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Changes of starch composition by postflowering environmental conditions in kernels of maize hybrids with different endosperm hardness☆

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ABSTRACT

Starch composition of maize grains is of great importance when used in animal feed and many processing industries. Maize production involves hybrids with different kernel composition and hardness, sown at areas that range from subtropical to temperate cold climates. Therefore, it is relevant to understand how the environment influences starch composition. The objective of this work was to analyze the effect of location and sowing date on starch composition of maize grains. Field experiments were carried out at five locations across the argentinean maize-production area during two growing seasons. At each location, two sowing dates and three hybrids differing in endosperm hardness (i.e. semi-dent, a semi-flint and flint) were evaluated. Late sowing dates reduced amylose percentage and amylose/starch ratio. This last variable increased as latitude decreased. Minimum temperature during effective grain filling period explained those latitude and sowing date effects. This finding would be helpful to estimate starch composition of maize kernels to be expected in order to satisfy specific end uses.

1. Introduction

Kernel hardness is a variable of great significance to maize producers, traders and processors. Kernel hardness is related to bulk density, storability, attack of storage insects and breakage susceptibility, milling characteristics, dry and wet milling yields and production of special foods (Pomeranz et al., 1984). Maize dry milling industry demands high kernel hardness in order to maximize yield of coarse fractions (flaking grits) during grinding (Chandrashekar and Mazhar, 1999; Hill et al., 1991). On the other hand, wet milling market demands intermedium kernel hardness to obtain the major starch yield as possible (Eckhoff, 2004). For animal feed however, hard endosperm reduces digestive action in animals (Rooney and Pflugfelder, 1986), so soft endosperm is preferred.

Grain endosperm is mainly composed of protein and starch. Starch represents about 70% of the maize endosperm and it consists of two types of carbohydrate chains, amylose and amylopectin. The first one represents about 25% of starch and has predominantly linear α-1,4-linked glucans, whereas amylopectin has α-1,4-linked chains branched extensively with 1,6-linkages (Ball et al., 1996). Starch is contained in granules, called amyloplasts (Sabelli and Larkings, 2009), which are dispersed in a rigid matrix of proteins throughout the endosperm.

Abbreviations: meantlp, mean temperature during lag phase; mintlp, minimum temperature during lag phase; maxtlp, maximum temperature during lag phase; meantgf, mean temperature during effective grain filling; mintgf, minimum temperature during effective grain filling; maxtgf, maximum temperature during effective grain filling; meanrlp, mean global radiation during lag phase; cumrlp, cumulative global radiation during lag phase; meanrgf, mean global radiation during effective grain filling; cumrgf, cumulative global radiation during effective grain filling; SS, source/sink ratio; KN, kernel number; KW, kernel weight; SP, starch percentage; AP, amylose percentage; ASR, amylose/starch ratio; PP, protein percentage

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Table 1
Silking date and meteorological variables during the lag phase and effective grain filling period for five locations, two growing seasons and two sowing dates. Data correspond to means of daily mean, minimum and maximum temperatures and mean and cumulative solar radiation (average for three hybrids).

				Temperature						Global Radiation			
				Lag phase			Effective grain filling			Lag phase		Effective grain filling	
Location	Year	Sowing date	Silking	Mean	Minimum	Maximum	Mean	Minimum	Maximum	Mean	Cumulative	Mean	Cumulative
				(°C)						($MJ\ m^{-2}$)			
Corrientes	2009–10	Early	12/10/2009	26.1	21.3	30.9	27.4	22.6	32.2	20.7	269.0	22.9	779.9
		Late	3/1/2010	27.1	21.9	32.4	23.3	18.1	28.6	21.7	259.8	15.7	691.7
	2010–11[a]	Early	12/6/2010	24.6	18.6	30.6	26.5	20.6	32.5	24.3	316.1	23.3	814.2
Paraná	2009–10	Early	12/17/2009	25.2	19.6	30.7	25.1	19.5	30.7	19.9	259.2	22.2	821.3
		Late	2/9/2010	25.4	20.4	30.3	23.1	17.7	28.5	18.2	236.9	18.5	757.1
	2010–11	Early	12/28/2010	26.1	19.6	32.5	25.1	18.9	31.3	24.3	316.5	22.5	810.8
		Late	2/15/2011	23.8	18.8	28.8	20.9	14.8	27.0	18.2	254.7	19.4	990.7
Pergamino	2009–10	Early	12/21/2009	23.6	18.0	29.3	23.9	17.6	30.1	21.4	320.9	23.1	1064.3
		Late	2/15/2010	20.9	15.3	26.5	19.2	12.0	26.4	18.6	315.5	15.7	782.9
	2010–11	Early	1/2/2011	23.0	15.8	30.3	21.1	14.3	28.0	24.4	365.3	22.7	974.3
		Late	2/12/2011	21.4	15.4	27.4	17.8	9.4	26.2	20.4	348.7	17.1	838.3
Balcarce	2009–10	Early	1/6/2010	21.5	13.8	29.2	21.2	15.3	26.9	23.0	367.3	18.6	930.2
		Late	2/15/2010	18.8	13.5	24.1	16.7	11.1	22.2	16.9	354.2	12.6	567.3
	2010–11	Early	1/11/2011	22.5	15.4	29.6	20.9	15.0	26.7	24.1	386.1	19.4	930.7
		Late	2/11/2011	20.8	15.0	26.5	18.5	11.6	25.3	19.4	349.6	14.9	760.5
Viedma	2009–10	Early	1/15/2010	25.0	17.4	32.5	19.8	13.5	26.1	27.2	380.8	19.4	1143.6
		Late	2/16/2010	20.4	14.7	25.9	16.2	9.8	22.5	18.7	356.1	14.8	724.5
	2010–11	Early	2/1/2011	22.8	14.0	31.5	19.4	12.1	26.7	26.7	400.8	19.1	1030.9
		Late	2/18/2011	21.7	14.7	28.6	17.5	10.0	24.9	20.6	371.5	17.1	683.1

[a] Only early sowing date was carried out this year at this location.

Starch and protein percentage are usually related and there is abundant evidence for a negative starch/protein relationship (e.g. Seebauer et al., 2010). Robutti et al. (2000) found that starch concentration was negatively correlated with kernel hardness, and horny endosperm presented higher amylose content than floury endosperm. Endosperms with high amylose/starch ratio would be more compressible and therefore become denser and harder at harvest than endosperms with a high proportion of amylopectin (Dombrink-Kurtzman and Knutson, 1997).

Kernel hardness is an intrinsic property of the genotype (Duarte et al., 2005) but it is also modulated by the crop growing conditions (Cirilo et al., 2003, 2011; Eyhérabide et al., 2004; Tanaka et al., 2005). The environment could alter starch composition by acting on enzymes of the biosynthetic starch pathway i.e.: those involved in substrate production, the elongation of the α-1,4-glucan chains and their branching, and the maintenance of granule crystallinity (Beckles and Thitisaksakul, 2014). In wheat and barley, increases in temperature during grain filling increased kernel amylose concentration (Hurkman et al., 2003; Savin and Nicolas, 1999; Shi et al., 1994). During starch synthesis, the starch branching enzyme branches the chain to produce amylopectin (James et al., 2003). Lenihan et al. (2005) proposed that changes in the amylose/starch ratio in maize as result of differences at growing environments could be explained by the direct effect of temperature on the enzymatic activity in endosperm cells. Increases in temperature could decrease total starch branching enzyme activity increasing amylose/starch.

Starch content and composition, as well as other kernel components, are defined during the grain filling period. Delayed sowings in a temperate climate caused lower rates of grain filling, shorter duration of grain filling, and a decrease in final weight of kernels (Cirilo and Andrade, 1996). Actis (2007) found that starch percentage in maize kernels had lower variation through environments than amylose/starch ratio. In that work, kernels from late sowing dates, with lower temperatures during grain filling, presented less amylose concentration than those from early sowing dates.

Argentinean maize production areas range from subtropical to temperate cold climates (Hall et al., 1992), and constitute with the Corn Belt of the USA, Europe and Northwest China the temperate maize mega-environments (Fischer et al., 2014). Locations and sowing dates modify environmental conditions (i.e. temperature and incident radiation) during grain filling which in turn could affect starch composition. Understanding how growth conditions determine grain starch composition is essential for the development of production strategies with the aim of obtaining convenient grain quality in maize. So, the objective of our research was to analyze the effect of location and sowing date on starch composition in maize hybrids differing in endosperm hardness.

2. Materials and methods

2.1. Experimental design and growing conditions

Field experiments were carried out at five locations across the argentinean maize-production area: Viedma (40°49′ LS), Balcarce (37° 50′ LS), Pergamino (33° 53′ LS), Paraná (31° 43′ LS) and Corrientes (27° 27′ LS) during two growing seasons (2009–10 and 2010-11). Locations vary in air temperature and incident global solar radiation; thus, they were considered as a source of variation. Locations also vary in soil type: fine silty clay thermic Aridic Gypsiustert (Viedma), silty clay loam Typic Argiudoll (Balcarce), silty clay loam Typic Argiudoll (Pergamino), fine mixed thermic Aquic Argiudoll (Paraná) and fine clay loamy mixed Hyperthermic Udipsamments (Corrientes). At each location, treatments (sowing date and hybrid type) were arranged in a split-plot design with three replicates. Sowing dates were assigned to main plots, whereas hybrids were assigned to the sub-plots. Sub-plots had 35 m^2 (5 rows, 0.7 m apart, and 10 m long). Sowing dates were mid-October (early) and mid-December (late). Hybrids were: a semi-dent type with high yield potential (Dk190, Monsanto Argentina S.A.), a semi-flint hybrid with high yield potential but unstable in flint type expression (Cóndor, Syngenta Agro S.A.) and an hybrid with limited grain yield potential but strong flint type expression (M522, Dow AgroSciences S.A.). These hybrids are similar in cycle length having a relative maturity around 121, for this reason there were no differences among hybrids silking date or grain filling duration.

Plots were hand-planted at three seeds per hill and thinned to the

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