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RESEARCH ARTICLE

Evaluation of key undesirable morphological traits in Sugarcane (*Saccharum* spp.) hybrid progenies

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Abstract

Sugarcane (*Saccharum* spp.) is a key tropical crop grown mainly for sugar production and biofuel. Continuous improvement in sugarcane breeding is critical for developing high- yielding, stress-resistant varieties that address evolving agricultural and industrial demands. Although breeding programs typically focuses on desirable traits, studying undesirable traits is equally crucial to mitigate their negative impact on yield, quality and overall crop performance. This study evaluates undesirable morphological traits in sugarcane, specifically focusing on cane pithiness, growth cracks, leaf sheath adherence and hairiness within hybrid progenies. These traits negatively impact sugarcane quality and yield, posing challenges for breeding programs aimed at developing high-performing and resilient varieties. A total of 1,203 clones were assessed in clonal selection I across 27 parental combinations. A standardized scoring system was utilized to quantitatively evaluate pithiness and growth cracks, revealing distinct variations among parental genotypes. Leaf sheath adherence strength was determined through manual detachment tests, while hairiness was classified based on trichome presence. Key findings from the progeny evaluations identified parents such as Co 86032, ISH 100, Co 11015, ISH 69, Co 97015 and Co 98010 as consistently producing progeny with reduced pithiness and minimal growth cracks. Conversely, genotypes like CoV 89101, CoH 13, MS 68/47, CoC 671, CoH 70 and ISH 229 were associated with higher frequencies of undesirable traits. By refining hybridization strategies and focusing on specific parental combinations, this study aspires to enhance breeding efficiency, reduce the occurrence of inferior clones and ultimately improve the economic sustainability of sugarcane production.

Keywords

growth crack; internode pithiness; leaf sheath hairiness and adherence; sugarcane clones; undesirable traits

Introduction

Sugarcane (*Saccharum spp.*) is a vital crop with a significant role in global agriculture, primarily recognized as a major source of sugar. It makes substantial contribution to the world economy, generating billions of dollars in revenue and supporting millions of livelihoods. In recent years, the crop's importance has expanded beyond sugar production to include bioenergy, with sugarcane biomass increasingly utilized for renewable energy sources, such as ethanol (1). Globally, sugarcane accounts for approximately 80 % of the world's sugar supply (2). In 2023, global sugarcane production reached 1.9 billion metric tons, led by Brazil with 700 million metric tons, followed by India with 446.4 million metric tons. Within India, Uttar Pradesh contributed 205.6 million metric tons to India's output (3). Varieties developed from sugarcane often achieve high sugar content, enhancing their economic value. As demand for efficient, high-quality sugarcane varieties grows, breeders face mounting pressure to develop hybrids with robust traits, including higher sucrose levels, improved fiber quality and resilience against diseases (4).

Despite these advancements, the breeding process presents substantial challenges, particularly the emergence of undesirable traits that can negatively impact yield and quality. To address these challenges, breeders must identify and strategically minimize these undesirable traits. A critical aspect of this process is the careful selection of parental lines, as their genetic composition plays a pivotal role in determining the success of hybridization and the phenotypic traits of the progeny (5, 6).

Undesirable traits, such as cane pithiness, growth cracks (splitting), leaf sheath adherence and leaf sheath hairiness, significantly contributes to the production of inferior clones in sugarcane. Each year, thousands of seedlings are generated, making the selection process far more extensive compared to other crops. The breeding cycle is particularly lengthy, spanning 12 to 15 years, with a low average selection rate of only 1 successful clone out of every 2300 seedlings (7). The presence of these undesirable traits in hybrid progenies often results in rejection, as they compromise both the quality and yield of the crop.

Large-scale evaluation of parental lines under field conditions provides invaluable insights into their potential to enhance the quality and resilience of resulting hybrids (8). Identifying both superior and less desirable parental lines based on their qualitative traits is essential for optimizing the breeding process. By concentrating on elite genetic profiles, breeders can make well-informed decisions to directly improve the quality and adaptability of new sugarcane varieties.

Pithiness in sugarcane internode arises from genetic predisposition, environmental stress and agronomic practices, leading in hollow cavities that adversely affect crop viability (9). Stress factors such as drought, nutrient deficiency and pest infestations promote uneven growth, thereby increasing the occurrence of pithiness. Implementing effective irrigation strategies, balanced fertilization and robust pest control measures can help mitigate this issue. Pithy canes lead to reduced juice yield and lower sugar concentrations, negatively impacting processing efficiency and profitability (10).

Growth cracks in sugarcane internodes stems from structural stress, environmental pressures, or genetic variation (11). These vertical splits worsen water loss, reduce cane quality and create entry points for pests and diseases. Breeding strategies aimed at enhancing structural integrity can improve resilience and productivity, thereby addressing these detrimental effects.

Leaf sheath adherence significantly influences harvesting efficiency, disease susceptibility and overall plant health (12). Strong adherence complicates harvesting operations and promotes conditions for pests and diseases, while weak adherence aids self-de-trashing (13, 14). Breeding programs focused on achieving optimal adherence can improves resilience and lower pest risks, thus improving overall efficiency.

Leaf sheath hairiness, while providing s stress tolerance and pest resistance, poses challenges for manual harvesting (15). In labour-intensive regions, dense trichomes can cause skin irritation, reducing worker efficiency. Therefore, breeding programs should prioritize reduced hairiness to balance agronomic benefits with worker comfort, ensuring sustainable productivity (16).

This study visually assessed undesirable traits such as cane pithiness, growth cracks, leaf sheath adherence and leaf sheath hairiness in hybrid progenies during clonal selection in sugarcane. By evaluating the performance of progenies, the study aims to identify parental lines that exhibit minimal or no undesirable traits, thereby providing valuable genetic resources for breeding programs. This approach enhances selection efficiency and improves crop quality. By identifying and avoiding specific crosses involving parents that produce a higher frequency of undesirable traits, breeders can reduce the prevalence of inferior clones. Additionally, this study promotes the efficient use of land, labor and capital by transitioning from broad, extensive selection methods to more focused and intensive approaches.

Materials and Methods

The genetic material for this study was developed through controlled crosses conducted at the Sugarcane Breeding Institute, Coimbatore, India. This study involved twenty bi-parental crosses and seven general collections (GC), resulting in a total of twenty-seven parental combinations. The collected fluff (seeds) was initially sowed in a fluff nursery at the Sugarcane Research Station, Cuddalore, in 2022. After 90 days, the seedlings were transplanted into a ground nursery. Clones from the ground nursery were subsequently advanced to Clonal Selection I in 2023.

The present study evaluated 1203 clones in Clonal Nursery I. An augmented randomized complete block design, as described by (17), was employed to ensure robust experimental validity. The setup included 13 blocks, each containing six standard check varieties (CoC 25, CoG 7, CoC 671, Co 11015, Co 86032 and CoC 13339) to ensure consistent comparative assessments across all blocks.

Observations recorded

In this study, visual assessments were conducted for traits such as pithiness, growth crack (splitting), leaf sheath adherence and leaf sheath hairiness, as these traits directly influence sugarcane quality, harvesting efficiency and overall cane and sugar yield. The Protection of Plant Varieties and Farmers' Rights Authority (PPV&FRA), under the Government of India, provides specific descriptors for evaluating the characteristics of individual plants (18).

Pithiness was assessed at the harvest stage, 360 days after planting (DAP). This evaluation at maturity provided a precise measure of the cane's internal structural integrity. A standardized scale based on DUS descriptors, ranging from 1 to 9, was utilized for the assessment:

1: No pithiness observed; the cane is solid throughout.

3:Minimal pithiness, with slight hollow areas but a predominantly solid structure.

5: Moderate pithiness, characterized by noticeable hollow areas affecting structural integrity.

7: Severe pithiness, with large cavities that compromise the cane's usability.

9: Extremely pithy canes, predominantly hollow and unsuitable for harvesting or processing (18-21).

Various degrees of growth cracks were identified on the surface of the sugarcane canes. These longitudinal fissures, which extend along the length of the stalks, were assessed for severity, revealing a spectrum from small, narrow cracks to deeper and more pronounced openings. Growth crack was assessed at the maturity stage (300 DAP) (18, 20). The depth, length and width of the cracks were meticulously measured to provide insights into the structural stress experienced by the plants.

Leaf sheath hairiness was classified into three distinct categories: absent, sparse and dense (18, 20, 22).

- The "absent" category shows a smooth, hairless sheath surface, indicating a lack of trichome development.
- The "sparse" category displays a minimal presence of hairs along the sheath.
- The "dense" category exhibits a thick covering of hairs, which may enhance resistance to pests and reduce water loss through the leaf surface.

Hairiness was assessed at the end of grand growth stage (240 DAP).

Leaf sheath adherence was assessed by pulling dry leaves manually and categorizing the degree of attachment into three distinct types: weak, medium and strong (18, 20, 23). Adherence was assessed at the maturity stage (300 DAP).

- Weak adherence (self-detaching): Dry leaves detached completely and with minimal effort, indicating natural detachment and limited attachment of the sheath to the stalk.
- Medium adherence (semi-clasping): Dry leaves were partially detached, with portions of the sheath remaining attached, requiring moderate effort for removal.
- Strong adherence (tight clasping): Dry leaf sheaths were firmly attached to the stalk and required significant force for detachment, indicating a high degree of attachment.

Statistical analysis

The statistical analysis for this study was carried out using R Studio software (version 4.3.1) with the "psych" and "dplyr" packages. To summarize the central tendency and variability of the data, first-order statistical measures, such as mean and range, were calculated. For trait evaluation, the study adhered to the standardized descriptors outlined by the PPV&FRA scoring criteria, ensuring consistent, reliable and accurate assessments across all analyzed traits (18-20, 22).

Results and Discussion

The Table 1 highlights a diverse range of parental lines, including Co, CoA, CoC, CoH, CoS, CoV, CoVC, ISH, MS and NB, underscoring the extensive genetic diversity integrated into the

Table 1. Summary of clone distribution based on parentage in sugarcane hybrid crosses

Sr. No.	Parentage	Clone number	Total no. of clones
1	CoC 671 x Co 87023	C 230001 to C 230045	45
2	ISH 100 x Co 11015	C 230046 to C 230059	14
3	CoA 7602 x Co 97015	C 230060 to C 230103	44
4	ISH 100 x ISH 69	C 230104 to C 230137	34
5	Co 98008 x ISH 229	C 230138 to C 230151	14
6	CoC 671 x ISH 229	C 230152 to C 230167, C 230293 to C 230436	160
7	CoV 89101 x CoH 13	C 230168 to C 230250	83
8	CoV 89101 x CoH 70	C 230253 to C 230266	14
9	Co 98010 x Co 11015	C 230271 to C 230292	22
10	CoS 8408 x Co 87272	C 230437 to C 230454	18
11	NB 94-545 x Co 11015	C 230455 to C 230590	136
12	CoC 90063 x Co 97015	C 230591 to C 230646	56
13	CoV 09356 x CoA 7602	C 230647 to C 230680, C 231170	35
14	CoVC 14062 x CoVC 14061	C 230681 to C 230772	92
15	Co 86032 x ISH 229	C 230773 to C 230789, C 231171	18
16	Co 2000-10 x Co 97015	C 230790 to C 230802	13
17	Co 94012 x BO 91	C 230803 to C 230831	29
18	MS 68/47 x CoC 90063	C 230832 to C 230910	79
19	ISH 100 x CoA 14321	C 230917 to C 230927	11
20	Co 86032 x Co 09004	C 230928 to C 230945	18
21	MS 68/47 GC	C 230968 to C 230989	22
22	ISH 69 GC	C 230996 to C 231015	20
23	CoC 08336 GC	C 231023 to C 231117, C 231260, C 231261	97
24	CoC 24 GC	C 231118 to C 231164, C 231234 to C 231256	70
25	C 29442 GC	C 231175 to C 231193	19
26	CoA 92081 GC	C 231194 to C 231216	23
27	Co 86032 GC	C 231217 to C 231233	17
			1203

breeding program. Notably, certain parental lines, like "CoC 671," "ISH 229" and "Co 97015" appear multiple times, indicating their significance in breeding for desirable traits such as high yield, disease resistance and drought tolerance.

This underscores the strength of the sugarcane breeding program, which is designed to generate diverse genetic combinations and identify high-performing clones for development into commercially viable cultivars.

Internode pithiness

The evaluation of potential parental lines for sugarcane clones exhibiting pithiness, assessed across a scale, revealed distinct differences in the contributions of various progenitors, as depicted in Table 2. Clones derived from progenitors classified as contributing "less or no pithiness" demonstrated a notable proportion with lower pithiness scores. For examples, clones from Co 86032 GC exhibited 88.2 % at scales 1 and 3, suggesting minimal pithiness. Similarly, crosses such as ISH 100 × Co 11015 and Co 98010 × Co 11015 displayed a high percentage of clones (71.4 % and 68.2 %, respectively) within the lower pithiness range, indicating these progenitors' effectiveness in producing clones with reduced internal pith.

Conversely, progenitors associated with greater contributions to pithiness consistently produced clones with a marked tendency for increased pithiness levels. For instance, the cross MS 68/47 × CoC 90063 resulted in 46.8 % of clones exhibiting significant pithiness (scales 7 and 9). Additionally, Co 98008 × ISH 229 progeny exhibited 64.3 % of clones within the upper pithiness range, highlighting their tendency to pass on traits associated with higher pithiness traits (18, 20, 21).

Pithiness in sugarcane, evaluated on a scale from 1 (none) to 9 (full), measures the degree of hollowness in the stalk, providing a standardized method for comparing pithiness across different clones (18, 20, 21), as shown in Fig. 1. Crosses involving ISH 100 with ISH 69 and Co 11015, consistently produced progeny with a high frequency of solid, firm canes. However, when ISH 100 was crossed with CoA 14321, a higher occurrence of hollow canes was observed. In these crosses, ISH 100 served as the female parent (24). These results suggest that the pithiness in the progeny may be linked to genetic factors inherited from CoA 14321. Further molecular studies are needed to confirm the specific genes responsible for this undesirable trait in cane development.

When CoC 90063 was crossed with Co 97015, the

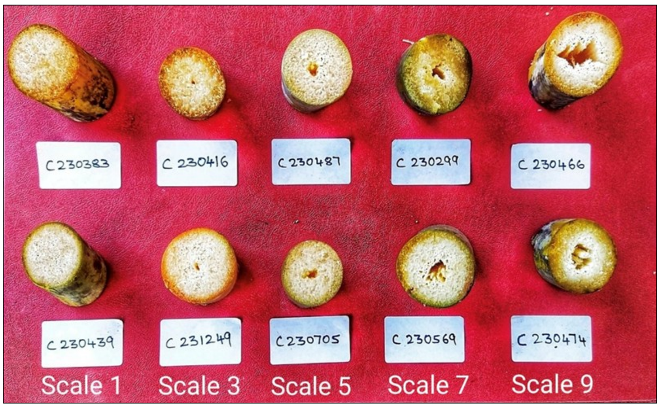

Fig. 1. Visual grading of internode pithiness in sugarcane clones using a 1 to 9 scale (1 = no pithiness, 9 = severe pithiness).

resulting progeny exhibited minimal pithiness. In contrast, when MS 68/47 was crossed with CoC 90063, a higher proportion of progeny displayed significant pithiness. Notably, when CoC 90063 was used as the male parent with MS 68/47 as the female parent, the frequency of pithiness increased (24, 25). This may suggest that while CoC 90063 positively contributes to reducing pithiness, incorporating MS 68/47 in breeding programs requires careful selection to effectively manage pithiness levels in the progeny clones.

Among the evaluated parental combinations, ISH 100 and Co 11015 are present in 3 out of 5 crosses, underscoring their substantial role in generating progenies with no or minimal pithiness. Their consistent contribution highlights their value as key parental lines in breeding programs aimed at developing clones with reduced pithiness (8). Including these lines in breeding strategies can enhance the potential for producing high -quality sugarcane varieties that meet industry standards for stalk integrity and processing efficiency.

Growth cracks

The evaluation of growth cracks, an undesirable trait in sugarcane, revealed significant differences across various progenitors, as summarized in Table 3. Progenitors like CoV 89101 × CoH 13, CoVC 14062 × CoVC 14061, CoC 671 × Co 87023 and CoV 89101 × CoH 70 exhibited splitting rates ranging from 19.3 % and 28.6 %, underscoring their higher susceptibility to this undesirable trait. In contrast, progenitors such as Co 98008 × ISH 229, Co 86032 × Co 09004 and Co 86032 GC demonstrated no evidence of growth cracks, indicating their potential as stable, crack-resistant sources.

Table 2. Potential parental lines producing sugarcane clones with pithiness levels ranging from 1 (none) to 9 (full)

	Sr. No.	Parentage	Clone number	Total no. of clones	Scales 1-9					% of clones	
					1	3	5	7	9	With scale 1&3	With scale 7&9
	1	ISH 100 × ISH 69	C 230104 to C 230137	34	9	11	9	5	0	58.8	14.7
	2	CoC 90063 × Co 97015	C 230591 to C 230646	56	5	28	20	3	0	58.9	5.4
	3	Co 98010 × Co 11015	C 230271 to C 230292	22	3	12	4	2	1	68.2	13.6
Parents with less or no pithiness	4	ISH 100 × Co 11015	C 230046 to C 230059	14	5	5	0	4	0	71.4	28.6
	5	Co 86032 GC	C 231217 to C 231233	17	6	9	2	0	0	88.2	0.0
	6	ISH 100 × CoA 14321	C 230917 to C 230927	11	0	1	6	3	1	9.0	36.3
	7	ISH 69 GC	C 230996 to C 231015	20	0	4	7	8	1	20.0	45.0
Parents with more pithiness	8	MS 68/47 × CoC 90063	C 230832 to C 230910	79	0	9	33	29	8	11.4	46.8
	9	Co 98008 × ISH 229	C 230138 to C 230151	14	1	2	2	8	1	21.4	64.3

Table 3. Potential parents producing growth crack (splitting and non-splitting) in sugarcane clones

	Sr. No.	Parentage	Clone number	Total no. of clones	No. of split clones	% of split clones
Parents with no splitting growth crack	1	Co 98008 × ISH 229	C 230138 to C 230151	14	0	0
	2	Co 86032 GC	C 231217 to C 231233	17	0	0
	3	Co 86032 × Co 09004	C 230928 to C 230945	18	0	0
Parents with splitting growth crack	4	CoV 89101 × CoH 13	C 230168 to C 230250	83	16	19.3
	5	CoVC 14062 × CoVC 14061	C 230681 to C 230772	92	18	19.6
	6	CoC 671 × Co 87023	C 230001 to C 230045	45	10	22.2
	7	CoV 89101 × CoH 70	C 230253 to C 230266	14	4	28.6

The extent and intensity of splitting, likely caused by structural stress or genetic factors, varied significantly (18, 20), as shown in Fig. 2. These differences were characterized by variations in the length and depth of vertical fissures, with certain genotypes exhibiting a pronounced tendency toward cracking. Notably, the parent *Co 86032* displayed complete resistance to growth cracks, with no instances observed across both biparental crosses and general collections. This resistance, combined with its high sucrose content, makes Co 86032 a highly valuable candidate for breeding programs (26). Crossing high-yielding but crack-prone parental lines with the crack-resistant Co 86032 presents a strategic approach to generating progenies with reduced splitting and enhanced sucrose content (8, 23).

In contrast, progenies from crosses involving CoV 89101 with CoH 13 and CoH 70 exhibited increased splitting rates of 19.3 % and 28.6 %, respectively. In both cases, CoV 89101 served as the female parent. This observation suggests that CoV 89101, either independently or in specific combinations (e.g., CoV 89101 × CoH 13 and CoV 89101 × CoH 70), contributes to a higher frequency of splitting in progeny. Thus, while CoV 89101 may possess desirable traits, its inclusion in breeding programs necessitates careful parental selection and strategic crossbreeding to mitigate the risk of splitting in progenies.

Fig. 2. Visual assessment of varying intensities of growth cracks (splitting) in the internodes of different sugarcane clones.

Adherence of leaf sheath

The categorization of potential parents based on the detachment strength of leaf sheaths offers insights into their ability to produce clones with varying levels of leaf sheath retention, as depicted in Table 4. Parents contributing to weak (self-de-trashing) leaf sheaths detachment, where the sheaths detach easily, include ISH 100 × Co 11015, CoA 7602 × Co 97015, CoC 671 × Co 87023 and Co 94012 × BO 91, with detachment percentages ranging from 31.8 % to 57.1 %. Notably, ISH 69 GC and CoS 8408 × Co 87272 both showed 100 % of their clones exhibiting weak detaching characteristics, making them highly efficient for self-de-trashing (12, 13).

Parental crosses classified as contributing to medium (semi-clasping) leaf sheath detachment include NB 94-545 × Co 11015, Co 98010 × Co 11015 and Co 86032 × ISH 229, with detachment percentages between 59.1 % and 91.9 %. Among these, NB 94-545 × Co 11015 showed the highest percentage of semi-clasping detachment, with 91.9 % of clones exhibiting this trait. Co 11015 shows both weak and medium leaf sheath adherence traits, appearing in three out of four parental combinations within the medium adherence category. This suggests that Co 11015 has strong potential for producing progenies with weak to medium adherence in leaf sheath, making it a promising choice for breeding programs focused on these characteristics (12, 14).

Table 4. Categorization of potential parents based on detaching strength of leaf sheaths

	Sr. No.	Parentage	Clone number	Total no. of clones	No. of clones having	% of clones
Parents contributing weak (self-de-trashing)	1	Co 94012 × BO 91	C 230803 to C 230831	29	11	37.9
	2	CoC 671 × Co 87023	C 230001 to C 230045	45	19	42.2
	3	CoA 7602 × Co 97015	C 230060 to C 230103	44	19	43.2
	4	ISH 100 × Co 11015	C 230046 to C 230059	14	8	57.1
Parents contributing medium (semi clasping)	5	Co 86032 × ISH 229	C 230773 to C 230789, C 231171	18	16	88.9
	6	Co 98010 × Co 11015	C 230271 to C 230292	22	20	90.9
	7	NB 94-545 × Co 11015	C 230455 to C 230590	136	125	91.9
	8	CoS 8408 × Co 87272	C 230437 to C 230454	18	18	100.0
	9	ISH 69 GC	C 230996 to C 231015	20	20	100.0
Parents contributing strong (tight clasping)	10	CoC 24 GC	C 231118 to C 231164, C 231234 to C 231256	70	23	32.9
	11	CoV 89101 × CoH 13	C 230168 to C 230250	83	32	38.6
	12	CoC 08336 GC	C 231023 to C 231117, C 231260, C 231261	97	49	50.5
	13	MS 68/47 GC	C 230968 to C 230989	22	13	59.1

Finally, progenitors contributing to strong (tight clasping) leaf sheath retention, where the leaf sheaths are more difficult to detach, include MS 68/47 GC, CoC 08336 GC, CoV 89101 × CoH 13 and CoA 24 GC, with detachment percentages ranging from 32.9 % and 59.1 %. Selecting parents that favor weak rather than strong adherence can help reduce rainwater retention, pest and disease incidence and the formation of aerial roots. These factors ultimately influence crop quality and yield (20, 27). This classification of parental lines offers valuable insights for breeding programs aimed at developing sugarcane varieties with specific leaf sheath adherence traits.

Leaf sheath hairiness

The data on potential progenitors for leaf sheath hair characteristics reveals distinct tendencies among parent lines, as shown in Table 5. Certain progenitors consistently produce hairless leaf sheath clones, such as ISH 100 × Co 11015, ISH 100 × ISH 69, CoS 8408 × Co 87272 and ISH 100 × CoA 14321, all of which yielded progeny with 0 % incidence of hairiness. In contrast, progenitors more likely to produce clones with leaf sheath hairiness include CoC 671 × ISH 229 with 11.3 % hairiness, CoV 89101 × CoH 70 at 14.3 % and Co 86032 × ISH 229 with 16.7 %. The highest incidence of hairiness was observed in CoA 92081 GC, with 17.4 %, underscoring the variability among progenitors in their propensity to contribute hairiness traits.

In the group of progenitors producing hairless leaf sheaths, ISH 100 stands out, appearing in three out of the four combinations that consistently result in hairless clones. This suggests a strong association between ISH 100 and the hairless leaf sheath trait, emphasizing its reliability in generating progeny devoid of leaf sheath hairiness (22, 23).

Leaf sheath hairiness exhibits significant variation among progenitors (Fig. 3), with some lines reliably producing hairless clones, while others yield a substantial number of clones with hairy leaf sheaths (18-20). This indicates the pivotal role of specific parent lines in determining the expression of this trait and highlights the importance of selecting appropriate progenitors in breeding programs aimed at managing leaf sheath hairiness in sugarcane.

Among progenitors producing clones with leaf sheath hairiness, ISH 229 appears in two out of four combinations with higher incidence. These combinations, CoC 671 × ISH 229 and Co 86032 × ISH 229, highlight key differences between the parents: CoC 671 is known for its profuse leaf sheath hairiness (11), while Co 86032 has smooth leaf sheaths (26). In both cases, ISH 229 was used as the male parent (25). This suggests that ISH 229, when crossed with both hairy and smooth leaf sheath parents, significantly contributes to progeny with a pronounced tendency for hairiness, suggesting a strong genetic influence of ISH 229 on this trait. Further molecular studies are necessary to validate the inheritance patterns of hairiness in these progenies.

Fig. 3. Visual assessment of leaf sheath hairiness variation in sugarcane clones.

Conclusion

The assessment of the parental combinations yielded several insightful conclusions. Crosses involving genotypes such as Co 86032, ISH 100, Co 11015, ISH 69, Co 97015 and Co 98010 consistently produced progeny with a reduced occurrence of undesirable morphological traits, particularly regarding cane pithiness, splitting and leaf sheath hairiness. These parents exhibit strong potential for use in breeding programs focused on enhancing sugarcane quality by minimizing problematic traits.

On the other hand, parental lines like CoV 89101, CoH 13, MS 68/47, CoC 671, CoH 70 and ISH 229 were associated with a higher frequency of progenies displaying these undesirable traits. This highlights their limited suitability in breeding strategies aimed at improving morphological characteristics. However, it is important to note that these parents do not inherently produce such traits; rather, the emergence of undesirable traits may depend on specific combinations.

Further studies are necessary to confirm the precise contributions of each parent to these traits. As a result, future hybridization efforts should prioritize the use of the former group of parents while exercising caution in the selection of the latter. This approach will facilitate more efficient and targeted breeding programs, ultimately leading to the development of superior sugarcane cultivars.

Table 5. Potential parents producing hairless and hairiness leaf sheath clones

	Sr. No.	Parentage	Clone number	Total no. of clones	Hairiness absent	Hairiness present	Hairiness present %
Parents contributing hairless leaf sheath clones	1	ISH 100 × CoA 14321	C 230917 to C 230927	11	11	0	0
	2	ISH 100 × Co 11015	C 230046 to C 230059	14	14	0	0
	3	CoS 8408 × Co 87272	C 230437 to C 230454	18	18	0	0
	4	ISH 100 × ISH 69	C 230104 to C 230137	34	34	0	0
Parents contributing hairiness leaf sheath clones	5	CoC 671 × ISH 229	C 230152 to C 230167, C 230293 to C 230436	160	142	18	11.3
	6	CoV 89101 × CoH 70	C 230253 to C 230266	14	12	2	14.3
	7	Co 86032 × ISH 229	C 230773 to C 230789,	18	15	3	16.7
	8	CoA 92081 GC	C 231194 to C 231216	23	19	4	17.4

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Authors' contributions

AT and TT contributed to drafting the initial version of the manuscript, with TT acting as the corresponding author. PJ and LA were responsible for conceptualization, data curation and supervision. ST managed the literature search and revisions. DS oversaw the entire project, providing guidance on both conceptualization and overall supervision. SN and GP provided guidance and revisions. All authors have reviewed and approved the final manuscript.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interests to declare.

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