Traits of the sugar cane associated with tons of cane per hectare and sucrose (% cane)

Características de la caña de azúcar asociadas con toneladas de caña por hectárea y sacarosa (% caña)

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Abstract

In the initial stages of clonal selection, indirect selection for variables tons of sugar cane per hectare (TCH) and sucrose (% cane) is used, based on some agronomic traits associated with TCH and sucrose (% cane). This indirect selection can increase efficiency to the extent that better knowledge about the nature and magnitude of the associations among the characteristics of interest required and, between the latter and productivity indicators. The aim was to estimate genetic correlations between agronomic traits (causal factors) and performance variables (response variables), also decompose its magnitude by path analysis. Five characters of interest, cane length, diameter, stalk population per meter, TCH and sucrose (% cane) were evaluated in five locations in the geographic area of the semi–dry valley of the Cauca River to 17 varieties and two witnesses (CC 85–92 and MZC 74–275) on plant–cane using Latice experimental design. To estimate the genetic correlation coefficients and path coefficients (path coefficient) the GENES software was used. The analysis showed that for high TCH varieties and sucrose (% cane) must first be selected clones carried high above the control range 85–92 CC (334 cm) to ensure a high sucrose content, and then you can make a second screening by thick stems of larger diameter than the control (32 mm) and high stalk population equal to or higher than the control (14 stems/m).

Key words: Path analysis, breeding, *Saccharum* spp.

Resumen

En las etapas iníciales del proceso de selección clonal en caña de azúcar (*Saccharum* spp.) se realiza la selección indirecta para las variables toneladas de caña por hectárea (TCH) y porcentaje de sacarosa. Esta selección indirecta puede aumentar su eficiencia en la medida que se precise mejor el conocimiento acerca de la naturaleza y la magnitud de las asociaciones existentes entre las características de interés y entre éstas y los indicadores de productividad. El objetivo del presente trabajo fue estimar las correlaciones genéticas entre las variables de tipo agronómico (factores causales) y las de rendimiento (variables de respuesta), además descomponer su magnitud mediante análisis de sendero. Se evaluaron cinco caracteres de interés en caña de azúcar (altura, diámetro de tallos, población de tallos por metro, TCH y sacarosa (% caña)) en cinco localidades de la zona semiseca del valle del río Cauca para 17 variedades y dos testigos (CC 85–92 y MZC 74–275) en plantilla utilizando un diseño experimental Latice. Para estimar los coeficientes de correlación genética y de sendero ('path coefficient') se utilizó el software GENES. El análisis mostró que para obtener variedades con alto TCH y alta sacarosa (% caña), primero se deben seleccionar clones con altura superior que la variedad testigo CC 85–92 (334 cm) para asegurar un contenido alto de sacarosa y posteriormente hacer un segundo tamizado por tallos gruesos de diámetro mayor que el testigo (32 mm) y alta población de tallos igual o superiores que el testigo (14 tallos/m).

Palabras clave: Análisis de sendero, fitomejoramiento, *Saccharum* spp.

Introduction

To obtain sugarcane (*Saccharum* spp.) varieties with high tons and concentration of sucrose (% cane) is one of the initial goals of the Variety Program of the Research Center of Sugarcane of Colombia (Cenicaña), clonal selection process that comprises all the variability produced at the initial stages of crossings known as State I ((Victoria *et al.*, 2013). However, to choose the best individuals for high cane production and high sucrose is difficult since it is almost impossible to measure these characteristics in all the individuals.

For a wise choice of the best individuals it is important that the breeder knows the associations that exist, for example, between cane productions vs. agronomic traits such as plant height and stem population. Therefore, the good understanding of these kind of association easiness the indirect selection for TCH by observing in the field the characteristics known as 'causes'. In this case is relevant the path analysis, which evaluates whether a relationship between two variables is like cause and effect, or is determined by the influence of one or more variables (Singh and Chaudhary, 1977; Vencovsky and Barriga, 1992; Cruz and Regazzi, 1997). In this type of analysis the coefficient estimator uses the path coefficient for measuring the direct influence of one variable on another, independently of the others, and thus splits the correlation coefficients (genetic, phenotypic or environmental) in its direct and indirect effects (Li., 1977). As result, if the cause-effect relationships are well defined it is possible to represent the whole system of variables by a path diagram (Prakash and Lal., 2007).

Correlations and path analysis are used as a tool to help in the selection process of plant and animals (Ntawuruhunga *et al.*, 2001; Yadav and Ram., 2002; Espitia *et al.*, 2006; Gorgulu., 2011; Santos *et al.*, 2014).Although the literature on this kind of studies on sugarcane is scarce, at international level there are some studies reported in Brazil (Pagano *et al.*, 2012), Pakistan (Khan *et al.*, 2013) and Fiji Islands (Prakash and Lal., 2007). In Colombia, there are no reports on this studies for sugarcane, therefore, due to the importance of using path analysis to know the nature and magnitude of the correlations among the agronomical interesting characters and their decomposition, it is required to apply these studies in the genetic plant breeding programs of this species.

This study had as specific objectives: (1) to estimate the genetic correlations among the characters: stem diameter (DIA), stem height (ALT), population (POB), cane tons per hectare (TCH) and sucrose (% cane) (SAC) and; (2) to decompose by path analysis the previous correlations in their direct and indirect effects on production of cane and sucrose (% cane) in function to the other three characters studied.

Materials and methods

To have a representative area of the sugarcane production zone of Colombia, the research comprises the sugar mills with larger area in the semidry zone and the agro-ecological zones 6H1, 11H1 and 15H1 that represent 58% of the total (209,493 ha) area sown in sugarcane.

The plant material included two control varieties (CC 85–92 and MZC 74–275) and 17 varieties: two from the series 97, one from the series 98, one from the series 99, five from the series 00 and eight from the series 01 (Table 1).

Five experiments were sown in the field using a Lattice 4 x 5 design with three replicates in stripes, in plots with six rows spaced 1.65 to

Table 1. Parents of the sugarcane varieties evaluated in the regional test 97-01.

Variety	Parents	
	Mother	Father
CC 00-2639	CC 93-7513	CC 93-7436
CC 00-2924	CC 87-504	?
CC 00-3068	CP 78-2086	ICA 69-11
CC 00-3079	PR 61-632	CP 57-603
CC 00-3191	CP 78-2086	?
CC 01-1228	CCSP 89-1997	?
CC 01-1305	CC 87-117	CC 82-04
CC 01-1484	MZC 74-275	?
CC 01-1508	CCSP 89-1997	?
CC 01-1567	CC 93-7449	?
CC 01-1789	RD 75-11	CP 82-1995
CC 01-678	CC 93-4076	M 336* PR 980
CC 01-746	MZC 74-275	?
CC 97-7170	MZC 74-275	⊗1
CC 97-7565	V 71-51	MZC 74-275
CC 98-426	MZC 74-275	⊗
CC 99-1405	CC 94-5787	CC 91-1599
MZC 74-275	POJ 2878	CP 57-603
CC 85-92	Co 775	?

1: ⊗ Selfing.

1.75 m along the plot with row lengths between 70 and 122 m, in soils: (1) Palmira (Pachic Haplustolls) with fine loam texture, agro-ecological zone 11H1, in the plot 20A of the plantation Cabaña from Manuelita Sugar mill; (2) Palmira (Pachic Haplustolls) with fine loam texture, agro-ecological zone 41B, in the plot 20ª of the plantation San Rafael from Mayagüez Sugar mill; (3) Galpón (Typic Calciusters) and Corintians (Typic Haplusterts) with fine texture, agro-ecologic zone 6H1, in the plot 506 of the plantation Marsella from Providencia Sugar mill; (4) La selva (Vertic Haplustolls) with fine silty over sandy texture, agro-ecological zone 15H1, in the plot 50 of the plantation La Luisa from Riopaila Sugar mill; (5) Corintians (Typic Haplusterts) with fine texture, agro-ecological zone 6H1, in the plot 87A of the plantation Esmeralda from Sancarlos Sugar mill.

The agronomic characteristics studied were: (1) plant height in cm (ALT) measured in 10 mature stems in different plants from the base till the natural breaking point; (2) stem diameter in mm (DIA) at the middle third height in 10 mature stems; (3) stem population per meter (POB) counting the number of milling stems in 10 m expressed as stems/m; (4) tons of cane per hectare (TCH) by weighting the total milling stems/area of each plot, expressed as equivalent per ha and; (5) sucrose (% cane) (SAC) that was analyzed in the Cane Laboratory of Cenicaña using 10 milling stems and following the direct analysis methodology. The first three evaluations were done at 12 months, while the TCH and sucrose (% cane) were measured by manual green harvesting of the plot at ages of 14 and 16.3 months.

The estimation of the genetic correlation coefficients (r_G) for character pairs and the path analysis were done using the GENES software (Cruz., 2013), which estimates the different types of correlation coefficients using the variance and covariance matrices for each pair of characters of interest (ej., X and Y) and using the classic correlation formulas as follows: (1) genetic correlation ($r_{G(XY)}$), $r_{G(XY)} = COV_{G(XY)} / S_{G(x)} . S_{G(y)}$, where: $r_{G(XY)}$ and $COV_{G(XY)}$ are the genetic correlation and covariance between the X and Y characters, respectively; $S_{G(x)}$ and $S_{G(y)}$ are the genetic standard deviation of X and Y, respectively (Cruz., 2006). To determine these correlations, the estimations were done with the mean values of each one of the evaluated characteristics.

Once the different correlation coefficients were estimated (r) their statistical significance was tested, giving the null hypothesis: Ho: r = 0 vs. the alternate hypothesis: Ha: r ≠ 0, by the 't' test. The calculated 't' value was compared with a 't' of the Table (Tt) at the significance levels (P < 0.05, 0.01) with n = 2 degrees of freedom. The decision rule was if tc ≥ Tt, then the r value (correlation) is statistically different from zero.

Path analysis were performed for TCH and sucrose (% cane) (effect variables) in function to the diameter, population and height (cause variables) of cane; these analysis were originated based on the use of the genetic correlation matrix.

To estimate the direct effects in each one of the analysis, the GENES software uses a genetic correlation matrix, decomposes it and organizes it in the following matrix system: $P = A^{-1}.R$, where A^{-1} is the inverse of the correlation matrix between the cause variables, R is the vector the correlation coefficient between the cause variables with the effect variable and, P is the vector of the pathway coefficients. The GENES software, beside the direct effects, allows the estimation of the indirect effects, the pathway coefficient due to the residual effects or to other variables that are not considered in the study (h) and the determination coefficient (R^2) (Cruz, 2006).

Results and discussion

The Pearson phenotypic correlations have a low practical values, are risky and can lead to mistakes, because they include the association among characters of genetic and environmental nature; in consequence, the results and the discussion are based on genetic correlations. These correlations (Table 2) show a high association of sucrose with plant height and between TCH with stem diameter and plant population. In turn, the plant population is negatively correlated with sucrose (% cane), generating a constraint

Table 2. Genetic correlations between sugarcane characters. Sugar producing area of Colombia.

Characteristic	Height	Diameter	Population	Sucrose (% cane)
Diameter	0.63 **			
Population	-0.30 **	-0.33 **		
Sucrose (% cane)	0.90 **	0.01	-0.40 **	
TCH	0.42 **	0.82 **	0.89 **	0.56 **

* P < 0.001, according to 't' test.

between increasing TCH and sucrose and also limits the efficient performance of the Variety Program of Cenicaña in the semidry zone of the Cauca river valley.

At present it is not known if detected significant correlations for the variable of interest are due to the direct effects of them or to indirect effects through other variables. Path analysis (Table 3) helped to clarify this situation and showed that the TCH has a high correlation with the population and stem diameter, indicating that the direct effect is high and confirms that to achieve a high yield of cane are required high populations of plants with thick stem diameter, which coincides with the findings of Pagano *et al.* (2012) who made studies in Brazil using half siblings families and found that the familiar selection for the TCH variable is highly associated with the number of stems, both from the sowing and ratoon. Portela *et al.* (2013) in Brazil found high association between TCH and the stem population, whereas the stem diameter did not have an indirect effect through the number of stems.

Plant height as determinant of TCH and sucrose (% cane) is important but, its effect is through stem diameter, that means that when taller plants are selected they should have thick diameters because both characteristics are associated (Figure 1). The above means that tall but skinny stems do not favor the increase in TCH. These results agree with the protocols applied by the Variety Program of Sugarcane of Louisiana (USA) that uses the components stem diameter and stem number per clone at the initial stages of the progeny test (Sousa and Milligan, 2005).

The results of this study are important in Colombia, where the highest productivity of sugarcane in the world is obtained, as to further increase this productivity, the introgression of materials with largest populations of stems and greater plant height which is associated to thicker stems is required.
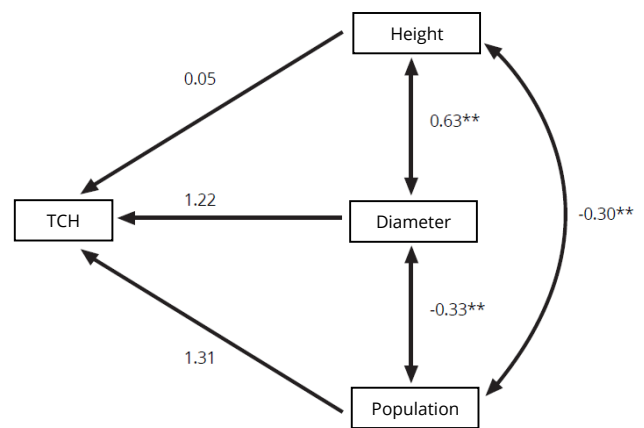
The sucrose (% cane) in Cauca river valley

Figure 1. Path analysis diagram for TCH in sugarcane based on the genetic correlations. Sugarcane produccing zone of Colombia.

conditions is variable in time because harvest is done throughout the year and rainfall and temperature are variable and affect the sucrose concentration in the plant. In most of the sugarcane producing countries harvest is performed during the dry season which contributes to the concentration of sucrose (% cane), therefore these results do not allow valid comparisons as base for confirmation or contrast. The results of this study show that sucrose (% cane) is highly associated with plant height (Figure 2) favoring the light interception for a high photosynthesis rate (Thippeswamy *et al.*, 2003).

Nonetheless, the high plant population reduce the content of sucrose indirectly by the diameter, since in thick stems it is not possible to concentrate sucrose due to the dilution effect, which agrees with the findings of Khan *et al.* (2013) who consider that the sugar production has a negative correlation with the stem diameter. A possible strategy to select plants with intermediate diameter is to use varieties with short or medium internodes. In the local conditions of this study the skinny diameters are associated with high sucrose contents but have low cane production. The selection per family allows to handle at the same time the two characters, because both, diameter and sucrose, show high heritability in wide sense

Table 3. Results of the path analysis for the direct effects (in the diagonal) and indirect (outside the diagonal) from the three sugarcane characteristics at age 12 months. TCH and sucrose (% sucrose) in the first harvesting based on the use of the genetic correlations in environments from the semidry zone of the Cauca river valley (Colombia).

Characterisitic	Height	Diameter	Population	Sucrose	Height	Diameter	Population	TCH
Height	**1.43**	-0.62	0.09	0.90**	**0.05**	0.77	-0.40	0.42**
Diameter	0.90	**-0.98**	0.10	0.01	0.03	**1.22**	-0.44	0.82**
Population	-0.44	0.33	**-0.28**	-0.40**	-0.02	-0.41	**1.31**	0.89**

** P < 0.001, according to the 't' test.
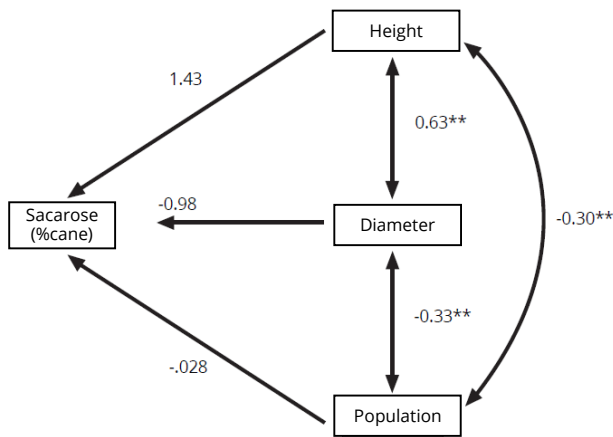
Figure 2. Path analysis diagram for sucrose (% cane) in sugarcane based on the genetic correlations. Sugarcane produccing zone of Colombia.

which allows selection of families of intermediate diameter with high sucrose (Shanthi *et al.*, 2011).

Conclusions

The data analysis in this study showed that to obtain varieties with high TCH and sucrose (% cane) is necessary, first to select taller clones than the control variety CC 85-92 (334 cm), in order to guaranty a high sucrose content and later, perform a second screening for thicker stems with larger diameters than the control (32 mm) and high stem population similar or higher than the control (14 stems/m).

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