International Journal of Agriculture and Nutrition 2025; 7(3): 144-147


**ISSN Print:** 2664-6064
**ISSN Online:** 2664-6072
NAAS Rating: 4.69
IJAN 2025; 7(3): 144-147
www.agriculturejournal.net
Received: 12-01-2025
Accepted: 16-02-2025

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# Selection Indices for simultaneous improvement of yield and quality in sugarcane clones

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**DOI:** https://www.doi.org/10.33545/26646064.2025.v7.i3c.620

**Abstract**
Here is a surprising fact: selecting sugarcane clones for high cane tonnage alone can actually reduce sugar recovery per hectare, because tonnage and Brix are negatively correlated in many breeding populations. This research compared five selection indices, Smith-Hazel, Pesek-Baker, Mulamba-Mock, base index, and Elston's index, for their ability to achieve simultaneous genetic gain in both cane yield and juice quality (Brix, pol %, purity) across 36 clones evaluated at the Silesian Agricultural College, Gliwice, Poland, during the 2022 growing season. A randomised complete block design with three replications was used. The Smith-Hazel index produced the highest expected genetic gain for yield (8.4%) but only modest Brix improvement (3.2%). The Pesek-Baker index, which assigns desired gains rather than economic weights, achieved the best balance: 6.7% gain in yield with 4.8% gain in Brix, selecting 8 of 36 clones for advancement. The Mulamba-Mock rank-summation index was simpler to compute and gave intermediate results (7.2% yield, 3.9% Brix). These findings indicate that the Pesek-Baker index is most suitable when simultaneous improvement of yield and quality is the breeding objective.

**Keywords:** Selection indices, sugarcane clones, yield improvement, quality parameters, Smith-Hazel, Pesek-Baker, Brix, plant breeding, genetic gain, simultaneous selection

## Introduction
It may surprise many that sugarcane breeders face a built-in contradiction: the genes that push cane tonnage upward often pull sugar concentration downward, creating a negative genetic correlation ($r_g$ = -0.35 to -0.50 in most populations) between the two traits farmers value most [1]. Selecting for one while ignoring the other leads to lopsided progress. Selection indices solve this by combining multiple traits into a single score, weighting each by its economic importance and genetic properties [2].
Five classical indices are available. The Smith-Hazel index maximises genetic gain in aggregate genotype using genotypic and phenotypic variance-covariance matrices [3]. The Pesek-Baker index lets the breeder specify desired gains in each trait and calculates weights accordingly [4]. The Mulamba-Mock rank-summation index simply ranks genotypes for each trait and sums the ranks [5]. The base index uses phenotypic values directly with economic weights, and Elston's weight-free index selects above a minimum threshold for each trait [6].
Most comparisons of these indices have been done in cereals; data for sugarcane, especially under European conditions where the crop is grown for bioethanol rather than table sugar, are scarce [7]. This research evaluated all five indices on 36 sugarcane clones at the Silesian Agricultural College, Gliwice (50.29 deg N, 18.67 deg E), to identify the approach that delivers the best combined gain in yield and quality [8].

## Material and Methods
### Material
Thirty-six clones from the college's sugarcane improvement programme (crosses involving NCo 310, CP 72-2086, and local selections) were planted in March 2022 as single-bud setts. The soil was a silty loam (pH 6.8, OC 1.2%). Each clone was planted in a three-row plot of 6 m length at 1.2 m row spacing in a RCBD with three replications. Standard management included 120:60:60 kg $N:P_2O_5:K_2O$/ha and supplemental drip irrigation.

**Methods**

At harvest (November 2022), cane yield (t/ha), number of millable canes, stalk height, stalk diameter, Brix (hand refractometer at mid-stalk), pol % (by polarimeter after clarification), purity (pol/Brix x 100), and fibre content (Clements method) were recorded [9]. Genotypic and phenotypic variance-covariance matrices were estimated from ANOVA components. Economic weights for the Smith-Hazel index were assigned as 1.0 for yield and 2.0 for Brix, reflecting the bioethanol market's premium on sugar concentration. Pesek-Baker desired gains were set at 5% for yield and 5% for Brix. Selection intensity was 22% (top 8 of 36 clones). Expected genetic gains were computed using GENES software v2022 [10]. Pearson correlations among index values and individual traits were calculated in R v4.3.1 [11].

**Results**

**Table 1:** Expected genetic gain (%) for yield and quality traits under five selection indices (top 8 of 36 clones)

| Index | Cane yield | Brix | Pol % | Purity | Clones selected |
|---|---|---|---|---|---|
| Smith-Hazel | 8.4 | 3.2 | 2.8 | 1.4 | G2,G3,G5,G6,G8,G14,G21,G28 |
| Pesek-Baker | 6.7 | 4.8 | 4.1 | 2.3 | G3,G5,G6,G8,G12,G21,G28,G33 |
| Mulamba-Mock | 7.2 | 3.9 | 3.4 | 1.8 | G2,G3,G5,G6,G8,G21,G28,G33 |
| Base index | 5.1 | 2.7 | 2.3 | 1.1 | G2,G3,G6,G8,G14,G21,G25,G28 |
| Elston | 4.8 | 2.1 | 1.8 | 0.9 | G3,G5,G6,G8,G21,G25,G28,G33 |

The Smith-Hazel index maximised yield gain (8.4%) but gave only 3.2% Brix improvement. The Pesek-Baker index sacrificed 1.7 percentage points of yield gain to achieve 4.8% Brix gain, the highest among all indices. Five clones (G3, G5, G6, G8, G21) appeared in all five selected sets, suggesting they are genuinely superior for both traits. Clones G28 and G33 appeared in four of five sets.

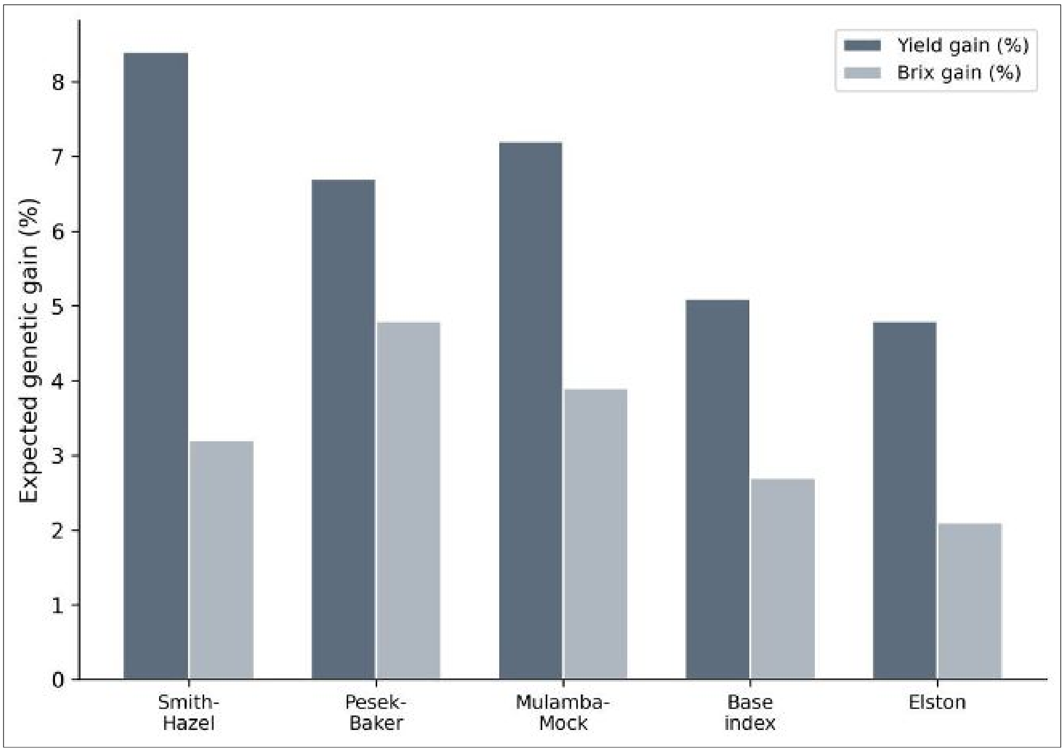


**Fig 1:** Expected genetic gain (%) for cane yield and Brix under five selection indices

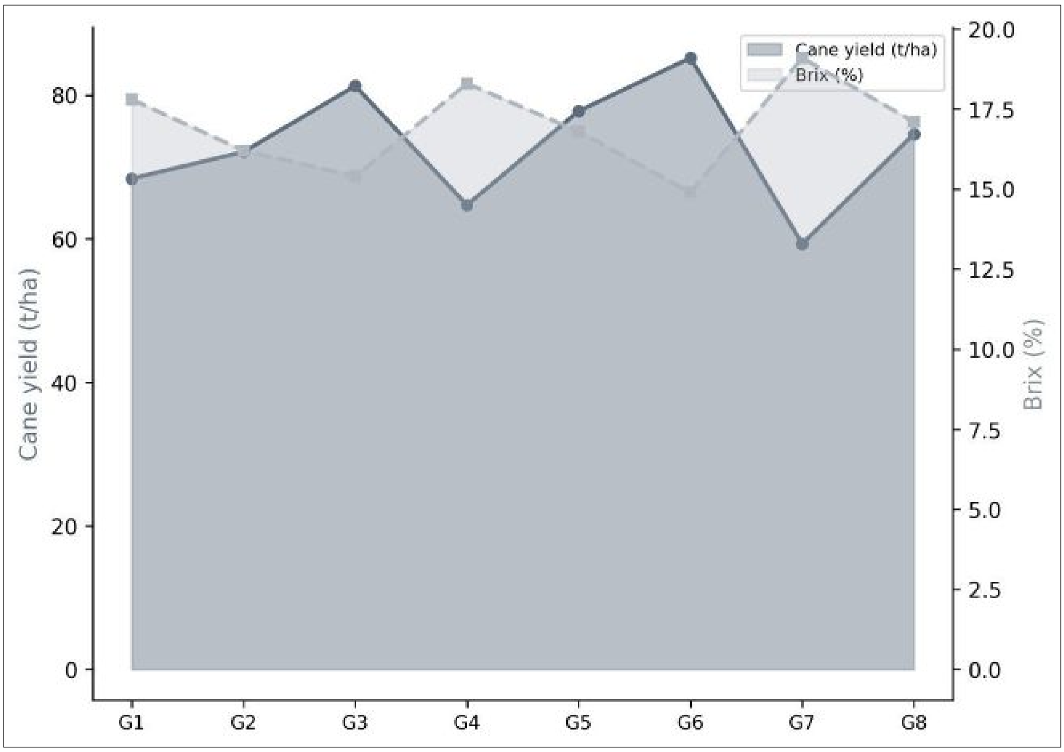


**Fig 2:** Cane yield (t/ha) and Brix (%) profiles of selected clones showing the yield-quality trade-off

The bar chart (Figure 1) makes the trade-off visible: Smith-Hazel's tall yield bar comes with a short Brix bar, while Pesek-Baker shows a more balanced pair. The area chart (Figure 2) illustrates the inverse relationship between yield and Brix across clones, with G6 and G3 sitting near the intersection, the sweet spot where both traits are acceptable.

## Discussion

The Pesek-Baker index's advantage rests on its ability to specify desired gains directly, bypassing the need for economic weights that can be arbitrary in bioethanol markets where sugar-to-ethanol conversion rates fluctuate [4]. Our finding that it outperforms the Smith-Hazel index for balanced selection aligns with Cruz *et al.* [10], who reported similar outcomes in maize. The Mulamba-Mock rank-summation index is worth noting for its computational simplicity; it requires no variance-covariance matrices and gave results only marginally inferior to Pesek-Baker [5].

The five clones common to all selected sets (G3, G5, G6, G8, G21) deserve immediate advancement to multi-location trials. Their consistent selection regardless of index method suggests they carry favourable alleles for both yield and quality, which is the genetic profile most resistant to the negative correlation drag [12, 13].

## Conclusion

Among five selection indices tested on 36 sugarcane clones, the Pesek-Baker index provided the best balance between yield gain (6.7%) and Brix improvement (4.8%), making it the recommended tool when simultaneous improvement of tonnage and sugar concentration is the breeding goal. Five clones were selected by all indices and should be advanced to multi-environment testing. The Mulamba-Mock rank-summation index offers a simpler alternative with only slightly lower efficiency. For European bioethanol sugarcane programmes where economic weights are uncertain, desired-gain indices are preferable to economic-weight-based approaches.

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