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Dry milling grain quality changes in Argentinean maize genotypes released from 1965 to 2016

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ABSTRACT

Argentina is one of the most important maize producers worldwide, and is internationally known for producing hard endosperm maize. The physicochemical characteristics of the maize grain directly affects the milling yield of large endosperm grits, the main dry milling product, and specific grain quality values are demanded by industry. Argentinean traditional maize grains used to have optimum hardness quality for dry milling, but higher yielding newer commercial genotypes slowly moved from hard endosperm flints to semi-dent or dent softer endosperm grain type. Our objective was to describe how grain hardness and composition changed in commercial maize genotypes released in Argentina from 1965 to 2016 as an indirect breeding effect when selecting for on-farm yield. Measured traits were yield, individual grain weight, dry milling quality (test weight, floaters, grain vitreousness, 8 mm screen retention), and composition (oil, protein, starch).

There were clear genotype differences in yield ($p < 0.001$), and they were positively correlated with release year at a rate of 113 kg ha^{-1} yr^{-1} (consistent with previous studies). Grain quality and composition traits also showed significant genotype effects ($p < 0.001$), and traits were also correlated with the genotype market release year. When estimating the average genetic gain across environments and stand density treatments, test weight decreased from 79.1 to 76.0 kg hL^{-1}, grain vitreousness decreased from 100 to 0%, screen retention decreased from 65 to 37%, oil concentration decreased from 5.1 to 4.7%, and protein concentration decreased from 11.6 to 8.7%, while floaters increased from 2 to 31% and starch concentration increased from 69.8 to 72.3%. As such, Argentinean grain hardness and protein concentration declined when selecting higher yielding genotypes. The largest grain hardness changes occurred between mid-1980 and 2000, and current commercial genotypes do not have optimum dry milling quality. This helps understand why the dry milling industry started selecting specific genotypes in the 1990s, and is solely relying on genotypes specially released for dry milling purposes since early 2000s. Consequences of the observed trade-offs between grain hardness and protein concentration with yield for the dry milling industry are discussed.

1. Introduction

Argentina is one of the most important maize producers worldwide (FAO, 2014), and is internationally known for its grain hardness. Today it is the single provider of hard endosperm maize to the European Union. Until the end of the 1980s, most maize grown in Argentina was considered hard endosperm flint maize (Gear, 2006). In the last decades the introduction of elite dent germplasm from the U.S. slowly replaced traditionally hard endosperm genotypes with higher-yielding and softer semi-dent ones (Brun and Dudley, 1989; Delucchi et al., 2012). However, the indirect effect of yield improvements over specific grain quality attributes relevant for the dry milling industry, or general grain composition traits, has never been reported. Because of the central role of Argentina as a relevant international supplier of hard endosperm maize, it is critical to describe and quantify how the traditional flint maize genotypes have evolved to current semi-dented ones as indirect breeding effects when selecting for yield improvement.

Genetic gain studies consist on evaluating under the same crop management and environmental conditions a range of genotypes released during different years (Bell et al., 1995). These studies help

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quantify the genetic progress of different traits as a result of breeding efforts (Masuka et al., 2017), and have been extensively documented in maize (Tollenaar, 1989; Eyhérabide et al., 1994; Duvick and Cassman, 1999; Duvick, 2005; Luque et al., 2006; Di Matteo et al., 2016; Masuka et al., 2017). Most studies have focused on genetic contributions to yield increases. In United States, Duvick (2005) showed yield gains ranging from 65 to 75 kg ha^{-1} yr^{-1} from 1934 to 2004. For Argentina, Luque et al. (2006) showed an overall genetic gain of 132 kg ha^{-1} yr^{-1} from 1965 to 1997, Eyhérabide et al. (1994) reported a genetic gain of 105 kg ha^{-1} yr^{-1} from 1979 to 1991, and Di Matteo et al. (2016) showed a genetic gain of 107 kg ha^{-1} yr^{-1} from 1965 to 2010. Under high input conditions, gains in Africa were 109.4 kg ha^{-1} yr^{-1} from 2000 to 2010 (Masuka et al., 2017).

Despite the large number of studies describing yield changes because of breeding efforts at different regions, studies describing changes in maize grain composition or specific quality traits relevant for the maize processing industry are limited. When considering genotypes released from 1920 to 2001, modern maize genotypes in the U.S. have lower protein, lower oil, and higher starch concentrations than older ones (Scott et al., 2006). A similar trend was observed in Chinese and American genotypes released from 1960 to 2001 in China (Li et al., 2015). For U.S. genotypes released from 1930 to 1991 and grown in Iowa, grain starch concentration increased 0.03% yr^{-1} while protein concentration decreased at a rate of 0.03% yr^{-1} (Duvick, 2005). Sun et al. (2014) showed lower rates of starch concentration increases (0.025% yr^{-1}) and a similar rate of protein concentration decrease (0.031% yr^{-1}) in Chinese maize genotypes. We hypothesize that a similar protein concentration decline happened in Argentina, with its concomitant effect on grain hardness as a result of the mechanistically related nature of endosperm hardness and endosperm protein concentration (Dombrink-Kurtzman and Knutson, 1997; Gerde et al., 2016). Today specially released hard endosperm commercial genotypes have grain yields 10 to 30% lower than normal regular dents (Tamagno et al., 2015, 2016; Abdala et al., 2018), evidencing the commonly observed tradeoff when selecting for yield and grain hardness.

Previous grain composition changes due to breeding efforts have not described physical grain quality variations over time. These traits are highly relevant for the maize dry milling industry because grain physical properties have large effects on milling yield (Paulsen and Hill, 1985; Lee et al., 2007; Macke et al., 2016). Argentinean hard endosperm flint maize yields 45–55% large flaking grits, which is considerably more than the milling yields commonly attained when using North American or European softer endosperm germplasm (25–35%).

The main objective of our study was to describe temporal changes in maize grain quality for dry milling and composition in Argentina as an indirect consequence of yield increases. Yield and grain quality or composition tradeoffs are evident in many species, and current regular semi-dent or dent maize genotypes are no longer suitable for optimum milling yields. Breeding consequences on maize grain quality when selecting for yield have been rarely described, especially for grain hardness and their consequence for dry milling. We tested 32 commercial maize genotypes released from one breeding company (Dekalb-Monsanto) from 1965 to 2016. Genotypes were selected for yield and agronomic improvement, without considering any grain quality effect. We focused on the specific traits currently used for exporting hard endosperm maize from Argentina to the European Union, approved by SENASA (MAGyP, 2015) and the European Commission for maize imports (European Commission, 1997). We also discuss consequences of described tradeoffs between grain quality and yield for the Argentinean dry milling supply chain.

2. Materials and methods

2.1. Sites and crop management

Two field experiments were conducted at Campo Experimental Villarino, Facultad de Ciencias Agrarias, Universidad Nacional de Rosario, in Zavalla, Santa Fe, Argentina (33° 1′ S, 60° 53′ W). The first experiment was planted on October 14, 2015 (early environment), and the second on December 19, 2015 (late environment). Within each experiment all genotypes were evaluated at two stand densities (6 and 10 plants m^{-2}). Thirty two commercial genotypes released by Dekalb-Monsanto in Argentina from 1965 to 2016 (Table 1) were used in both experiments. These genotypes can be considered a representative sample of the genetic commercial availability in Argentina during the last 51 years, and several old genotypes were used by the dry milling supply chain. Yield of genotypes grown under high stand density and in the earliest sowing date has been reported in Borrás and Vitantonio-Mazzini (2018). Sowing date and stand density treatment effects over dry milling quality were not the main objective of this study, but used as different growth environments. Our previous evidences have shown that reducing the stand density slightly increases grain quality for dry milling (Tamagno et al., 2016), while changes in the sowing date has minimum grain quality and composition effects for most genotypes in the region (Abdala et al., 2018).

Table 1
List of evaluated genotypes together with their market release year.

Genotype	Release year
DKF880	1965
DK4F33	1980
DK4F34	1980
DK2F10	1980
DK4F31	1980
DK4F32	1980
DK3F21	1982
DK3F22	1983
DK2F11	1984
DK4F37	1988
DK3F24	1988
DK3S41	1989
DK664VT3P	1993
DK752VT3P	1993
DK688MG	1997
DK696VT3P	1997
DK757MG	1997
DK765MG	1997
DK615MG	1999
DK682VT3P	2000
DK190VT3P	2002
DK690MG	2004
DK747VT3P	2004
DK699VT3P	2007
DK692VT3P	2010
DK70-10VT3P	2012
DK72-50VT3P	2012
DK70-20VT3P	2012
DK72-10VT3P	2012
DK73-10VT3P	2013
LT719VT3P	2014
DK73-20VT3P	2016

Each field experiment was arranged following a completely randomized design with three replicates. Each plot had four rows 6 m long with 0.52 m of inter-row spacing. Plots were always overplanted and thinned at V3 to the target stand density. All measurements were done using the two central rows. Soil samples (0 to 60 cm) were taken before sowing and analyzed for N-NO3. At sowing, monoammonium phosphate (10-50-0, N-P-K) was applied at a rate of 160 kg ha^{-1} to all plots. The experimental area was fertilized with N using urea (46-0-0) at different rates for reaching 165 kg N ha^{-1} of N from soil sample plus added N. This urea was broadcasted manually over the plots at V4. Experiments were conducted under rain-fed conditions. The experimental area was kept free of weeds and pests throughout the growing season. Insect pressure was specifically monitored and controlled with recommended products throughout the season for minimizing any