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Comparative Assessment of Extraneous Matter Contamination and Juice Quality in Sugarcane Harvested Using Manual and Mechanical Loading Systems at Blairmont Estate, Guyana

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Abstract
Sugarcane delivered to processing factories contains variable quantities of non-stalk material that may influence cane quality and factory handling. This study evaluated two field systems at Blairmont Estate, Guyana: manual cutting followed by hand loading, and manual cutting followed by mechanical loading using a Bell loader. A randomized complete block arrangement with three field replications per system was reported for a second-ratoon crop of cultivar DB96-33, approximately 51 weeks old, in Follow Smith Field 51. Composite samples were collected from each punt and separated into cleaned cane and cane retained with extraneous matter (EM). Trash, tops and soil were quantified, while juice Brix, Pol and purity were determined. The mechanical-loading system had higher descriptive means for trash (3.52%), tops (4.78%) and soil (1.26%) than hand loading (0.98%, 1.79% and 0.14%, respectively); however, reported treatment tests were not significant for trash (p = 0.1061), tops (p = 0.2559) or soil (p = 0.4070). This study reported factorial ANOVA identified system effects for Pol (15.305% manual; 13.563% mechanical loading; p = 0.0281) and purity (78.812% and 72.230%; p = 0.0464), while Brix did not differ significantly (p = 0.2712). Cane category effects were also reported for Pol (p = 0.0419) and purity (p = 0.0259), but not Brix (p = 0.7659). No interaction was detected for any juice-quality variable. These findings indicate that the tested mechanical-loading system was associated with lower mean Pol and purity, although inference is limited by three field replicates, one field and cultivar, and unresolved pairing in the original factorial model. The experiment did not measure commercial sugar recovery, factory extraction or operational costs. A larger, multi-field study with punt-level repeated-measures analysis and standardised analytical protocols is required before estate-wide recommendations are made.

Keyword: *Saccharum* spp., Guyana, Brix, Pol, Bell loader, extraneous matter, cane loading, purity, sugarcane quality

1. Introduction

1.1 Sugarcane Production and the Importance of Delivered-Cane Quality

Sugarcane (*Saccharum* spp.) is an economically important tropical and subtropical industrial crop, serving as a major feedstock for sugar production and several associated industrial products, including bagasse-derived energy, molasses, ethanol and other bio-based products. The economic contribution of sugarcane production extends beyond agricultural output because the performance of the industry depends on the efficiency and coordination of activities throughout the production and processing chain. These activities include crop establishment, agronomic management, harvesting, loading, transportation, cane preparation and factory extraction. Li and Yang (2015) [13] highlighted the importance of integrating sugarcane

agriculture with industrial processing and the utilisation of associated products, while Teixeira *et al.* (2023) [24], in their review of sugarcane supply-chain optimisation, demonstrated that operational efficiency depends on coordinated planning across harvesting, transportation and industrial processing. These perspectives indicate that improving sugar production requires attention not only to field productivity but also to the quality and efficiency of the processes through which harvested cane is delivered and processed.

In Guyana, sugar production has historically contributed substantially to national employment, rural livelihoods and export earnings. Nevertheless, the industry has experienced persistent structural and operational difficulties, including declining productivity, labour constraints, deteriorating infrastructure and challenges in maintaining competitive production costs. The Commission of Inquiry into the Guyana Sugar Corporation (2015) [4] documented operational and institutional weaknesses affecting the industry, while the Ministry of Agriculture (2017) [18] highlighted declining production, labour shortages and deteriorating field and factory performance as major concerns requiring operational reform. These challenges are particularly important for estates such as Blairmont, where maintaining an appropriate balance between labour availability, harvesting capacity and factory supply is essential.

Harvesting efficiency and delivered-cane quality are closely interconnected. Ahmed and Alam-Eldin (2015) [1], in their comparative evaluation of manual and mechanical sugarcane harvesting at Sennar Sugar Factory in Sudan, demonstrated that mechanisation could reduce harvesting costs and improve loading efficiency, although mechanical harvesting was associated with higher trash content than manual harvesting. Their findings illustrate an important operational trade-off: improvements in harvesting capacity and labour efficiency do not necessarily translate into improved delivered-cane cleanliness. Similarly, Ma *et al.* (2014) [14] emphasised that harvesting performance is influenced by machine configuration, operating conditions and crop characteristics, all of which can affect the quality of harvested material. Consequently, the assessment of harvesting and loading practices should consider both operational performance and the physical and chemical quality of cane delivered to the factory.

The importance of delivered-cane quality is therefore not restricted to the quantity of cane supplied to the factory. The proportion of sucrose-bearing stalk material relative to non-stalk components can influence the composition of the raw material entering the processing system. Variations in cane cleanliness may also influence subsequent juice extraction and clarification requirements. Although the studies by Ahmed and Alam-Eldin (2015) [1] and Ma *et al.* (2014) [14] provide useful evidence concerning harvesting-system performance, their findings predominantly relate to broader harvesting technologies and operational mechanisms rather than specifically isolating mechanical loading following manual cutting. This distinction is important for interpreting estate-level operational comparisons. Accordingly, an assessment of the relationship between loading practices, extraneous matter contamination and juice quality under actual commercial field conditions is warranted to provide evidence relevant to the operational requirements of Guyana's sugar industry.

1.2 Extraneous Matter: Definitions and Operational Significance

Extraneous Matter (EM) refers to non-stalk materials accompanying harvested sugarcane during cutting, loading and transportation to the processing factory. Depending on the harvesting system and the operational conditions under which cane is collected, these materials may include immature cane tops, green and dry leaves, trash, soil particles and other foreign materials. In the present investigation, EM was classified into three principal components: tops, trash and soil. These components are important because they differ in their physical and chemical characteristics and may influence cane composition, juice quality and factory processing in different ways. Consequently, evaluating EM as a single aggregate measurement may obscure the individual contributions of its constituent materials.

The effects of vegetal impurities and mineral contamination on sugarcane processing have been demonstrated in several experimental investigations. Larrahondo *et al.* (2009) [12], examining conventional and mechanical harvesting systems in Colombia, reported that extraneous matter contributed to post-harvest sucrose losses and influenced the quality of cane delivered to the factory. However, their findings also indicated that contamination levels were influenced by the interaction between harvesting practices and sugarcane variety, suggesting that the effects of EM are not necessarily uniform across production systems. Eggleston *et al.* (2010) [7] further demonstrated that the individual tissue components accompanying harvested cane differ in their clarification behaviour. Their investigation of green leaves, dry leaves, growing-point regions and stalk tissues showed that vegetal impurities could increase juice colour, turbidity, suspended particles and clarification difficulties. Importantly, the effects differed according to tissue type, demonstrating that the quality and composition of impurities may be as important as their total quantity.

Mineral contamination presents a different processing challenge from vegetal impurities. Bakir *et al.* (2016) [2] investigated the flocculation properties of soil impurities entering sugar factories and demonstrated that clay mineral composition, particle size and cation-exchange characteristics influenced juice clarification and settling behaviour. Their findings suggest that the impact of soil contamination depends not simply on the mass of soil entering the factory but also on its mineralogical and physicochemical properties. This contrasts with the effects of vegetal materials, which may contribute additional fibre, colour precursors and soluble non-sucrose constituents. Thus, the separate assessment of soil, tops and trash provides a more informative understanding of contamination than an overall EM percentage alone.

Experimental evidence has also demonstrated that the consequences of extraneous matter depend on the harvesting operation and the composition of the contaminants. Hoi and Martincigh (2012) [8], using controlled additions of different cane impurities, reported that dry leaves produced substantial adverse effects on sugar recovery, while cane tops and green leaves influenced juice composition and subsequent processing through different mechanisms. Similarly, Martins and Ruiz (2020) [15] demonstrated that operational conditions during mechanised harvesting influenced the composition of impurities entering harvested cane. Higher harvester displacement speeds increased vegetal impurities, whereas lower cutting heights increased mineral contamination. These findings illustrate that vegetal and mineral impurities may

respond differently to operational adjustments and should therefore be evaluated independently.

Comparative field evidence further supports the importance of distinguishing contamination components. Chaudhary *et al.* (2023) [3], investigating manual and mechanical harvesting across six locations in northern India, reported higher mean trash and green-top content in mechanically harvested cane than in manually harvested cane, together with differences in sugar-recovery indicators. However, their findings were obtained from mechanical harvesting operations involving cutting and associated harvesting mechanisms and therefore cannot be directly equated with a system in which cane is manually cut and subsequently loaded using a mechanical loader. Complementing these findings, Roussel *et al.* (2021) [22], through laboratory-scale simulations of sugarcane processing, demonstrated that increasing the quantities of tops and green leaves could adversely affect juice composition, increase clarification requirements and increase the risk of evaporator fouling. Collectively, these studies demonstrate that the operational significance of EM depends on its composition, quantity and interaction with factory processing conditions. They also justify the separate quantification of trash, tops and soil when evaluating the effects of different loading practices at Blairmont Estate.

1.3 Harvesting and Loading Technology

Sugarcane harvesting systems have evolved to address challenges associated with labour availability, field productivity and the timely delivery of harvested cane to processing factories. Broadly, harvesting operations may involve burnt-cane or green-cane practices and manual or mechanical harvesting approaches. Mechanical harvesting systems may operate through whole-stalk or chopper-harvesting configurations and incorporate mechanisms for base cutting, stalk feeding, topping, cleaning and material discharge. Ma *et al.* (2014) [14], in their critical review of commercial sugarcane harvester technology, identified base-cutting and feeding mechanisms as major determinants of harvesting efficiency, stalk damage, billet quality and the amount of extraneous material retained in harvested cane. Their review emphasised that machine performance depends on both engineering design and operational adjustment, suggesting that mechanisation alone does not guarantee improved raw-material quality.

Comparative evaluations of manual and mechanical harvesting have demonstrated that these systems involve different operational advantages and limitations. Ahmed and Alam-Eldin (2015) [1] reported that mechanical harvesting at Sennar Sugar Factory reduced harvesting costs and increased the quantity of cane loaded per trailer compared with manual harvesting. However, mechanical harvesting also produced higher trash percentages, illustrating the potential conflict between operational efficiency and cane cleanliness. Similarly, Chaudhary *et al.* (2023) [3] reported greater extraneous matter content in mechanically harvested cane compared with manually harvested material across several locations in India. Their investigation also demonstrated that separating the cane portion from accompanying tops, trash and cut material was important when evaluating the resulting quality and sugar-recovery differences. Nevertheless, these studies primarily compared complete manual and mechanical harvesting systems, whereas the present investigation concerns a narrower operational comparison.

The influence of machine operation on harvested-cane quality has also been examined at the level of individual operating parameters. Martins and Ruiz (2020) [15] demonstrated that increased displacement speed during mechanised harvesting was associated with greater vegetal impurity content, whereas reduced cutting height increased mineral impurities. These findings suggest that contamination may be influenced by adjustable operational characteristics rather than being an unavoidable consequence of machinery use. Meert *et al.* (2020) [17], examining quantitative and qualitative sugarcane losses under different harvesting methods and cultivars, further demonstrated that both harvesting method and varietal characteristics should be considered when interpreting field losses. Together, these investigations highlight the importance of distinguishing between the effects of harvesting technology, crop characteristics and machine operating conditions.

Beyond contamination of harvested cane, mechanised field operations may also influence soil physical conditions through machinery traffic and loading pressures. Zhao *et al.* (2019) [27] demonstrated that small-scale mechanical harvesting and tractor-related soil compaction could adversely affect early sugarcane growth. Similarly, Delmond *et al.* (2024) [6] investigated the contribution of mechanised harvesting operations to soil compaction and identified machinery traffic as an important factor influencing soil physical conditions. Although soil compaction is distinct from soil contamination in delivered cane, these studies demonstrate that the adoption of mechanical equipment should be evaluated in relation to both crop-quality and field-management considerations.

Importantly, the operational contrast investigated at Blairmont Estate does not represent a comparison between completely manual harvesting and fully mechanised harvesting. Both treatments involved manual cutting, with the principal difference occurring during the loading operation: manual cutting followed by hand loading compared with manual cutting followed by mechanical loading using a Bell loader. Consequently, the findings should be interpreted in relation to the loading systems examined rather than attributed to mechanical base cutting, topping or extractor-fan cleaning mechanisms. This distinction is particularly important when comparing the present investigation with studies involving conventional mechanical harvesters. Although previous research has established that mechanical harvesting can influence extraneous matter contamination and cane quality, comparatively less estate-specific information is available concerning the contribution of mechanical loading following manual cutting. Assessing this operational contrast is therefore important for determining whether the use of a Bell loader is associated with differences in delivered-cane cleanliness and juice-quality characteristics under Blairmont Estate conditions.

1.4 Cane juice quality: Brix, Pol and Purity

The assessment of sugarcane juice quality commonly involves the determination of Brix, Pol and purity, which provide complementary information concerning the soluble-solids composition and apparent sucrose content of extracted juice. Brix represents the refractometric estimate of total dissolved solids in juice and therefore includes sucrose and non-sucrose soluble constituents. Pol represents the apparent sucrose content determined through polarimetric analysis under specified analytical conditions, while apparent purity

is calculated as the ratio of Pol to Brix multiplied by 100. Consequently, purity provides an indication of the proportion of total soluble solids represented by apparent sucrose. These measurements are related but should not be interpreted as interchangeable indicators of cane quality.

The relationship between these parameters has been demonstrated through investigations examining temporal and compositional variations in sugarcane juice. Xiao *et al.* (2017) [25], analysing juice-quality characteristics throughout the crushing season in Guangxi, China, reported changes in Brix, polarization, apparent purity, sucrose content and reducing sugars associated with crop maturity and seasonal conditions. Their findings demonstrated that Brix, Pol and purity may vary together during certain stages of maturity but do not necessarily respond identically to environmental and physiological changes. In particular, increases in reducing sugars associated with late-season quality deterioration illustrated why Brix alone may be insufficient for characterising the sucrose-related quality of cane juice.

The reliability of juice-quality measurements also depends on the analytical procedures used for sample preparation and determination. ICUMSA Method GS5-1 (2022) provides an official analytical procedure for determining polarimetric sucrose content, dissolved solids and fibre in prepared cane and bagasse using visible polarimetry following clarification and refractometry. In comparison, ICUMSA Method GS5-2 (2024) describes an official reference procedure for cane prepared using a hydraulic press, combining polarimetry, refractometry and gravimetry. The latter method is particularly relevant to studies employing hydraulic pressing for juice extraction. However, the two methods differ in their specified analytical approaches, and their applicability depends on the actual laboratory preparation and measurement procedures employed.

Research investigating alternative analytical and sampling approaches has further demonstrated the importance of methodological consistency. Nawi *et al.* (2014) [21] examined the use of portable visible and shortwave near-infrared spectroscopy to predict Pol and Brix from clear and raw sugarcane juice samples. Their findings demonstrated the potential of spectroscopic techniques for rapid assessment, although predictive accuracy depended on the type of juice sample analysed. Similarly, Mat *et al.* (2014) [14] investigated the prediction of sugarcane quality parameters using visible-shortwave near-infrared spectroscopy applied directly to cane internodes and reported promising predictive performance for Brix, fibre and moisture content. More recently, Corrêdo *et al.* (2021) [5] compared different sample-preparation and scanning strategies for predicting sugarcane quality using visible and near-infrared spectroscopy. Although their results supported the potential for reduced-preparation quality monitoring, they also demonstrated that the sample preparation approach influences predictive performance and the interpretation of quality measurements.

These studies collectively demonstrate that sugarcane juice quality is influenced by crop maturity, sample composition and analytical methodology. While alternative spectroscopic approaches may facilitate rapid quality assessment, conventional refractometric and polarimetric measurements remain important for laboratory determination and comparison with established reference procedures. In the present investigation, Brix was determined using a refractometer, Pol was measured following juice clarification and polarimetric analysis, and purity was calculated from the relationship between Pol and Brix. The use of these complementary indicators enables an assessment of whether observed differences in loading system and cane cleanliness are associated with changes in total soluble solids, apparent sucrose content and the relative proportion of sucrose within the soluble-solids fraction.

1.5 Post-Harvest Deterioration and Factory Implications

Sugarcane is a highly perishable agricultural raw material, and its quality can deteriorate following cutting because of physiological, enzymatic and microbial processes. The interval between harvesting and factory processing is particularly important because sucrose inversion and microbial activity may progressively alter the chemical composition of cane and extracted juice. Solomon (2009) [23] identified harvest-to-mill delay, ambient temperature, humidity, cultivar, cane maturity and storage conditions as important factors influencing post-harvest deterioration and sucrose losses. These processes can contribute to reduced recoverable sucrose and create additional difficulties during industrial processing. Misra *et al.* (2022) [19], in their review of post-harvest sugarcane biology and storage technologies, similarly emphasised the importance of managing the interval between cutting and crushing to reduce primary and secondary sucrose losses. Their review further identified microbial proliferation and the production of metabolites such as dextran as important contributors to deterioration and processing difficulties.

Experimental investigations have provided additional evidence that deterioration depends on both storage conditions and the duration of post-harvest handling. Yusof *et al.* (2000) [26], examining delayed juice extraction and storage, demonstrated that storage conditions and temperature influenced the physicochemical characteristics of sugarcane juice, including sugar composition, acidity, colour and microbial characteristics. More recently, Muhtadi *et al.* (2024) [20] evaluated the effects of sugarcane variety and milling delay on cane and sugar yield. Their study demonstrated that the magnitude of deterioration differed among varieties and that delays of up to four days were associated with reductions in stalk weight, juice quality and sugar yield compared with immediate processing. These findings indicate that post-harvest deterioration is not determined solely by elapsed time but may also depend on varietal characteristics and the conditions under which harvested cane is handled and stored.

The relationship between harvesting practices and post-harvest deterioration has also been investigated in relation to dextran formation. Kouzi and Kontro (2024) [11], examining sugarcane cultivar Co 6806, reported that the duration of post-harvest delay was more influential in dextran accumulation than the harvesting practices evaluated. Their findings suggested that harvesting conditions, including burning and stalk chopping, may contribute to deterioration risk, but the interval between harvesting and processing remains a particularly important factor requiring management. This interpretation is consistent with Solomon (2009) [23] and Misra *et al.* (2022) [19], although the specific magnitude of deterioration may differ among cultivars and production environments.

Beyond sucrose deterioration, the presence of extraneous matter may create additional challenges during factory processing. Hoi and Martincigh (2012) [8] demonstrated that different vegetal impurities, particularly dry leaves, green leaves and cane tops, exerted different effects on juice extraction, sucrose losses and milling performance.

Similarly, Roussel *et al.* (2021) [22], using laboratory simulations of sugarcane processing, reported that increased quantities of tops and green leaves adversely affected juice and syrup composition, increased lime requirements and elevated the potential for evaporator fouling. These findings indicate that the effects of extraneous matter extend beyond the initial quality of extracted juice and may influence subsequent clarification and processing operations. Nevertheless, the magnitude of these effects depends on the composition and quantity of the contaminants and the characteristics of the factory processing system.

Although previous studies have established important relationships between post-harvest deterioration, extraneous matter contamination and factory performance, these processes should be distinguished when interpreting the results of the present investigation. The Blairmont Estate experiment focused on the measurement of trash, tops and soil and the laboratory determination of Brix, Pol and purity in cleaned and extraneous-matter-containing cane samples. It did not directly investigate the effects of storage duration, microbial activity, dextran formation, commercial cane sugar (CCS), factory extraction efficiency or actual sugar recovery. Consequently, post-harvest deterioration and factory-processing effects provide important scientific context for understanding the potential operational significance of cane quality, but they cannot be treated as mechanisms or outcomes directly demonstrated by this experiment. The present study therefore provides an initial assessment of the relationship between loading practices, extraneous matter contamination and laboratory juice-quality characteristics under the operational conditions of Blairmont Estate.

1.6 Research Gap, Rationale and Objectives

Although mechanisation has been introduced in sugar industries to address labour and operational constraints, there is a need for estate-specific evidence on the relationship between the actual loading systems used, delivered-cane contamination and juice quality. This study identifies a lack of local comparative measurements at Blairmont Estate. A field-based comparison can provide an initial indication of whether hand loading and Bell-loader loading differ in the levels of trash, tops and soil associated with cane and whether juice quality differs between cleaned and EM-containing cane.

The objectives were to: (i) quantify trash, tops and soil associated with the two operational systems; (ii) compare Brix, Pol and purity between systems; and (iii) compare juice quality in cleaned cane and cane retained with EM. The null hypotheses were that the operational system would not affect EM or juice quality, and that cane category would not affect juice quality. Given the small number of field replicates, the study was designed as a preliminary estate-level evaluation rather than a definitive assessment of all harvesting systems used in Guyana.

1.7 Theoretical Framework

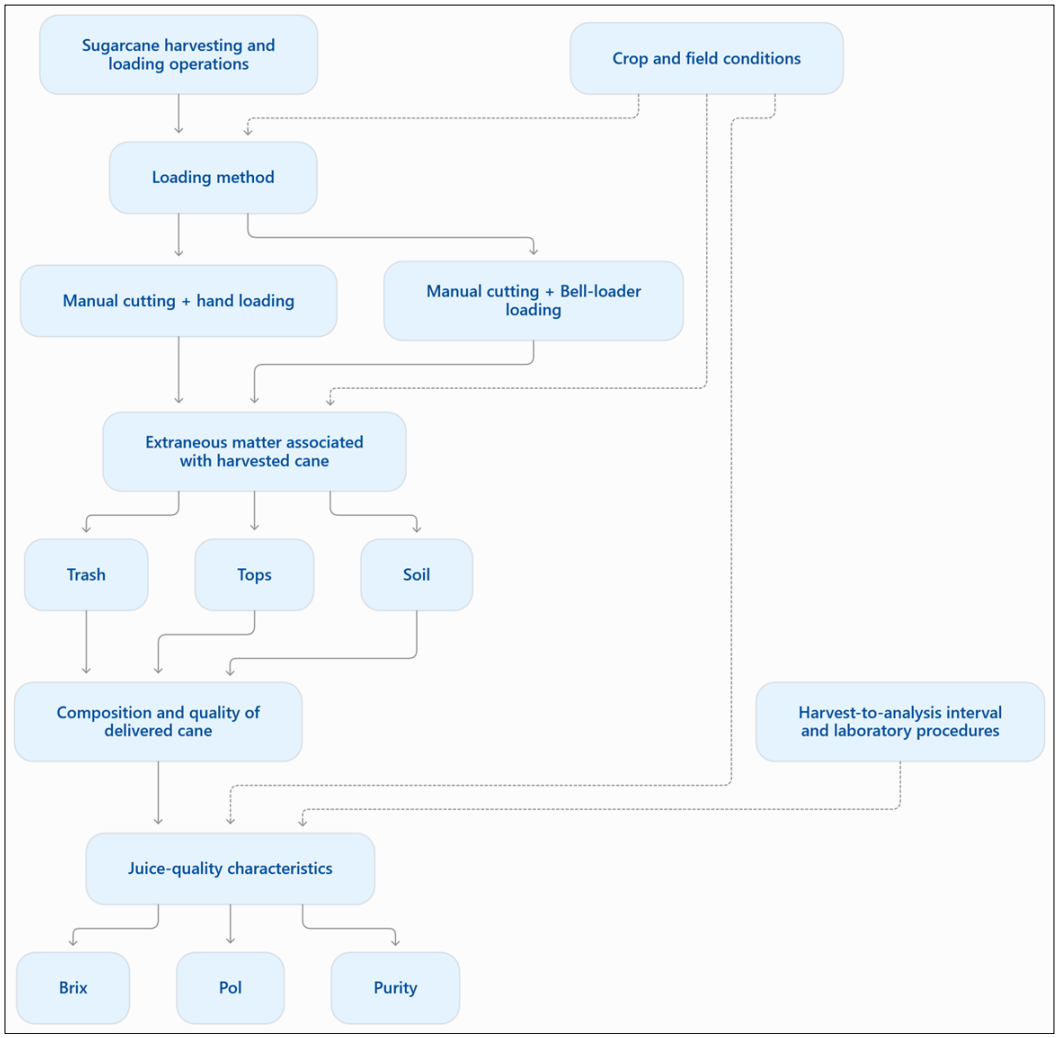


Fig 1: Theoretical framework illustrating the relationship between sugarcane loading systems, extraneous matter contamination and juice quality

The theoretical framework (Figure 1) illustrates the proposed relationship between sugarcane loading systems, extraneous matter contamination and juice quality. It establishes the premise that the method used to load harvested sugarcane may influence the amount of non-stalk material, including trash, tops and soil, accompanying the cane. These contaminants may subsequently be associated with variations in juice-quality characteristics, particularly Brix, Pol and purity. The framework also recognizes that crop and field conditions, harvest-to-analysis intervals and laboratory procedures may influence the observed results. It therefore provides the scientific basis for investigating whether differences in loading operations are associated with variations in extraneous matter content and the quality of sugarcane juice.

1.8 Conceptual Framework

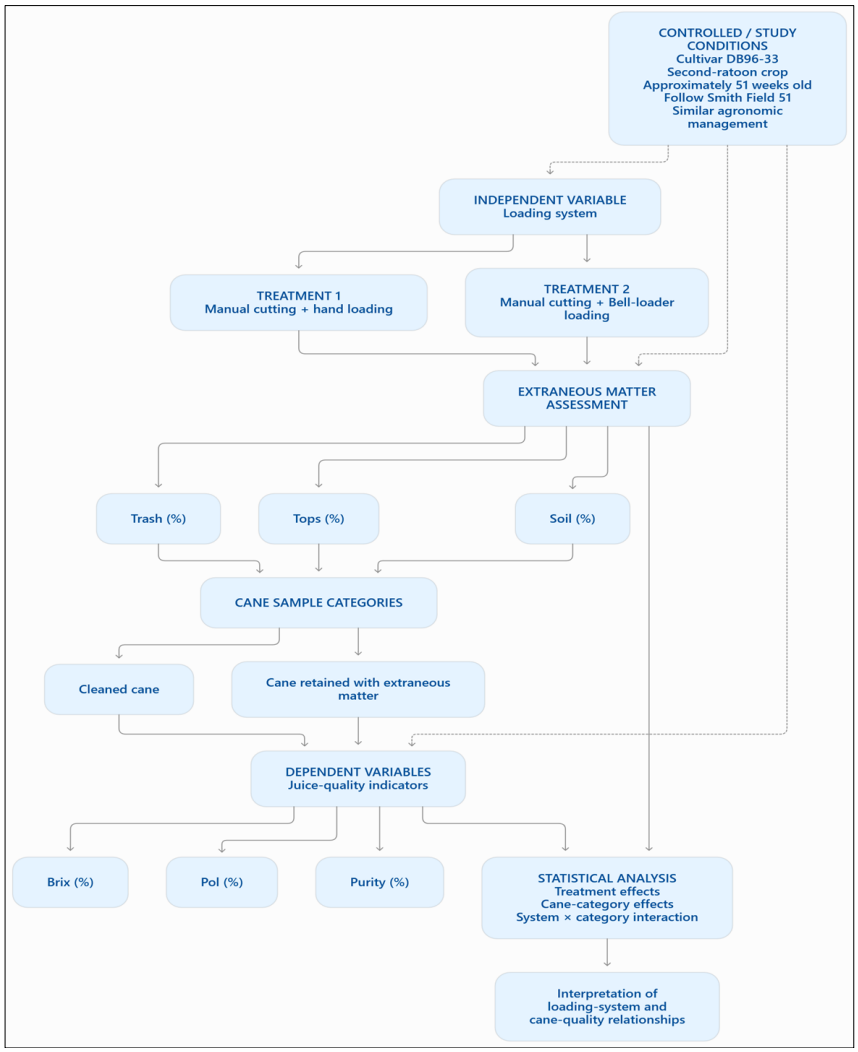


Fig 2: Conceptual framework of the independent, sample-category and dependent variables in the assessment of sugarcane loading systems at Blairmont Estate, Guyana

The conceptual framework (Figure 2) translates the theoretical relationships into the specific variables and experimental procedures used in this investigation at Blairmont Estate, Guyana. Loading system represents the independent variable, comprising manual cutting followed by hand loading and manual cutting followed by mechanical loading using a Bell loader. Extraneous matter was assessed through the measurement of trash, tops and soil, while the cane samples were classified into cleaned cane and cane retained with extraneous matter. The dependent variables were Brix, Pol and purity, which were determined through laboratory analysis. Statistical analysis was subsequently used to examine the effects of loading system, cane category and their interaction on juice quality. Collectively, the framework demonstrates how the research variables were operationalised to evaluate the relationship between loading practices, cane cleanliness and juice-quality characteristics.

2. Materials and Methods

2.1 Study Site and Crop Description

Table 1: Study site and crop characteristics

Characteristic	Crop Characteristic
Study location	Blairmont Estate, West Bank Berbice, Guyana; Follow Smith (F/S) Field 51
Coordinates	6.266531° N, 57.614534° W
Cultivar	DB96-33
Crop stage	Second ratoon (2R)
Crop age	Approximately 51 weeks at harvest
Soil type	Onverwagt Clay, soil series 41
Field layout / drainage	Dutch-layout drainage system
Pre-harvest burning	10 April 2026

As shown on Table 1, the experiment was conducted at Blairmont Estate, West Bank Berbice, Guyana, in Follow

Smith (F/S) Field 51 (reported coordinates 6.266531° N, 57.614534° W). The field was selected because the crop stand was considered relatively uniform and suitable for the operational treatments. The crop was a second-ratoon (2R) stand of cultivar DB96-33, approximately 51 weeks old at harvest, established on Onverwagt Clay (soil series 41) under a Dutch-layout drainage system. The agronomic management was similar across experimental plots. Detailed soil chemical properties, field elevation, rainfall and soil moisture at harvest were not considered in this study.

2.2 Pre-Harvest Preparation: The field was burnt on 10 April 2026 before harvesting, following the estate's reported operational practice (Table 1). A pre-harvest assessment was undertaken to estimate available cane. Plot identification boards were installed, punts were labelled by treatment and replication, and care was taken to maintain sample identity during loading and transport. The exact harvest date, time of day and meteorological conditions at harvest were not considered in this study.

2.3 Treatments and Experimental Design: Two treatments were compared in this study (Table 2). T_1 consisted of manual cutting followed by hand loading. T_2 consisted of manual cutting followed by loading with a Bell loader. Both systems therefore involved manual cutting; the treatment contrast primarily represented the loading operation. The field design was described as a randomized complete block design with two treatments and three replications. Each punt was designated as the experimental unit. The punt capacity was reported as 21.12 m³.

Table 2: Experimental treatments, punt characteristics and actual sample collection

Parameter	T_1: Manual cutting + hand loading	T_2: Manual cutting + Bell-loader loading
Cutting operation	Manual	Manual
Loading operation	Hand loading	Mechanical loading using Bell loader
Field design	RCBD; 3 blocks/replications	RCBD; 3 blocks/replications
Experimental unit	One sugarcane punt	One sugarcane punt
Punt capacity	21.12 m³	21.12 m³
Mean cane weight per punt	3.84 t	3.62 t
Total cane weight across 3 punts	11.52 t	10.86 t
Mean composite sample per punt	61.06 kg	60.15 kg
Total composite sample across 3 punts	183.18 kg	180.45 kg
Subsampling procedure	10 subsamples per punt, taken from different positions including upper, middle and lower load layers	Same procedure

An average of 3.84 t cane per punt for T_1 (11.52 t across three punts) and 3.62 t per punt for T_2 (10.86 t total). The corresponding composite samples averaged 61.06 kg and 60.15 kg per punt, respectively. Ten subsamples were collected from different locations within each punt, including upper, middle and lower portions of the load, and combined to form a composite sample.

2.4 Sample handling and cane categories

Table 3: Sample categories and laboratory analytical procedures

Stage / Measurement	Procedure
Composite sample handling	Ten subsamples from different positions in each punt were combined into a composite sample; samples were transported to Blairmont Field Laboratory
Cane categories	Each punt composite was divided into cleaned cane (tops, trash and soil removed) and cane retained with extraneous matter
Extraneous matter	Tops, trash and soil were separated and weighed individually; percentages calculated relative to initial sample mass
Fibre preparation	Each category was shredded using a Jeffco Cutter laboratory mill; mixed in a catchment pan; 600 g fibre sample weighed
Juice extraction	Hydraulic press operated at 10,000 psi
Brix	20 mL juice placed on refractometer prism and soluble-solids reading recorded
Pol	200 mL juice clarified with 20 g Octapol, filtered through Whatman No. 91 filter paper and analysed using an automatic polarimeter; Smith table used to derive Pol
Purity	Calculated as (Pol % ÷ Brix %) × 100

Composite samples were transported to the Blairmont Field Laboratory. Each composite was separated into two sample categories: cleaned cane, from which tops, trash and soil were removed, and cane retained with its extraneous matter. The removed EM components were weighed separately. The two categories were processed independently for juice-quality assessment. Importantly, these two categories were derived from the same punt composite; they are paired subsamples within the same field experimental unit, not independent field replications (Table 3).

2.5 Quantification of extraneous matter

Table 4: Replicate-level extraneous matter measurements by loading treatment

Treatment	Replication	Trash (%)	Tops (%)	Soil (%)
T_1: Manual + hand loading	1	1.05	2.40	0.27
T_1: Manual + hand loading	2	0.83	0.99	0.08
T_1: Manual + hand loading	3	1.07	1.97	0.08
T_2: Manual + Bell-loader	1	3.57	2.37	3.54
T_2: Manual + Bell-loader	2	4.94	7.49	0.18
T_2: Manual + Bell-loader	3	2.06	4.48	0.07

Trash, tops and soil were weighed separately using the laboratory balance. Component percentage was calculated as the component mass divided by the initial sample mass, multiplied by 100. Total EM percentage was calculated as the sum of the measured EM component masses divided by initial sample mass, multiplied by 100 (Table 4).

2.6 Laboratory preparation and juice extraction: Each cane category was shredded using a Jeffco Cutter laboratory mill. The shredded material was mixed in a catchment pan to improve homogeneity, after which a 600 g fibre sample was weighed. Juice was extracted using a hydraulic press operated at 10,000 psi. The extracted juice was used for Brix and Pol measurements (Tables 5 and 6). This study does not provide details of instrument model numbers, calibration dates, duplicate determinations, reference materials, analytical temperature or quality-control acceptance criteria.

2.7 Brix, Pol and purity determination

Table 5: Juice-quality means by loading system and cane category

Response variable	Manual + hand loading	Manual + Bell-loader loading	Cleaned cane mean	Cane retained with EM mean
Brix (%)	19.383	19.133	19.500	19.017
Pol (%)	15.305	13.563	15.218	13.650
Purity (%)	78.812	72.230	79.388	71.653

For Brix, 20 mL of juice was placed on a refractometer prism, and the soluble-solids reading was recorded. For Pol, 200 mL of juice was clarified with 20 g of Octapol and filtered through Whatman No. 91 filter paper. The clarified juice was analysed using an automatic polarimeter (Tables 5 and 6). The report states that a Smith table was used in deriving the Pol percentage. Purity was calculated using Purity (%) = [Pol (%) / Brix (%)] × 100.

Table 6: Juice-quality means for each loading-system × cane-category combination

Juice-quality variable	Manual + hand loading: Cleaned cane	Manual + hand loading: Cane with EM	Bell-loader: Cleaned cane	Bell-loader: Cane with EM
Brix (%)	19.63	19.13	18.70	18.90
Pol (%)	16.00	14.61	14.43	12.69
Purity (%)	81.51	76.10	77.26	67.20

For future reproducibility, the analytical protocol should be mapped explicitly to an ICUMSA method. GS5-1 (2022) is an official method using VIS-polarimetry after clarification and refractometry; GS5-2 (2024) is an official reference method for cane prepared using a hydraulic press (ICUMSA, 2022, 2024) [9, 10].

2.8 Statistical analysis: Data was analyzed using Statistix 10 and Microsoft Excel 2016. Extraneous matter components were analysed separately using an RCBD ANOVA with treatment as the fixed effect and replication/block as the block factor. Brix, Pol and purity were analysed using a factorial ANOVA with system, cane category and their interaction. Mean separation was reported using Fisher's least significant difference at $\alpha = 0.05$.

2.9 Data processing and visualization: The charts were generated from the replicate-level values transcribed using Microsoft Excel 2016. Figure 1 displays treatment means for the three EM components. Figures 2-4 display the four system-by-category means for Brix, Pol and purity, alongside the three individual replicate observations per cell. No confidence intervals or standard-error bars are presented because the original experimental-unit structure and inferential model require confirmation. The visualisations are intended to reveal the pattern and spread of the observations without implying a more precise estimate than the dataset supports.

3. Results

3.1 Extraneous matter components

The mean percentages of all three measured EM components were numerically higher under manual cutting followed by Bell-loader loading than under manual cutting and hand loading (Table 7; Figure 3). Trash was 3.52% under mechanical loading compared with 0.98% underhand loading; tops were 4.78% compared with 1.79%; and soil was 1.26% compared with 0.14%. These correspond to

descriptive increases of approximately 259%, 168% and 800%, respectively, relative to the manual-loading means. The large proportional increase for soil should be interpreted cautiously because the baseline manual mean was very low.

Table 7: Extraneous matter composition of sugarcane harvested using manual and mechanical loading systems at Blairmont Estate, Guyana

Component	Manual + hand load (%)	Manual + Bell-loader (%)	Descriptive difference (Percentage Points)	ANOVA (P)
Trash	0.98	3.52	2.54	0.1061
Tops	1.79	4.78	2.99	0.2559
Soil	0.14	1.26	1.12	0.4070

None of the reported treatment tests were statistically significant at $\alpha = 0.05$. Therefore, the data does not provide sufficient statistical evidence to reject the null hypothesis of no system effect for any individual EM component. The observed mean differences nevertheless identify contamination components that warrant monitoring in a larger trial.

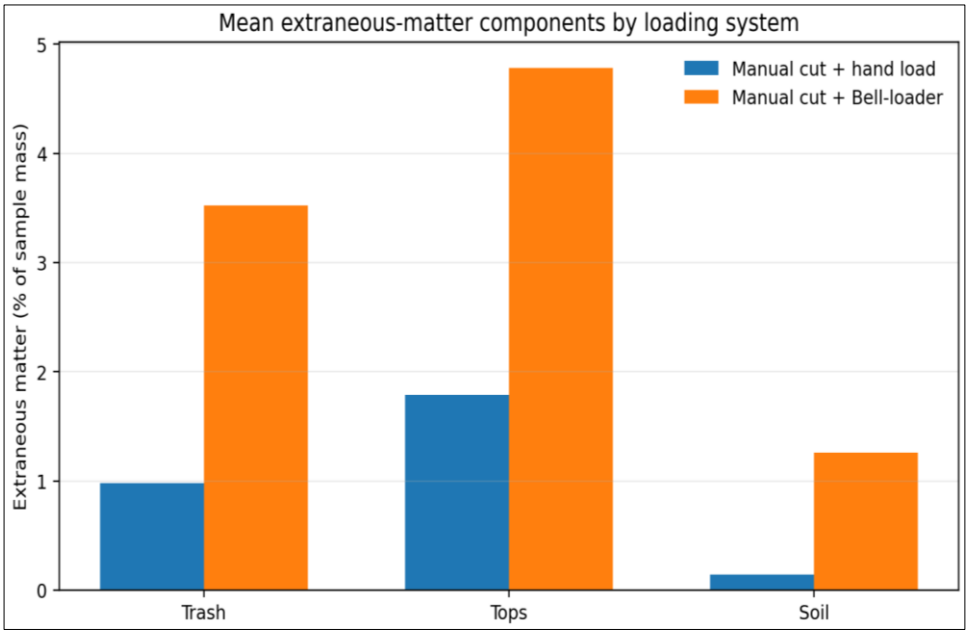


Fig 3: Treatment means for trash, tops and soil

3.2 Brix response

Factorial ANOVA found no significant main effect of system on Brix ($F = 1.47$, $p = 0.2712$), no significant effect of cane category ($F = 0.10$, $p = 0.7659$), and no significant system-by-category interaction ($F = 0.53$, $p = 0.4946$). System means were 19.383% for manual cutting/hand loading and 19.133% for manual cutting/Bell-loader loading. Category means were 19.500% for cleaned cane and 19.017% for cane containing EM. The four combination means ranged from 18.90% to 19.63% (Figure 4).

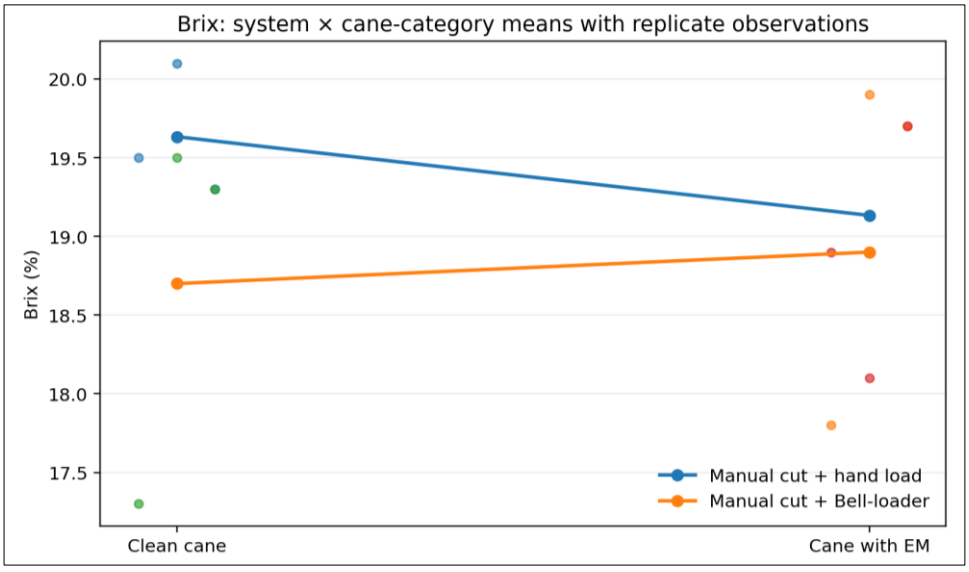


Fig 4: Brix values by loading system and cane category

3.3 Pol response

Factorial ANOVA identified a significant system effect on Pol (F = 8.29, p = 0.0281). The mean Pol was 15.305% for manual cutting/hand loading and 13.563% for manual cutting / Bell-loader loading, a descriptive decrease of approximately 11.4% relative to the manual system. Cane category also had a significant effect (F = 6.65, p = 0.0419): cleaned cane averaged 15.218%, whereas cane containing EM averaged 13.650%. The system-by-category interaction was not significant (F = 0.07, p = 0.7989). Combination means were 16.00% (manual / clean), 14.61% (manual / EM), 14.43% (Bell-loader / clean) and 12.69% (Bell-loader / EM), (Figure 5).

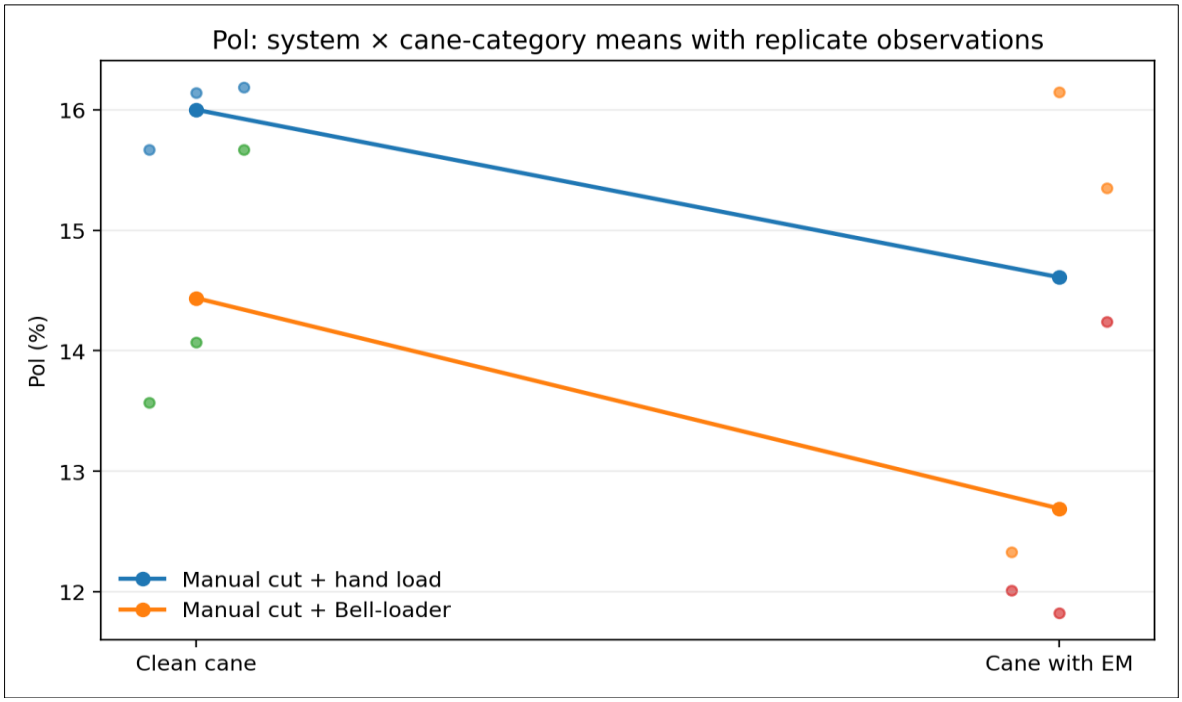


Fig 5: Pol values by loading system and cane category

3.4 Juice purity

Juice purity differed significantly by system in the reported analysis (F = 6.26, p = 0.0464). Manual cutting / hand loading had a mean purity of 78.812%, compared with 72.230% for Bell-loader loading, a descriptive decrease of approximately 8.4%. Cane category was also significant (F = 8.64, p = 0.0259): cleaned cane averaged 79.388%, while EM-containing cane averaged 71.653%. The interaction was not significant (F = 0.78, p = 0.4108). The four-combination means were 81.517%, 76.100%, 77.260% and 67.200%, respectively (Figure 6).

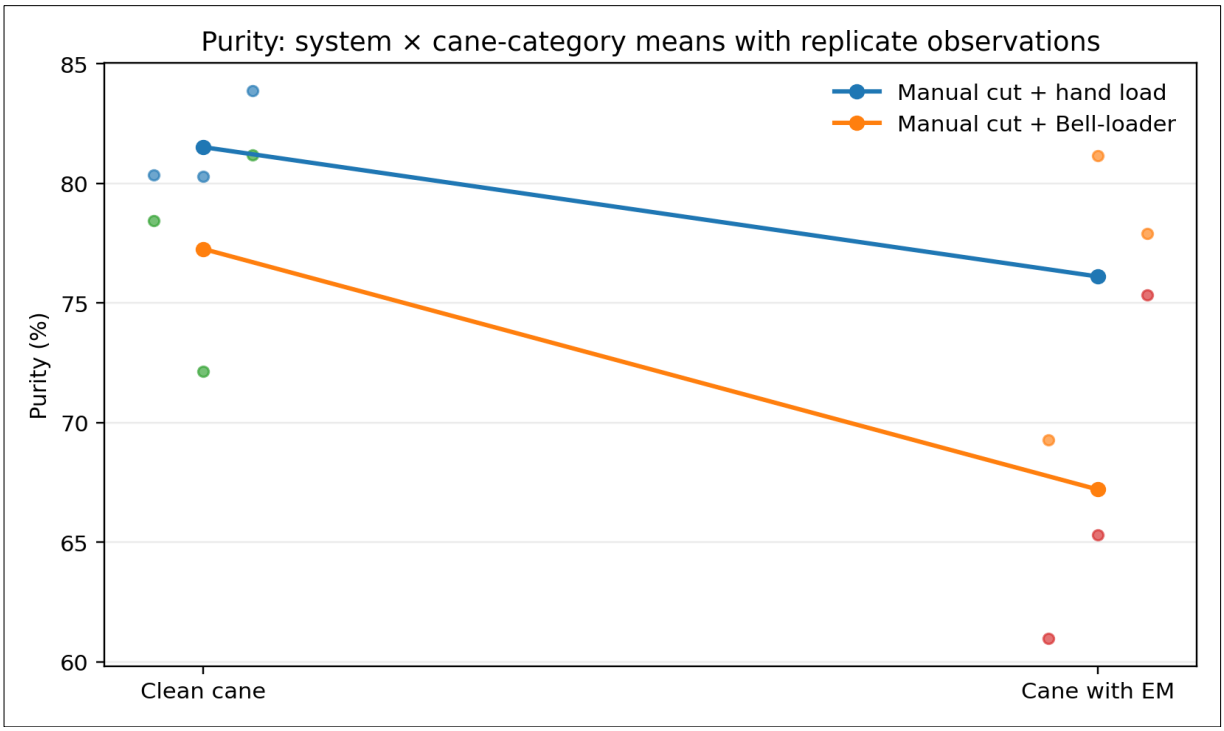


Fig 6: Juice purity by loading system and cane category

3.5 Consolidated Statistical Summary

Table 8: Reported factorial ANOVA results for juice-quality variables

Response	System effect F (P)	Cane-category effect F (*p*)	System × category F (*p*)
Brix	1.47 (0.2712)	0.10 (0.7659)	0.53 (0.4946)
Pol	8.29 (0.0281)	6.65 (0.0419)	0.07 (0.7989)
Purity	6.26 (0.0464)	8.64 (0.0259)	0.78 (0.4108)

The factorial ANOVA results (Table 8) demonstrated that the measured juice-quality parameters responded differently to loading system and cane category. Brix showed no statistically significant main effect of loading system ($F = 1.47$, $p = 0.2712$), cane category ($F = 0.10$, $p = 0.7659$), or their interaction ($F = 0.53$, $p = 0.4946$). These findings indicate that the concentration of total soluble solids remained statistically comparable between the two loading systems and sample categories under the conditions of this investigation.

In contrast, Pol was significantly affected by both loading system ($F = 8.29$, $p = 0.0281$) and cane category ($F = 6.65$, $p = 0.0419$). Manual cutting followed by hand loading recorded a higher mean Pol (15.305%) than manual cutting followed by Bell-loader loading (13.563%), representing an approximately 11.4% lower mean under the Bell-loader system. Similarly, cleaned cane recorded a higher mean Pol (15.218%) than cane retained with extraneous matter (13.650%), representing an approximately 10.3% reduction in the latter category. The system-by-category interaction was not statistically significant ($F = 0.07$, $p = 0.7989$), indicating that the reported analysis did not detect a differential category response between the loading systems.

Juice purity demonstrated a similar pattern. Significant effects were reported for loading system ($F = 6.26$, $p = 0.0464$) and cane category ($F = 8.64$, $p = 0.0259$). Mean purity was higher under manual cutting and hand loading (78.812%) than under Bell-loader loading (72.230%), corresponding to an approximately 8.35% lower mean in the latter system. Cleaned cane also recorded higher mean purity (79.388%) than cane retained with extraneous matter (71.653%), representing an approximately 9.74% reduction. However, the interaction between loading system and cane category was not significant ($F = 0.78$, $p = 0.4108$).

The combination means further illustrate these descriptive differences. The lowest Pol (12.69%) and purity (67.20%) were recorded in the Bell-loader treatment's EM-containing cane category, while the highest values occurred in the cleaned cane category under manual cutting and hand loading. Nevertheless, because neither interaction was statistically significant, these combination means should be interpreted descriptively and should not be presented as evidence of a synergistic or treatment-specific interaction.

Collectively, the results suggest that loading system and cane cleanliness were associated with differences in Pol and purity, whereas Brix remained statistically comparable. The contrasting responses of Brix and the two sucrose-related indicators are analytically plausible because Brix represents total soluble solids, while Pol estimates apparent sucrose concentration and purity expresses the proportion of soluble solids represented by apparent sucrose. However, the experiment did not measure individual non-sucrose constituents and therefore cannot establish the chemical mechanism responsible for the observed differences.

These findings must be interpreted cautiously. Only three field replications were used per loading system, and the cleaned and EM-containing categories were obtained from the same punt composites. Consequently, they represent paired subsamples rather than independent experimental units.

4. Discussion

4.1 Interpretation of the Extraneous Matter Pattern

The mechanical-loading treatment produced higher descriptive means for trash, tops and soil. This pattern is consistent with the possibility that loader operation may entrain field residues or soil during collection and placement of stalks. However, because the treatment tests were not statistically significant, the experiment does not establish that Bell-loader loading caused a reproducible increase in each component. The high relative soil increase is partly a consequence of the very low manual-loading baseline, and the three field replications provide limited precision.

The comparison should be interpreted as an operational-system contrast under the conditions of one field and one crop. Both treatments used manual cutting; therefore, differences cannot be attributed to mechanical base cutting, harvester topping or extractor-fan cleaning. This matters when comparing the results with literature on full mechanical harvesters. Chaudhary *et al.* (2023) [3] compared mechanical and manual harvesting in relation to extraneous matter and losses, while Ma *et al.* (2014) [14] reviewed harvester mechanisms. Their work provides context, but the machinery and operations are not identical to the Bell-loader treatment tested here. A future experiment should record loader bucket geometry, ground clearance, approach angle, loading height, loading duration, operator identity, soil moisture, crop lodging and field surface condition. Direct observation or video-based assessment of bucket-ground contact could test whether soil and plant residues are being entrained during loading. A sampling method should also be standardised across the load; the source study used ten subsamples from upper, middle and lower layers, which is a useful starting point, but the number and spatial placement of samples should be validated against load heterogeneity.

4.2 Why Brix May Remain Stable While Pol and Purity Differ?

Brix measures total soluble solids rather than sucrose alone. The absence of a significant Brix response does not contradict the significant Pol and purity effects. If apparent sucrose declines while the total soluble-solids concentration remains relatively similar, purity can decrease. The pattern in this dataset is therefore analytically plausible: Brix varied relatively little across systems and categories, whereas Pol and purity showed lower means in EM-containing cane and in the Bell-loader system.

Nevertheless, the chemical mechanism was not directly investigated. The study did not quantify reducing sugars, ash, soluble salts, organic acids, dextran or other non-sucrose constituents. It is not possible to identify which compounds contributed to the purity differences. Follow-up work could measure conductivity ash, reducing sugars, glucose and fructose, dextran and fibre, alongside standard Pol and Brix measurements.

4.3 Pol and Purity: Implications for Delivered-Cane Quality

The reported system effects for Pol and purity suggest that the juice obtained from the hand-loaded treatment had higher apparent sucrose concentration and a higher sucrose-to-soluble-solids ratio. The significant category effects indicate that the cleaned-cane subsamples had higher values than their EM-containing counterparts. These results support the operational importance of cane cleanliness, but they do not demonstrate a quantified increase in factory sugar production. Pol and purity are quality indicators; factory recovery is also influenced by fibre, preparation index, extraction, clarification, evaporation, crystallisation, molasses exhaustion and process control.

The category comparison is particularly important because it is a laboratory contrast created by removing EM from a portion of the same punt sample. It is not equivalent to a field treatment in which one group of plots was harvested with a different topping or cleaning protocol. The category effect estimates the difference between prepared sample categories under the laboratory procedure and should not be interpreted as a fully independent agronomic treatment effect.

4.4 Relevance of Post-Harvest Deterioration

Harvest-to-mill delay is a potentially important confounder in cane-quality comparisons. Solomon (2009) [23] describes how delays and environmental conditions can promote sucrose inversion and microbial deterioration, with implications for juice quality and factory processing. Samples were collected immediately after loading but does not provide the time elapsed from cutting to laboratory extraction for each punt. If loading treatments differed in duration, the interval from cutting to sampling could also differ. Future studies should record timestamps at cutting, loading completion, sampling, milling and laboratory analysis, and should standardise the time to extraction wherever possible.

4.5 Implications for Mechanisation and Operational Decisions

The results do not support a blanket recommendation to abandon mechanical loading. Hand loading may be associated with better juice-quality means in this experiment, but it is also labour intensive and may have lower loading capacity. The study did not quantify labour hours, loading rate, fuel consumption, machinery costs, delays, safety, or tonnes loaded per hour. A defensible estate decision requires a multi-criteria comparison that includes delivered-cane quality, operational throughput, labour availability, costs and factory performance. Ahmed and Alam-Eldin (2015) [1] evaluated manual and mechanical sugarcane harvesting systems in Sudan using production efficiency, cost-effectiveness, loading efficiency, in-field losses and trash-related processing effects, illustrating the value of assessing quality and operational performance together.

A practical interim response is to retain mechanical loading where operationally necessary while introducing contamination monitoring and operator-focused adjustments. The estate could establish target ranges for trash, tops and soil, sample loads routinely, provide feedback to operators and compare contamination by loader, field, soil moisture and shift. Any operational intervention should be evaluated using before-and-after or randomised trials rather than assumed to be effective.

4.6 Soil and Machinery Considerations

The soil percentage in the delivered load is distinct from soil compaction in the field. Delmond *et al.* (2024) [6] reported that mechanised sugarcane operations can contribute to soil compaction, with tractor-trailer traffic identified as a critical operation in their study. The Blairmont experiment did not assess compaction, infiltration, root growth or ratoon performance. However, future assessments of mechanical loading should consider both contamination of cane loads and the longer-term effects of machinery traffic on soil physical condition.

4.7 Strengths and Limitations

The strength of the investigation is that it evaluated estate operations under field conditions and linked field contamination measurements with laboratory juice-quality indicators. The composite sampling procedure attempted to represent different vertical positions within each punt, and the study separated three EM components rather than reporting only total contamination. The paired clean/EM-containing sample comparison also provided a way to examine how sample cleanliness related to laboratory juice quality.

The main limitations are the small number of field replications, single cultivar, single field and single harvest period; the absence of a fully mechanised cutting treatment; incomplete documentation of weather and soil moisture; uncertain harvest-to-analysis intervals; and incomplete laboratory quality-control information. The most important statistical limitation is the paired structure of the cane categories. Reanalysis of the original observations is required before the reported significance tests can be treated as definitive. The results also do not include direct factory recovery, cane loss, labour productivity or cost outcomes.

5. Conclusion

This study evaluated the relationship between two sugarcane loading systems and the levels of extraneous matter and juice quality at Blairmont Estate, Guyana. The comparison involved manual cutting followed by hand loading and manual cutting followed by mechanical loading using a Bell loader. The findings provide preliminary evidence of differences in delivered-cane cleanliness and juice-quality characteristics under the two operational systems, although these differences must be interpreted within the limitations of the experimental design.

The results showed that the manual cutting and Bell-loader loading system recorded higher descriptive mean percentages of trash (3.52%), tops (4.78%) and soil (1.26%) compared with the manual cutting and hand-loading system (0.98%, 1.79% and 0.14%, respectively). However, none of these differences were statistically significant at the 5% significance level. Consequently, the study did not establish a statistically significant effect of loading system on the individual extraneous matter components, despite the consistently higher numerical values recorded under Bell-loader loading. These observations nevertheless identify trash, tops and soil contamination as important parameters for continued operational monitoring.

With respect to juice quality, the reported factorial ANOVA indicated significant loading-system and cane-category effects on Pol and purity, whereas Brix was not significantly affected by either factor. Manual cutting followed by hand loading recorded higher mean Pol (15.305%) and purity (78.812%) than manual cutting followed by Bell-loader loading (13.563% and 72.230%, respectively). Similarly, cleaned cane

recorded higher mean Pol (15.218%) and purity (79.388%) than cane retained with extraneous matter (13.650% and 71.653%, respectively). These findings suggest an association between loading system, cane cleanliness and the sucrose-related quality indicators examined. The absence of statistically significant system-by-category interactions for Brix, Pol and purity further indicates that the reported analysis did not demonstrate a differential effect of cane category between the two loading systems.

The contrasting responses of Brix compared with Pol and purity also highlight the importance of assessing multiple juice-quality indicators rather than relying exclusively on soluble-solids measurements. Although Brix remained statistically comparable, the lower Pol and purity values observed under Bell-loader loading and in EM-containing cane indicate differences in apparent sucrose concentration and the proportion of soluble solids represented by apparent sucrose. Nevertheless, the specific chemical mechanisms responsible for these differences were not investigated.

Overall, the findings suggest that manual cutting followed by hand loading was associated with lower descriptive extraneous matter levels and higher mean Pol and purity under the conditions of this investigation. However, the results do not establish that hand loading is universally superior to mechanical loading or that the observed differences translate into increased commercial sugar recovery, improved factory extraction efficiency or greater profitability. Such conclusions require direct measurements of factory recovery, operational productivity, labour requirements and associated costs.

The interpretation of the statistical findings must also remain provisional because the investigation involved only three field replications in a single field, using one cultivar and one crop stage. Furthermore, the cleaned and EM-containing cane categories were obtained from the same punt composites and therefore constitute paired subsamples rather than independent experimental units. Reanalysis of the original observations using an appropriate repeated-measures or mixed-effects model that accounts for the punt-level pairing and block structure is necessary to validate the reported factorial ANOVA results.

This investigation provides an initial field-based assessment of the relationship between sugarcane loading practices, extraneous matter contamination and juice quality at Blairmont Estate. The observed patterns support the need for routine monitoring of cane cleanliness and further evaluation of Bell-loader operating practices. Larger, adequately replicated investigations across multiple fields, cultivars and harvesting periods, supported by appropriate statistical analyses and direct factory-performance measurements, are required before definitive operational or estate-wide recommendations can be made.

6. Recommendations

Based on the findings of this study, the following recommendations are made: -

- Establish routine load-level sampling for trash, tops and soil at Blairmont Estate, recording field, punt, loader, operator, shift and soil condition.
- Review Bell-loader operating practices, particularly bucket-ground contact, approach angle, loading height and the disturbance of soil and field residues. Test operator training and equipment adjustments through monitored trials.
- Record soil moisture and rainfall before and during harvesting and assess whether wetter field conditions are associated with higher soil contamination.
- Expand the experiment to multiple fields, cultivars, ratoon stages and harvest dates, with adequate independent field replications determined by a priori power analysis.
- Include a true fully mechanised harvesting treatment if the objective is to compare manual, semi-mechanical and fully mechanical systems. Separating the effects of cutting, topping, cleaning, loading and transport where feasible.
- Reanalyse the current raw dataset using a model that recognises cane category as a paired/repeated subsample within punt and includes block structure. Report estimated contrasts, confidence intervals, residual diagnostics and exact p-values.
- Standardise and document sample splitting, sample mass, laboratory milling, juice clarification, instrument calibration, replicate measurements and time from cutting to analysis.
- Use recognised ICUMSA methods where applicable and document the method number, edition, deviations, calibration and quality-control procedures.
- Add chemical and processing indicators such as fibre, ash, reducing sugars, glucose/fructose, dextran and commercial cane sugar, where laboratory capacity permits.
- Integrate cane-quality measurements with operational data: tonnes loaded per hour, labour input, fuel use, loading delay, field losses, transport time and factory extraction/recovery.
- Do not infer sugar recovery, factory throughput or financial savings from Pol and purity alone; obtain factory mass-balance and cost data before making economic recommendations.

7. Compliance with Ethical Standard

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7.2 Declaration of competing interest: The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

7.3 Disclosure of conflict of interest

The authors certify that this submission is original work and is not under review at any other publication. The authors hereby declare that this manuscript does not have any conflict of interest.

7.4 Statement of informed consent: The authors declare that informed consent was obtained from all individual participants included in the study. All work utilized in this

study was fully cited and referenced so authors of prior researches are given their due credentials for their work.

7.5 Data Availability: Data will be made available on request.

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