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Evaluation of the Sugar Content along the Stalk Height of Sugarcane Plants for Different Growth Conditions. Statistical Analysis

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Abstract. The Brix degree is an indicator of sugarcane juice sugar content but it is not uniform along the plant stalk height. To evaluate the Brix on the height measurement of the stalk, three groups of sugarcane samples were compared. The groups consisted in different growth conditions under Portuguese mainland climate: (i) growth in a constructed wetland filled with clay brick fragments used to treat secondary wastewater; (ii) growth in a deactivated but irrigated constructed wetland filled with clay lightweight aggregate; (iii) growth in soil with irrigation. Some descriptive statistics were obtained for the three groups and 95% confidence intervals (also including bootstrap BCa procedure) were computed and compared. The one-way ANOVA demonstrates that different growth conditions do not affect the relative height position of the stalk average Brix representative internode. A simple linear regression was adjusted to model the relationship between the relative Brix with the relative measurement height and might be used to predict the sugarcane juice sugar content.

INTRODUCTION

Sugarcane is a valued crop in the tropical and sub-tropical regions for sugar and ethanol production [1, 2]. Sugarcane is not cultivated in non-tropical countries like Portugal (Mediterranean climate). However, previous works demonstrated that sugarcane can be cultivated in Portugal mainland when integrated in constructed wetlands (CW) for wastewater treatment [3, 4], which represents an important contribution to the sustainability of this treatment technology and to the correct management of arable land and fresh water resources. Cultivation control and optimization requires monitoring of several growth indicators, the most important of which is the sugar content [5, 6]. Sugar content of sugarcane plants may be assessed in the field using simple methods based on light refraction by sugarcane juice [7]. Light refraction expressed in Brix degrees (°Brix) correlates well with the sugar content [7]. However, the Brix readings vary with the height at which measurements are obtained on the sugarcane stalk and published works concluded that average sugar content may be assessed at the internode located in the middle of the stalk height, for sugarcane grown under typical agriculture conditions in tropical land fields [7]. In a recent work, the average Brix was correlated with the measurement height in sugarcane cultivated in pilot constructed wetlands systems located in Portugal mainland [8]. The aim of the present work was to evaluate the effect of three different growth conditions on the variation of sugar content along the stalk height. The coefficient of variation (CV), 95% confidence intervals (CI) and one-way ANOVA were used to compare the three groups of sugarcane and a linear regression model was also adjusted in order to explain the sugarcane juice sugar content along the stalk height.

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MATERIALS AND METHODS

Sugarcane plants (*Saccharum officinarum*) from three different growth conditions were compared for sugar content through °Brix refraction analysis:

(i) Sugarcane plants from a third ratoon cycle grown in a running pilot CW filled with clay brick fragments used for tertiary wastewater treatment, whose experimental setup is described in [9];

(ii) Sugarcane plants from plant cane cycle grown in a deactivated pilot CW filled with clay lightweight aggregate (LWA) with irrigation during the hot seasons, whose experimental setup is described in [10];

(iii) Sugarcane plants from a second ratoon cycle grown in soil, with fertilizers addition and irrigation in the hot seasons.

The study was conducted using sugarcane plants with more than 6 internodes. The plants were harvested and stalks were separated from leaves (Fig. 1 (a)). Then the stalks were divided into fragments corresponding to the internodes (Fig. 1 (b)). Representative samples from the fresh fibrate material of each internode were grounded and the crusher juice was analyzed for Brix value at 20 °C. The °Brix, which is an estimator of the soluble solids fraction, is correlated with the sugar content [7], was measured using a hand refractometer ATAGO, ATC-1.

(a) (b)

FIGURE 1. Photos of sugarcane stalks (a) and internodes fragments (b) before juice extraction for Brix measurement.

For each sugarcane plant, Brix average was calculated from the samples and a simple linear regression was used to estimate the internode position (I_j) whose value is representative of the plant average (B_j). To compare the average representative internode relative position (I_j/N_j), where N_j represents the quantity of internodes for each stalk j, for the three growth conditions the 95% CI were obtained and the one-way ANOVA was applied.

To evaluate the Brix data with the measurement height of the stalk, the relative Brix and the relative height ratios were calculated for each plant through equations 1 and 2,

$$\beta_{ij} = \frac{b_{ij}}{B_j} \quad \text{with} \quad B_j = \frac{1}{N_j}\sum_{i=1}^{N_j} b_{ij}, \tag{1}$$

$$\eta_{ij} = \frac{h_{ij}}{H_j} \quad \text{with} \quad H_j = \sum_{i=1}^{N_j} h_{ij}, \tag{2}$$

where β_{ij} represents the relative Brix of internode in the i^{th} position of stalk j, b_{ij} is the Brix of the same internode and B_j is the average Brix computed from the Brix of all internodes of stalk j. The i^{th} position was counted from the stalk base. The η_{ij}, h_{ij} and H_j represent the relative internode height in the stalk, each internode height in the stalk and the stalk j total height, respectively, with the same meanings for the subscripts i and j. Calculations were made with Microsoft Excel®2016 and IBM SPSS® 25.

RESULTS AND DISCUSSION

Figure 2 shows an example of the method considered to estimate the internode position, whose Brix value is representative of the plant average. The scatter plot represents the Brix for each internode (b_{ij}) and the dashed line was obtained through linear regression. The horizontal dotted line represents the stalk average Brix (B_j). The vertical dotted line marks the interception point which identifies the representative internode.

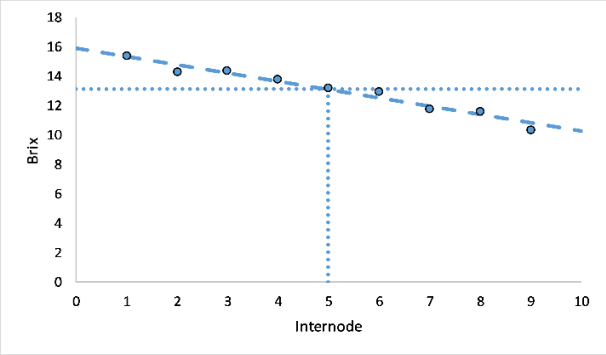

FIGURE 2. Example of representative internode identification.

The results obtained for the three groups of sugarcane plants according to the growth conditions are presented in Table 1. The averages of groups I and III are approximately equal (0.561, considering 3 decimal places) and the average of group II is a little bit less (0.556). Based on the standard deviation (SD), the absolute dispersion is almost equal considering groups I and III and smaller on group II (0.004). Regarding to the values of CV (%), all groups have a very small relative dispersion and group III has the highest value (1.426%). The range of the 95% CI of groups I and II are similar and group III has the biggest one (Fig. 3 allows the visualization of this behavior, which is relatively different considering the 95% bootstrap BCa CI).

TABLE 1. No. of stalks, total no. of internodes, average, SD, CV (%), 95% CI's for each group of sugarcane.

Growth condition group	Number of stalks	Total number of internodes	Average	SD	CV (%)	95% CI	95% CI Bootstrap BCa*
I – Brick CW	12	98	0.561	0.007	1.248	(0.557; 0.566)	(0.558; 0.565)
II – Clay LWA CW	6	54	0.556	0.004	0.719	(0.552; 0.560)	(0.556; 0.567)
III – Soil	7	58	0.561	0.008	1.426	(0.554; 0.568)	(0.557; 0.563)

*bootstrap results are based on 5000 bootstrap samples.

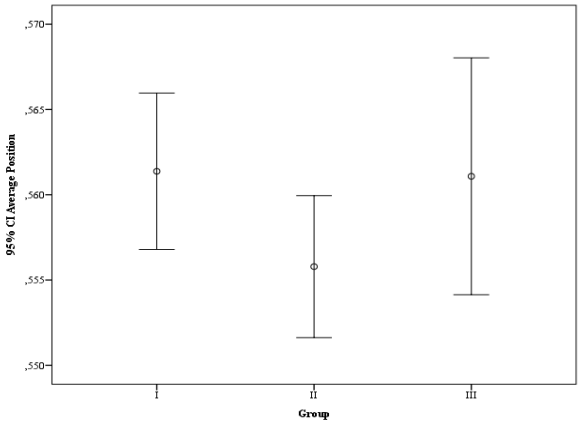

FIGURE 3. Graphical representation of the 95% CI, for the three groups.

The one-way ANOVA was applied, after verifying the assumptions of normality of data (with Shapiro-Wilk test) and homogeneity of variance (with Levene test). The results show that the average relative internode position is not statistically different across the three sugarcane groups, once the null hypothesis of the equality of means were not rejected for the usual significance levels considered, namely 5% (F-value = 1.526; p-value = 0.240).

After verifying, through the ANOVA results, that the growth conditions do not affect the relative position of the representative internode, the data for all groups were then analyzed jointly. Figure 4 shows the relative Brix as a function of the relative measurement height on the stalk. The adjusted model, represented by equation 3, is statistically significant (F-value = 589.914; p-value = 0.000 < 0.01; $r^2 = 0.739$).

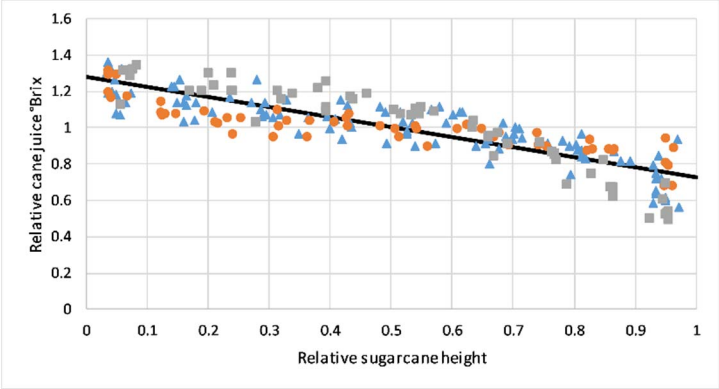

FIGURE 4. Regression of relative Brix as a function of the relative measurement height on the stalk (sample size of 210 observations). Different colors represent the three groups: ▲ sugarcane grown in Brick fragment CW; ● sugarcane grown in Clay LWA CW; ■ sugarcane grown in irrigated soil.

Equation 3 allowed the estimation of the average Brix degree of the sugarcane juice from the determination of the Brix degree of over the stalk internodes: Average sugarcane Brix = Internode Brix / β, with η = internode distance from the stalk bottom / stalk total height.

$$\hat{\beta} = (-0.548 \pm 0.044)\eta + (1.278 \pm 0.026). \tag{3}$$

CONCLUSIONS

The representative sugarcane stalk internode, whose analyzed Brix degree equals the stalk average Brix degree, was not significantly different among sugarcanes from three different growth conditions in the Portuguese mainland climate. The estimated linear regression allows to explain the relationship of Brix data against the relative measurement height and although the regression line does not perfectly fits the data the model might be used to predict the sugarcane juice sugar content from plant stalk samples obtained at any plant height.

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