality that provides to a wide range of end-products, like breakfast cereals, snacks, and other textured ingredients (Rooney and Serna-Saldivar, 2003). Flint kernels possess a major proportion of high density vitreous endosperm, associated with kernel hardness. Kernel hardness prevents grain damage during mechanical harvesting, manipulation and storage, and is specially appreciated for the production of large endosperm grits (Paulsen and Hill, 1985). The European Union has a special import permit for hard endosperm maize (Commission Regulation, 1997) that has traditionally been sourced only by flint maize from Argentina. During the last two decades Argentina has exported to the European Union around 350.000 metric tons per year of this special grain (SENASA, 2012).

In the last decades the introduction of dent germplasm has contributed to large increases in yield potential of Argentinean commercial genotypes (Brun and Dudley, 1989). The higher yield of GMO dent maize at production fields has led to a massive use of dent and semi-dent genotypes by farmers. Flint non-GMO production fields are currently conducted under contract, and farmers are paid a premium for this special product. Studies describing crop management options and physiological characteristics of flint hybrids

Abbreviations: KNP, kernel number per plant; KW, kernel weight.

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are scarce. Cirilo et al. (2011) described many traits related to yield performance of several flint genotypes grown under different agronomic practices. They did not, however, determined the traits that are behind yield differences among flint and dent germplasm. Most research using Argentinean genotypes are focused on dent germplasm (Gambín et al., 2006; Hernández et al., 2014). When dents are compared to other kernel types, like popcorn, it is evident there are specific differences in crop physiological traits that are behind yield and environmental responses (Severini et al., 2011).

Maize yield is determined by the number of harvested kernels and their individual weight (Otegui, 1995; Chapman and Edmeades, 1999). Kernel number is commonly considered the main yield component, highly correlated with final grain yield (Andrade et al., 1999). Kernel number determination is specifically related to three physiological processes, (i) the rate of plant biomass accumulation around flowering, (ii) the proportion of the plant biomass that is partitioned to the reproductive structure bearing the kernels (ear) during this period, and (iii) the kernel set efficiency per unit of accumulated biomass at the ear level during the flowering period (Vega et al., 2000). These three traits determine different physiological strategies for kernel set determination (e.g., high kernel set efficiency, plant growth rate or biomass partitioning). It is known that current commercial maize genotypes in Argentina vary for all these traits (Hernández et al., 2014). It is not known, however, if there are consistent kernel type differences in these yield determination traits when flint and dent germplasm is compared.

Although most yield variations are related to differences in kernel number determination, genotype and environmental variations in kernel weight (KW) can also affect grain yield. Genotypic differences in KW among Argentinean commercial genotypes are common (Borrás and Gambín, 2010). Differences in KW can be related to changes in the potential weight established early after flowering, or in the capacity of the crop to fulfill this potential. Working with a reduced set of genotypes Cirilo et al. (2011) have shown that kernel hardness is correlated with post-flowering assimilate availability per kernel, supporting the hypothesis that flint genotypes should have higher values when compared to dents. Differences in KW among dent and popcorn genotypes, however, are mostly related to changes in potential KW established at flowering, and these differences are related to the assimilate availability per kernel during the flowering period, when kernels are being set (Severini et al., 2011). This is also the mechanism behind most genotypic KW differences among dent commercial genotypes (Gambín et al., 2006).

Our general objective was to understand differences in yield determination between flint and dent commercial genotypes. In this particular study we first characterized a large number of flint and dent genotypes growing at different environments for describing their yield differences. We latter described specific physiological parameters to further understand the mechanisms behind these yield differences.

2. Materials and methods

2.1. Sites and crop management

Thirty one commercial genotypes were tested in five environments. Locations were Venado Tuerto (33°45′S 61°58′W), Franck (31°35′S 60°56′W), Laguna Larga (31°77′S 63°80′W), and Zavalla (33°1′S, 60°53′W). All trials were planted early during the growing season, between 15 September and 17 October, during the 2012/2013 growing season except at Zavalla were two seasons were tested (2011/2012 and 2012/2013). Plots were four rows 5.5 m long with 0.52 m row spacing. They were over planted and hand-thinned at V3 (Abendroth et al., 2011) to a uniform stand density of 8 pl m^{-2}. All measurements were done using the two central rows. The crops were all fertilized with 100 kg N ha^{-1} as urea (46-0-0 N-P-K) at V4 and 16 kg N ha^{-1} as monoammonium phosphate (10-50-00) at planting. Weeds and pests were controlled with common agronomic practices. Insect pressure was specifically monitored and controlled throughout the season for minimizing any possible effect.

Genotypes represented the most common commercial hybrids used by farmers in the temperate Argentinean central region, and were sourced from different companies. Twenty four genotypes were regular GMO dent (or semi-dent) kernel type. Seven genotypes were non-GMO flint kernel type. These seven flint genotypes are widely used by both local dry-milling industry and exporters.

2.2. Phenotypic measurements

Yield was analyzed by harvesting the two central rows from each plot. Additionally, in the two trials conducted in Zavalla several plant biomass measurements during the flowering and grain filling periods were done.

In both experiments at Zavalla fifteen consecutive plants were selected from the central rows and tagged 20 days (d) before flowering. A non-destructive alometric method for biomass estimations was used for measuring plant growth rate and plant biomass partitioning. The method based on allometric relations provides an accurate measure of plant biomass corresponding to tagged plants that remain in the field until harvest. We use this model to quantify total plant biomass at the individual plant level at the pre- and post-flowering stages (Vega et al., 2000; Borrás et al., 2009) for all 15 plants per replicate. Allometric models were developed from three additional tagged plants per replicate, which were immediately harvested after being measured. Shoot biomass was obtained after cutting plants in small pieces and drying them in a forced-air oven at 65 °C for at least 7 d. The pre-flowering models were based on the linear regression between shoot biomass (15 d before 50% anthesis; DBA) and stem volume. Stem volume was calculated from plant height (ground level up to the uppermost leaf collar) and stem diameter at the base of the plant. The post-flowering biomass sample was taken 15 d after 50% anthesis (DAA), and the allometric models utilized stem volume and maximum apical ear diameter with husks. A unique allometric model was made for each genotype at each growing season.

At physiological maturity (defined as 75% milk line; Hunter et al., 1991) all tagged plants were harvested and used to measure kernel number per plant (KNP), average KW per plant, and grain yield per plant. The above-ground weight of five consecutive plants per plot was measured after drying in a forced-air oven at 65 °C.

Plant growth rate around flowering (mg $plant^{-1}$ °Cd^{-1}) was calculated as the difference between the post-flowering and the pre-flowering biomass divided by the accumulated thermal time between sample dates (base temperature of 8 °C; Eq. (1)).

$$\text{PGR (mg plant}^{-1}\text{°Cd}^{-1}\text{)} = \frac{\text{Estimated biomass (mg plant}^{-1}\text{)}_{\text{DAA}} - \text{Estimated biomass (mg plant}^{-1}\text{)}_{\text{DBA}}}{\text{thermal time between samples}} \quad (1)$$

Ear biomass at 15 days after 50% anthesis was used to determine the partitioning coefficient of total above-ground plant biomass to reproductive structures, and calculated as the ratio between the ear biomass per plant (g $plant^{-1}$) and the total above-ground biomass (g $plant^{-1}$), both measured at 15 days after 50% anthesis (Eq. (2)).

$$\text{Partitioning Coefficient (\%)} = \frac{\text{Estimated ear biomass (g plant}^{-1}\text{)}_{\text{15DAA}}}{\text{Estimated biomass (g plant}^{-1}\text{)15DAA}} \quad (2)$$

Kernel set efficiency was calculated as the ratio between kernel number per plant and ear biomass 15 days after 50% anthesis (Eq.