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Influence of harvest timing on sugarcane quality parameters in ecuador: a multivariate analysis using PCA and MANOVA biplot

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This study evaluates the impact of pre-harvest wilting treatments (90, 75, 60, 45, and 30 days before harvest) on sugarcane quality in Ecuador, utilizing PCA Biplot and MANOVA Biplot to identify key factors affecting quality. The experiment was conducted on the CC-8592 sugarcane variety, with five treatments and four replications per treatment. Results showed a strong correlation between quality variables such as Brix, Pol, and juice purity, but no significant differences were observed among the wilting treatments. These findings suggest that pre-harvest wilting time does not significantly affect sugarcane quality under the studied conditions, indicating that other agronomic practices may have a greater impact on quality. Data on agronomic traits and quality parameters like weight, stem diameter, height, yield, brix, and juice purity were collected and analyzed. PCA Biplot findings revealed a strong correlation among quality variables, accounting for 98.5% of the cumulative variance, suggesting a significant interrelation with overall cane quality. However, MANOVA Biplot showed that wilting treatments did not significantly alter these quality metrics, indicating that other management practices may have a more substantial impact on sugarcane quality than the timing of wilting. The study highlights that while wilting is commonly used in sugarcane management, its effect is limited under the studied conditions in Ecuador. This research provides a basis for refining cultivation strategies and underscores the need for informed agronomic practices to enhance both the productivity and sustainability of sugarcane production.

Keywords Sugarcane quality, Multivariate analysis, Pre-harvest wilting, Ecuador, Sucrose content, Brix, Juice purity

Sugarcane (Saccharum spp.) is one of the most important crops worldwide and plays a central role in sugar and ethanol Production[1]. This relevance extends across diverse geographies, including Ecuador, where sugarcane cultivation not only contributes significantly to the agricultural economy but also forms an integral part of the cultural heritage of numerous communities. In this context, the crop represents a vital source of employment and a pillar for the livelihood of many rural families, emphasizing its economic and social importance within the Country[2,3].

Sugarcane production in Ecuador faces several challenges including agronomic practices and climatic conditions. The sustainability of sugarcane cultivation in Milagro has been questioned because of economic, ecological, and social constraints, with indicators below sustainable thresholds[4] . Environmental assessments of sugarcane-derived ethanol production have revealed significant warming potential distillation is one of the main contributions[5] . While the bioenergy potential of Ecuador's sugarcane bagasse is used to generate electricity, the exploration of dedicated bioenergy crops, such as giant reeds, could sustainably improve energy production[8]. Despite Ecuador's less favorable climatic conditions for sugarcane growth, research initiatives aim to develop adapted varieties and production technologies to overcome these challenges[7].

This study focuses specifically on the impact of pre-harvest wilting time (90, 75, 60, 45, and 30 days before harvest) on sugarcane quality, as this practice is commonly used in sugarcane management but its effects on quality parameters remain unclear. This task requires the application of advanced statistical techniques for an in-depth and detailed understandingil.

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The methodology of this study involved the detailed monitoring of experimental plots in the Milagro region, which is known for its tradition of sugarcane cultivation. Through a rigorous experimental design, different agronomic treatments were applied to evaluate their impact on key quality parameters, such as sucrose content (Pol), juice purity, and total soluble solids content (Brix). These parameters are of vital importance not only to determine sugar and ethanol yields but also to ensure the economic viability of the crop.

The present study focuse on evaluating the impact of agronomic management of sugarcane in Ecuador on the quality of the final product[4] , using multivariate analysis techniques such as PCA Biplot and MANOVA Biplots[8] to identify the main variables that influence crop quality. These techniques not only facilitate the identification of the variables that most influence quality but also make it possible to evaluate the effects of different management practices. These analyses are expected to shed light on the complex interactions that define sugarcane quality and provide a solid basis for the optimization of cultivation practices.

The results obtained through the PCA and MANOVA biplots provide detailed insights into how management practices impact sugarcane quality. This advanced statistical analysis is crucial for identifying the most beneficial and sustainable practices, pointing toward optimizing agronomic management that benefits both growers and the environment. Furthermore, these findings have the potential to contribute significantly to the scientific literature and agricultural practices, guiding future research and practical applications in this sector.

Methods

The experimental design was a completely randomized block design with five treatments and four replications per treatment. Each experimental plot consisted of six furrows, each 100 m long, with 1.5 m between furrows. A total of 72 samples were collected (5 treatments x 4 replications x 3 samples per replication). It was supplementally irrigated by gravity with approximately 1 600 3 /h with a frequency of 15 days until 9 months of cultivation. The experimental plots had six furrows per-100 m long and 1.5 m between furrows.

Five treatments, T1, T2, T3, T4, and T5, were applied in the range of 9 to 11 months of sugarcane cultivation, which implied that the plants were grown at 90, 75, 60, 60, 45, and 30 days before harvest. The treatments are listed in Table 1.

The trial was conducted with sampling in an agricultural field located in the Milagro canton, where agronomic characteristics such as weight, diameter, and height of the stalk, yield expressed in tons of sugar per hectare, sacks of sugar per ton of sugarcane, and analysis at CINCAE to determine pol, brix, and KTC, among others, were evaluated.

Sugarcane quality variables

Quality variables were determined by taking random samples from each experimental unit at 9, 9.5, 10, 10.5, and 11 months of crop age. Each sample consisted of ten primary, secondary, and tertiary stems, without considering "suckers" (shoots). The stems were taken to the chemistry laboratory of CINCAE to determine parameters related to juice quality.

Agronomic traits such as stalk weight, diameter, and height were measured manually using a digital scale and measuring tape. For quality parameters, sugarcane juice was extracted using a press method, and the following analyses were performed: sucrose content (Pol) was measured using a polarimeter, Brix was determined using a digital refractometer, and juice purity was calculated as the ratio of Pol to Brix multiplied by 100. For the analysis of sugarcane, the press method was used to defibrate the cane stalks and extract the juice. From the extracted juice, the percentage of °Pol (polarimeter method), moisture, fiber (gravimetric method), and purity were obtained from the ratio °Pol/brix multiplied by 100 (CINCAE 2023).

Statistical analysis

Data related to sugarcane quality variables were analyzed using multivariate statistical techniques, such as PCA Biplot and Manova Biplot, using R software version 4.3.1.

PCA biplot

Principal component analysis (PCA) was applied when the variables were continuous. The objective is to reduce the complexity of the dataset by representing the original matrix in a reduced dimension without losing its original information[9].

In addition to its main function, the PCA Biplot facilitates the analysis of relationships between variables, which are represented as vectors. These relationships were evaluated by considering the angles formed by each pair of variables. An acute angle suggests a direct correlation between the variables, whereas an obtuse angle indicates a direct correlation between the variables and an inverse relationship. On the other hand, right angles suggest linear independence between the variables[10,11].

Treatments	Age	Days before the harvest
T1	9.0	20/04/2021
T2	9.5	05/05/2021
T3	10.0	20/05/2021
T4	10.5	04/06/2021
T5	*11.0*	*19/06/2021*

Table 1. Treatments.

Axes	Own Value	Var. Explained	Cumulative Var.
1	2.40	83.49	83.49
2	1.01	15.01	98.5

Table 2. Eigenvalue explained variance and cumulative variance.

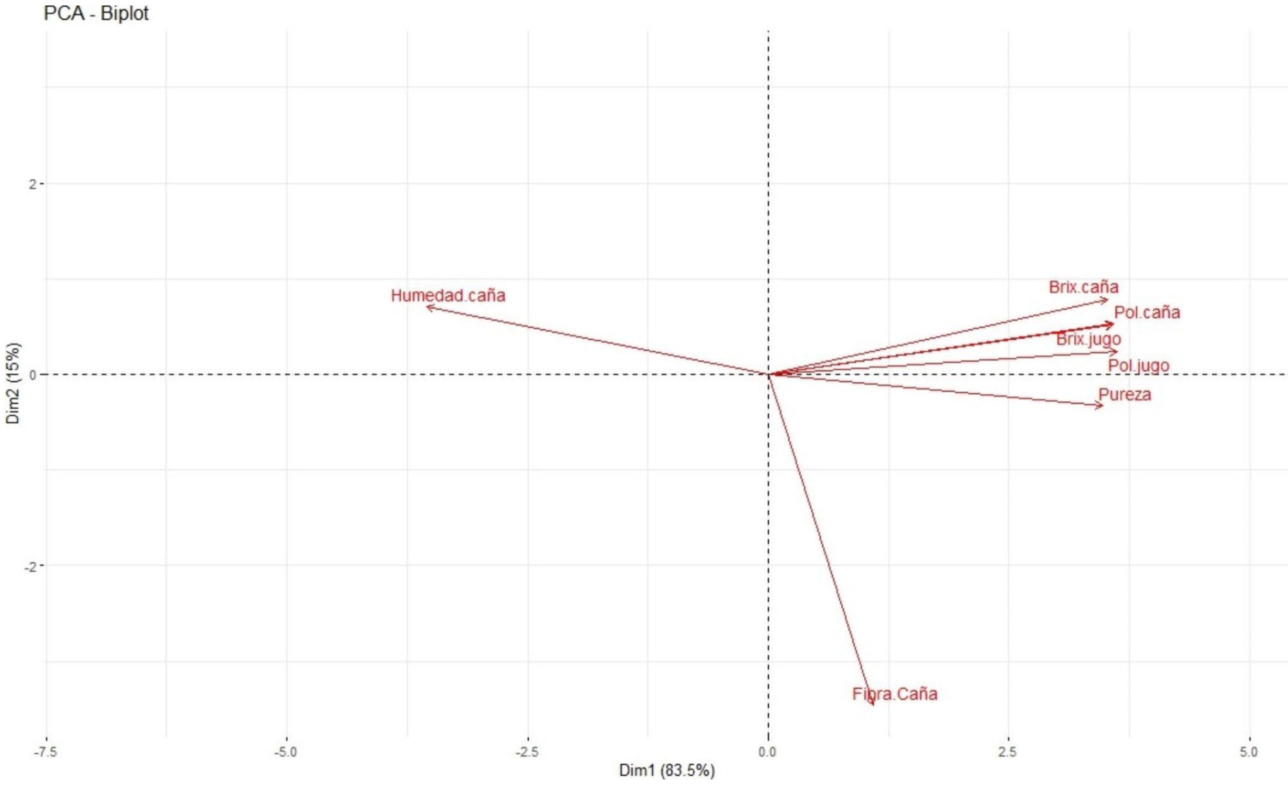

Fig. 1. PCA Biplot, variables, axes 1–2.

Manova biplot

The Canonical Biplot method is crucial for identifying key differences between groups and determining the variables that drive these distinctions[12,13]. It helps in the visualization of multivariate data, which facilitates the interpretation of complex results when dealing with numerous variables in MANOVA[14,15]. By using biplots, researchers can effectively analyze the relationships between variables and groups, improving the understanding of the underlying patterns in the data.

The use of canonical or Manova biplots is crucial in multivariate analysis, as it allows the exploration of complex relationships and highlights important variables that influence differences between groups.

Results and discussion

PCA biplot

A total of 72 sugarcane samples were analyzed, corresponding to five wilting treatments with four replications each. The PCA Biplot revealed a strong correlation between quality variables such as Brix, Pol, and juice purity, but no significant differences were observed among the wilting treatments. (Table 2), indicating that two axes are necessary to observe the characterization and quality of the 72 sugarcane samples.

In Fig. 1, the cumulative variance is 98.5%, and the cane quality variables are presented by vectors. The results showed a strong and direct correlation between sugarcane quality variables, such as Brix cane, pol cane, pol juice, and purity, which are related to different aspects of sucrose concentration and overall sugarcane quality. Brix measures the total concentration of soluble solids in the juice including sucrose, organic acids, and other substances. Pol refers specifically to the pure sucrose present, and purity is the ratio of Pol to the total soluble solids measured by Brix[16]. A strong and direct correlation between these indicators suggests that when sugarcane quality improves in terms of sucrose content (Pol), there is a corresponding increase in the concentration of total soluble solids (Brix) and thus in the purity of the extracted juice[17]. This was expected because sucrose is the main component of soluble solids in Sugarcane[18]. Measuring sucrose content, along with other soluble carbohydrates, such as water-soluble carbohydrates (WSC) and non-fibrous carbohydrates (NFC), is crucial for assessing the nutritional value of sugarcane for animal feed[19]. Understanding the inheritance patterns of sucrose accumulation and soluble solids content in cantaloupe can help in programs breeding to improve these traits[20]. In addition, co-crystallization of sugar beet and cane materials affects sugar quality, and the growth rate affects color inclusion in sucrose crystals[21].

A study of sugarcane clones found significant variations in sucrose content, and varieties with higher sucrose content produced higher sugar content. In addition, a two-point model using near-infrared spectrometers effectively calibrated sugar quality indicators, such as Brix and Pol, highlighting the importance of rapid and accurate assessment methods[16] . Sugarcane juice acidity parameters, including Brix, pH, and acidity levels, were evaluated to ensure quality standards[17]. Together, these findings emphasize the direct correlation between improved sucrose content (Pol) and higher soluble solid concentration (Brix), which ultimately improves the juice purity.

This indicates that the amount of fiber in sugarcane, which is a measure of the cellulosic and lignocellulosic components, is not directly related to the concentration of soluble solids[17,22]. Fiber does not contribute to soluble solids measured by Brix, which explains why there is no direct linear relationship between these two. This is related to the research of Ma[23] et al. (2022), who found that fiber content has no direct relationship with soluble solids measured by Brix in apples. Sugarcane yield and quality can be evaluated and optimized independently in terms of fiber content and concentration of sucrose and other soluble solids[7].

However, the analysis showed a strong inverse correlation between sugarcane moisture and purity; sugarcane moisture refers to the water content of the plant. An inverse correlation with purity indicated that as the water content increased, the relative sucrose concentration decreased (and vice versa), negatively affecting juice purity. This relationship has been highlighted by several studies. Wang Ji-huai's research on sugarcane varieties in the Zhanjiang area shows that as the ratio of apparent purity to gravity purity approaches 1, sugar content peaks, emphasizing the importance of purity in determining sucrose levels[24]. This is logical, as a higher water content dilutes soluble solids, including sucrose, decreasing the ratio of sucrose to total soluble solids, which reduces the purity of the extracted juice. Irrigation management and harvest timing are key aspects that can influence cane moisture content, and therefore, cane quality[25].

Figure 2 shows the PCA Biplot of the 72 sugarcane samples and the quality variables, the variance explained is 98.5%, and the groups were determined with the kmeans function of the stats package of R. Group 1 (red) shows the presence of 11 sugarcane samples that are best represented by the sugarcane moisture variable. Group 2 denotes the presence of 34 sugarcane samples with the highest correlation with the sugarcane fiber variable. Group 3 contained 26 sugarcane samples that correlated with variables such as Purity, Pol juice, pol cane, Brix juice, and Brix cane.

Group 1 was best represented by the variable "sugarcane moisture." This indicates that the 11 sugarcane samples in this group were mainly characterized by their water Content[26]. The study on sugarcane varieties under water deficit conditions found that different varieties showed significant differences in moisture-related parameters such as stomatal conductance, leaf transpiration and culm moisture content[27]. In addition, research on water stress at the tillering stage in sugarcane has identified genotypes with stable performance under drought conditions, highlighting the impact of water stress on biomass accumulation and yield[28]. These findings suggest

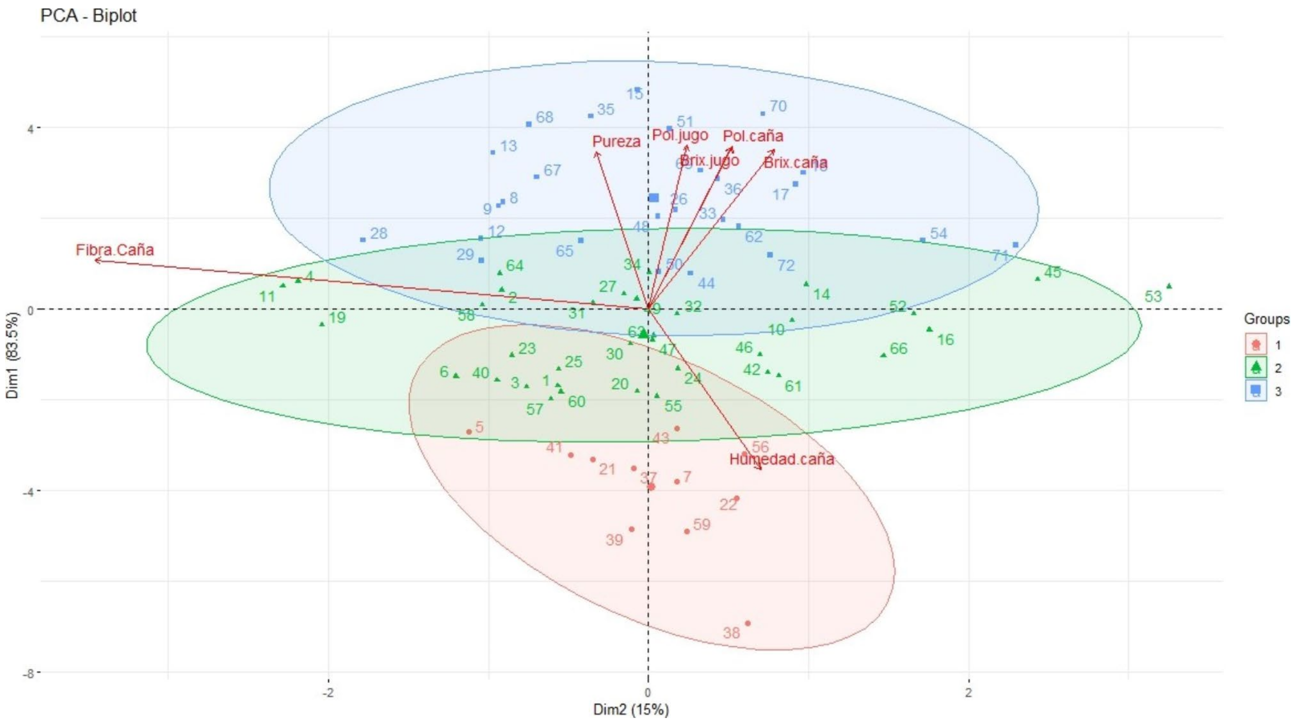

Fig. 2. Factor plot, PCA Biplot, samples and cane quality variables, axes 1–2.

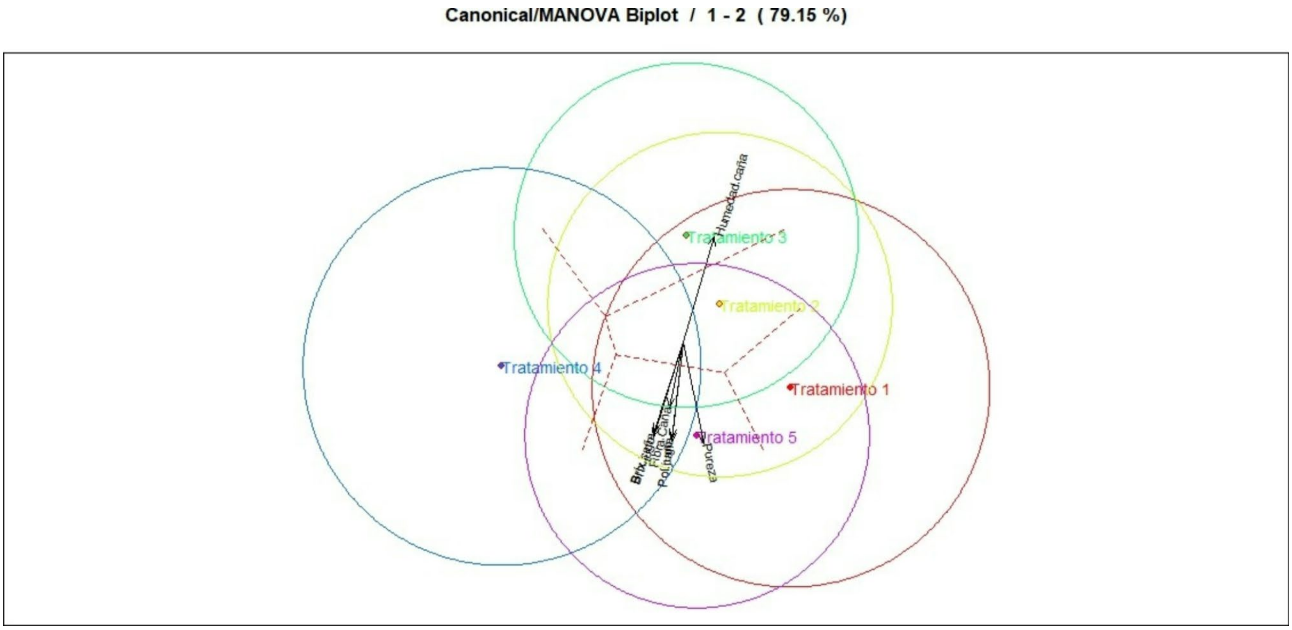

Fig. 3. Manova Biplot, axes 1–2.

that Group 1 samples could reflect sugarcane harvested under higher moisture conditions or during growth stages with elevated water content, aligning with the observed variations in moisture-related traits among different sugarcane varieties under different environmental conditions.

Group 2, composed of 34 samples, showed the highest correlation with "sugarcane fiber". The fiber content in sugarcane is a crucial quantitative trait that plays an important role in various applications. Research has shown that the fiber content in sugarcane is associated with markers identified through genome-wide association studies (GWAS)[29] . This group may represent sugarcane varieties that are naturally more fibrous or are at a growth stage that favors greater fiber development[29], and possibly more mature or harvested under conditions that affect plant fiber Composition[30].

Group 3, with 26 samples, probably represents sugarcane at its optimum quality for sugar production, with a high sucrose concentration and soluble solids, indicating ideal maturity and optimum growing conditions for sugar Production[18].

Manova biplot

The application of the Canonical Biplot (Vicente-Villardón, 1992) or Manova Biplo[31]offers a way to identify the main differences between groups and determine which variables are responsible for these discrepancies. This is essential because of the complexity of the results and their presentation when working with many variables in multivariate analysis of variance (MANOVA). The variability of the characteristics associated with the models and the interrelationships between the variables complicate the interpretation of the results.

The centers of the confidence regions are represented by dots that represent the means of the treatments. In the graphical methodology (Manova Biplot) to contrast the two treatments, significant differences were established when the circles did not overlap.

The Manova Biplot results offer valuable insights when applying the five treatments to the 72 sugarcane samplFig. ig. 3 shows that there are no significant differences in any of the sugarcane quality variables across the five different treatments. These results indicate that parched sugarcane at 90, 75, 60, 60, 45, and 30 days before harvest did not produce a significant impact on sugarcane quality, these findings are complemented by the research of Dalen[32] et al., (2022) which found no significant differences in sugarcane quality parameters when sugarcane was harvested at different intervals before the scheduled harvest date, suggesting that running out of sugarcane 90, 75, 60, 60, 45 and

Thirty days before harvest, there was no significant impact on sugarcane quality. However, several investigations have provided information on the impact of different factors on sugarcane quality. (1) It highlights the importance of potassium fertilizer in improving the growth, yield, and quality parameters of sugarcane[33]. (2) The effects of energy cane harvesting on different dates on biomass production and nutrient removal rates[32]. (3) Explore the quality differences between sugarcane and sweet sorghum juices[34]. (4) delves into the response of different sugarcane varieties to deficit irrigation[28]. This study highlights the importance of several factors, including nutrient management, harvest timing, and irrigation, in influencing sugarcane quality.

Research conducted on sugarcane cultivation under various treatments and conditions has provided valuable information on the impact of different practices on sugarcane quality. These studies explored the effects of potassium (K) fertilizer application rates, irrigation levels, and harvest times on sugarcane growth, yield, and quality parameters. The results of these experiments indicated that variations in irrigation levels and K fertilizer application rates significantly influenced growth, yield, sugar quality, and sugarcane insect pest incidence[35,36].

Limitations

This study has some limitations that should be considered. The research was conducted exclusively in the Milagro canton, Ecuador, which may limit the generalizability of the findings to other regions with different climatic and soil conditions. Additionally, only one sugarcane variety (CC-8592) was evaluated, which may restrict the applicability of the results to other varieties.

Conclusion

The study applied multivariate statistical analysis techniques, PCA Biplot and MANOVA Biplot, to evaluate how agronomic management affects sugarcane quality in Ecuador.

The results showed significant correlations between sugarcane quality and variables such as Brix, Pol, and Purity, without any notable impact of agronomic management practices on quality. These findings not only respond to the objective of this study, which is to evaluate the impact of agronomic management of the sugarcane crop in Ecuador on the quality of the final product by identifying management practices (to stop watering) with minimal or no influence on crop quality but also illuminate the complex interactions that define it. By shedding light on these interactions, this study provides a solid basis for optimizing cultivation practices.

The study concludes that pre-harvest wilting time (90, 75, 60, 45, and 30 days before harvest) does not significantly impact key sugarcane quality variables, such as Brix, Pol, and juice purity, under the conditions in Milagro canton. These findings suggest that other agronomic practices, such as fertilization and irrigation management, may have a greater influence on sugarcane quality. Future research should explore these factors to optimize sugarcane production in Ecuador.

Data availability

The datasets used and analyzed during the current study are available from the corresponding author upon reasonable request.

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C.A.S. Supervision, conceptualization, project administration, investigation, and writing – review & editing.D.P.G. Data curation, methodology, formal analysis, visualization, software usage, validation, and writing – original draft.P.A.M. Conceptualization, investigation, and writing – review & editing.F.P.O. Conceptualization, supervision, and writing – review & editing.

Declarations

Competing interests
The authors declare no competing interests.

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