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Physiological bases of genetic gains in sugarcane yield in Argentina

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ABSTRACT

Breeding and management efforts during the 20th century have increased sugar yield in almost all sugarcane areas worldwide. However, a close analysis of the trends during the last decades reveals that the rate of increase in sugar yield has been actually slowing down since the 1980s. An experiment was conducted to compare sugarcane varieties representing different eras of genetic improvement in Argentina (one widely grown self-pollination variety, 11 released sugarcane hybrids and one advanced breeding hybrid) during the 2010/11, 2011/12 and 2012/13 growing seasons under rainfed field conditions in Tucumán, the main sugarcane area of Argentina. The aim of the experiment was to quantify the achievements in sugarcane breeding since 1940 in Tucumán, by identifying the main crop physiological bases responsible for yield increases. Genetic gains for sugar yield were 0.08 and 0.14 Mg ha^{-1} y^{-1} for plant and ratoon cane, respectively. There was a linear increase in sugar yield, cane yield, sugar content and average stem weight with the year of release of the varieties throughout the period from 1940 to 2010. The increase in sugar yield was linearly and positively related to cane yield, sugar content and average stem weight, whereas the increase in cane yield was associated to average stem weight and not to the number of stems. Breeding also increased the total above ground dry biomass and the dry stem weight. However, the partitioning of total above ground dry biomass to stems or to sugar were not increased by breeding. These findings reveal that the varieties continuously released by Argentine sugarcane breeding programs have not reached a "plateau" in sugar yield.

1. Introduction

Genetic improvement has played an important role in yield increment in almost all the sugarcane producing countries. Although breeders have selected new varieties with important objectives, such as ratooning ability, disease resistance or fibre content, their main goal is sugar yield through the main yield components: cane yield and sugar content.

Breeding and management efforts during the 20th century have increased sugar yield from 4 to 14 Mg of sugar ha^{-1}, depending on the environment, with records being documented from Colombia (Cock, 2003), Hawaii (Wu and Arcinas, 2004), USA (Edmé et al., 2005), Australia (Jackson, 2005; Ming et al., 2006; Cox and Stringer, 2007) and Argentina (Fernandez de Ulivarri et al., 2009). These increases led to genetic gains ranging from 0.09 to 0.18 Mg of sugar ha^{-1} y^{-1}. Almost all these genetic gains in sugar yield were mainly associated with cane yield, whereas there was little progress in sugar content (Jackson, 2005). However, a close analysis of the trends in all these studies during the last decades reveals that the rate of increase in sugar yield has been actually slowing down since the 1980s.

In Argentina, increases in sugar production during different periods of the last century were due to the expansion of sugarcane cultivated areas and intensified use of inputs. These factors are not likely to occur at present due to economic and environmental constraints. Therefore, future sugar production increases with the consequent improved yield gains required for satisfying world sugar demands will strongly rely on genetic improvement.

In this context, breeding strategies using physiological knowledge could play an important role in yield gain. An alternative for identifying prospective physiological traits useful in yield improvement has been the analysis of the physiological traits that were instrumental in the breeding achievements made in the past (Reynolds et al., 2001).

Many studies have explored the physiological bases associated with genetic gains in different crops, such as wheat (Austin et al., 1980), barley (Wych and Rasmusson, 1983), maize (Tollenaar,

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Table 1
Sugarcane varieties grown, indicating year of release in Argentina, country of origin, and period in which the varieties were grown commercially.

Variety	Year of release in Argentina[1]	Country of origin	Commercial growth period	Relative maximum proportion of cultivated area in Argentina
TUC 26–45	1940	Argentina	1940–1960	+50% (1950)*
CP 34-120	1950	USA	1950–1970	wd
NCO 310	1960	South Africa	1960–Present	wd
NA 56-79	1964	Argentina	1964–Present	46% (1977)*
CP 48-103	1970	USA	1970–1880	7% (1977)*
NA 56-30	1970	Argentina	1970–1980	19% (1977)*
NA 63-90	1977	Argentina	1977–Present	25% (1987)*
CP 65-350	1987	USA	1987–1990	20% (1990*
CP 65-357	1989	USA	1989–Present	33% (1998)*
TUCCP 77-42	1994	Argentina	1994–Present	32% (1998)*
LCP 85-384	2001	USA	2001–Present	77% (2010)**
RA 87-3	2005	Argentina	2005–Present	8% (2008)**
FAM 91-209	–	Argentina	–	–

wd = without published data (recommended by sugarcane breeders R.A Sopena and/or R. Fernández Ullivarri).
* From Ahmed et al. (2007).
** From Ostengo et al. (2012).

1991) soybean (Morrison et al., 1999), rice (Peng et al., 2000) and sunflower (de la Vega et al., 2007). However, to the best of our knowledge, no study has reported the physiological bases associated with genetic gains in sugarcane. This lack of studies in sugarcane might contribute to the slowing down in sugar yield gains worldwide. Such studies could help to determine the rate of return from investment in breeding programs, but they could also lead to faster progress in sugar yield gains.

As sugarcane is one of the most important energy sources for humans (FAO, 2010), we aimed to quantify the achievements made by sugarcane breeding since 1940 in Tucumán, the main growing area in Argentina, by identifying the main crop physiological bases responsible for such achievements. For this purpose, representative varieties released from the 1940s to the beginning of the 21st century were grown during three consecutive seasons.

2. Materials and methods

2.1. General

An experiment was carried out under rainfed field conditions in the province of Tucumán, the main sugarcane producing area of Argentina. The experiment was conducted in Famaillá (27°03′S, 65°25′W, 363 m.a.s.l.), in the experimental fields of the National Institute of Agricultural Research (INTA) during the 2010/11, 2011/12 and 2012/13 growing seasons. The soil is fertile and is classified as Aquic Argiudoll.

Rainfall from planting to 2011 harvest was 1417.1 mm; from 2011 harvest to 2012 harvest it was 992.3 mm; and from 2012 harvest to 2013 harvest it was 1069.3 mm. Soil N—NO_3 content after winter was approximately 45 kg ha^{-1} (range 35–56) in all years. Fertilizers were broadcasted at tillering, applying 110 kg N ha^{-1} in 2011/12 and 2012/13, whereas no fertilization was used in 2010/11.

2.2. Treatments and design

Sugarcane varieties that were important for the development of sugarcane breeding in Argentina (Table 1) were compared. They were selected or introduced to the production system by the breeding programs of "Obispo Colombres" Experimental Station of Tucuman, "Chacra Experimental" of Colonia Santa Rosa, Salta, and INTA of Tucuman that planted 80,000, 200,000 and 25,000 seedlings per year, respectively (R. Sopena, personal communication). These programs are characterized by sugar production (cane yield and sugar content) and diseases resistant as selection criteria.

The varieties included a widely grown self-pollination variety (TUC 26–45), 11 released sugarcane hybrids selected due to their success during at least one decade in farm crops in Tucumán, and an advanced breeding hybrid of INTA's sugarcane breeding program performing consistently well in several comparative trials.

Treatments were arranged in a randomised complete block design with three replications. Plots, consisting of five 10-m long rows that were 1.60 m apart, were planted at commercial cane densities on 24 August 2010 (Romero et al., 2009). Commercial harvests were performed on 20 September 2011, 26 August 2012 and 29 August 2013.

Weeds and insects were controlled or prevented using recommended products. Ratoon stunting disease was prevented using seed cane from treated nurseries or by treating the seed cane with hydrothermotherapy. Other bacterial or viral diseases that commonly occur in Tucuman (leaf mosaic virus or red stripe) were not considered because they are controlled only genetically. Rust was not present during the trials.

2.3. Sampling and measurements

Plant samples were taken from all experimental units at ripening. Samplings were performed on 30 June, 02 July and 10 June for the growing seasons 2010/11, 2011/12 and 2012/13, respectively. These dates are around the optimum harvest date for Tucuman.

Samples consisted of all plants at one meter from the three central rows and were taken on both sampling dates. The samples were used to determine the number of stems, average stem weight, cane yield, sugar content and sugar yield on a fresh basis (as sugarcane commercial final products are the fresh stems) (Eqs. (1)–(3)). During the 2010/11 and 2011/12 seasons total above ground dry biomass, dry stem weight, and the partitioning of total above ground dry biomass to stems and to sugar, and the partitioning of dry stem weight to sugar were also determined (Eqs. (4)–(6)).

$$\text{Sugar yield} = \text{Cane yield} \times \text{Sugar content} \quad (1)$$

$$\text{Cane yield} = \text{Number of stems} \times \text{Average stem weight} \quad (2)$$

$$\text{Sugar yield} = \text{Number of stems} \times \text{Average stems weight} \times \text{Sugar content} \quad (3)$$

$$\text{Partitioning of total above ground dry biomass to stems} = \text{Dry stem weight}/\text{Total above ground dry biomass}) \quad (4)$$