

STRATEGIES USED FOR VARIETY SELECTION IN THE BREEDING PROGRAMME AT THE ZIMBABWE SUGAR ASSOCIATION EXPERIMENT STATION

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Abstract

Sugarcane breeding is expensive because the plant is perennial and the frequency in obtaining superior clones is low. Plant breeding involves developing strategies that will increase the probability of identifying superior varieties. This paper discusses the strategies used to select varieties with high sugar yield, good disease and pest tolerance and adaptable to the South-East Lowveld of Zimbabwe. Potential strategies for the future are described. In the Single Stools and Single Lines stages (unreplicated), the strategy is to discard all genotypes with undesirable traits. In the Variety Observation Trials, Advanced Variety Trials and Pre-release Variety Trials (replicated stages) the strategy is to select those varieties that show an advantage over the control cultivars (N14 and NCo376) in yield, cane quality, pest and disease tolerance and ratooning ability. Future strategies could focus on molecular genetic markers, physiological genetic markers and possibly replicating varieties at the single lines stage.

Keywords: sugarcane, plant breeding, varieties, selection

Introduction

Breeding new varieties of sugarcane is expensive because it is a large, perennial plant that requires large areas of land and other resources, and also because the frequency of obtaining good clones in the progeny from a cross between two existing varieties is invariably low (Allison, 1985). Rojas (1974) observed that it was not surprising that most breeding programmes yield an average of less than one new and superior variety every year despite the testing of millions of seedlings. Selection must therefore be carried out on as large and efficient a scale as possible to help ensure that at least some agriculturally acceptable clones are produced in the breeding programme (Allison, 1985).

Plant breeding can be termed a 'numbers game'. The production of a good variety from any cross cannot be guaranteed, and instead, plant breeding involves choosing strategies that increase the probability of identifying new superior varieties (Butterfield, 1995).

To illustrate some concepts in plant breeding, a character of an individual seedling, for example 'yield', may be represented as:

$$Y = G_A + G_I + E \quad (1)$$

G_A is the component due to the additive genotype. This can be predicted from parents, and is equivalent to the breeding value. G_I is the component due to the interactive genotype. This is due to chance combinations of genes that cannot be predicted. E is the environmental effect that can be controlled by selecting on appropriate sites, and by planting the right variety on

the right site. In short-term breeding, the aim is often to make many crosses, and select the superior individuals with fortuitously good combinations of genes, thus exploiting the G_1 component of the character.

The Zimbabwe Sugar Association Experiment Station (ZSAES) breeding programme was initiated in 1976 in collaboration with the South African Sugar Association Experiment Station (SASEX). Prior to this, all imported varieties tested had proved unsuitable, as they produced lower cane and sugar yields than NCo376 and had poor ratooning ability (Anon, 1977, 1979, 1981, 1983, 1985). Variety NCo376, despite its susceptibility to smut, remained the best variety. With advice from SASEX, it became clear to the industry that varieties with potential comparable to NCo376 could only emerge from a local breeding programme (Anon, 1977).

The objective of the selection programme was to produce adaptable, high yielding, high sucrose and smut tolerance varieties (Zhou, 1996a, 1998). Low sucrose is a problem in early harvested crops. Smut is one of the major diseases affecting the Zimbabwe sugar industry. Seed from 100 crosses is provided by SASEX each year and seedlings of these crosses are grown and screened under local conditions at ZSAES and on four estates (Zhou, 1996b).

Strategies and procedures used in the breeding programme will influence the phenotypic characteristics of sugarcane varieties that are eventually released to growers (Butterfield and Nuss, 2002). Breeding and selection is generally focused on sucrose yield, sucrose content and tolerance to pests and diseases. Because of the high selection pressure placed on these traits, released varieties can vary widely in agronomic traits such as stalk characteristics that impact on harvesting efficiencies and management practices.

The greater emphasis on selection for smut tolerance and high sucrose in the early years of the programme resulted in varieties with lower cane yields, higher ERC % cane, fewer stalks, higher smut tolerance and lower fibre than NCo376 (Zhou, 1998). The result has been that some of the released varieties with particularly low stalk populations appear to have poor ratooning ability.

The strategies for breeding programmes should include developing disease tolerant varieties. The long-term control of important sugarcane pathogens is based on selecting and releasing varieties with satisfactory tolerance. The benefit of growing sugarcane varieties that minimise losses from diseases and pests can be demonstrated by quantifying the effect of diseases and pests on susceptible varieties. Estimates of crop losses in susceptible varieties range from 40% for ratoon stunting disease (RSD) and mosaic, when 100% stalks are infected, to more than 75% for smut when 100% of stools are infected (Rutherford *et al.*, 2002).

Ratooning ability in sugarcane varieties is the ability to maintain yield as the number of ratoons increase, and depends on genotype, environment and crop management (Chapman *et al.*, 1992). King *et al.* (1965) acknowledged that ratooning increased profits in a sugarcane growing cycle.

Stability is the ability of the variety to produce high and consistent yields over a wide range of environments, seasons and times of planting (Petersen, 1994). Stability analysis gives a measure of the response of a variety to favourable and unfavourable growing conditions.

ZSAES selection programme procedures

The ZSAES selection programme has five stages: single stools, single lines, variety observation trials (VOTs), advanced variety trials (AVTs) and pre-release variety trials (PRVTs). The last three stages are replicated.

Seed from 100 crosses is sown in January and transplanted into bricks in February after six weeks in the glasshouse. Each cross is split into three sets of seedlings that are randomised before transplanting into the bricks. The seedlings remain in the bricks until August, when they are transplanted into the field. The stools in the field are cut back during the last week of November to increase tillering and smut. Smut inspections are done every month and all smut infected stools are cut back before selection. A 24-stalk sample is taken from each cross in each replication in May of the following year, and a statistical analysis is done for the family sucrose content. Single stool selection is done in June. Stalk numbers, heights and diameters are measured. A Calibrat (Béchet, undated) is used to measure stalk diameter. The yield per stool is estimated using the formula:

$$\text{Yield of cane} = (P \div 40) \times H \times D^2 \quad (2)$$

where:

- P = stalk population or stalk numbers
- H = height in cm \div 30
- D² = diameter squared in cm (direct reading from Calibrat).

Selected stools are planted in single lines in July, and are harvested at 12 months of age. Nearest neighbour analysis (Coetzee and Brunkhorst, 2000) is used to identify superior varieties. Yield estimates are done on the top 50% of the lines, and used to identify better ratooning lines.

The selected lines are planted into VOTs and replicated three times. The same varieties are planted into smut inoculation trials (SITs). The plant and first ratoon crops are harvested at 12 months of age.

The selected VOTs are planted into AVTs early (May) and late (October), with at least four replications. The AVTs are harvested at 12 months up to the third ratoon crops. The varieties in the AVTs are planted into SITs. At harvest, each stalk in a 20-stalk sample is split to assess eldana damage. Varieties to advance to PRVTs are selected from the first and third ratoons.

The PRVTs are planted at ZSAES, Hippo Valley, Triangle, Mkwesine and Mwenezana estates. The Hippo Valley site represents clay loam soils, the Triangle site represents sandy loam soils, and the ZSAES and Mkwesine represent sandy clay loam soils (the dominant soils in the Zimbabwe sugar industry). Mwenezana is 200 kilometres from ZSAES, and represents loamy sand soils (Table 1). The PRVTs are planted and harvested early (March, April, May), mid (June, July, August, September) and late season (October, November, December). They are harvested up to the third ratoon crop. Pre-harvest samples are collected from the ZSAES site to monitor maturity of the varieties from eight to 12 months. At harvest, each stalk in a 20-stalk sample is split to assess eldana damage.

Table 1. Soil types and textures at Zimbabwe sugar association experiment station (ZSAES), Hippo Valley, Triangle, Mkwesine and Mwenezana Estates.

Site	% Clay	% Silt	% Sand	Texture class
ZSAES	24 ± 3,2	7 ± 1,2	69 ± 3,5	Sandy clay loam
Hippo Valley	40 ± 2,0	20 ± 2,2	40 ± 1,5	Clay loam
Triangle	17 ± 2,2	9 ± 2,7	73 ± 2,1	Sandy loam
Mkwesine	29 ± 3,3	9 ± 1,4	62 ± 4,0	Sandy clay loam
Mwenezana	11 ± 2,2	9 ± 3,9	81 ± 3,6	Loamy sand

Strategies used

The strategies used are generally divided into unreplicated (single stools and single lines) and replicated stages (VOT, AVT and PRVT) of the programme. In the unreplicated stages, the strategy is to discard all genotypes with undesirable traits. In the replicated stages the strategy is to accurately quantify the levels of the desirable traits compared with the control varieties (N14 and NCo376) and select those genotypes that show an advantage over the controls. In the unreplicated stages, the family performance determines the numbers selected, whereas in the replicated stages the individual variety is selected on its own merit. The replicated stages also help to assess ratooning ability, adaptability to early, mid and late season harvesting, yield stability over sites and years, and adaptability to different soils.

Single stools

At the single stools stage, the strategy is to discard all smut-infected stools, and these are cut back before selection. An analysis of percentage smut infection is done and more varieties are selected from the crosses with the lowest levels of infection. Another strategy is to select more varieties from crosses with high sucrose content. Varieties selected from those crosses with low sucrose content should have much higher cane yield estimates than those from high sucrose crosses. The yield estimate of each individual stool and the cross statistics are used in the selection. The strategy is to select more stools from crosses with high mean stool yield and high variance, and also to select the high yield stools from crosses with low mean stool yield but high variance. This strategy assumes that the high variance is associated with greater genetic variability in a cross. Stevenson (1965) noted that a wide genetic variation provides excellent material for selection, while Allard (1960) also noted that the crossing was done to create genetic variability for selection. The strategy is to select at least 10% of the stools.

Single lines

The strategy is to evaluate cross performance and select more varieties from high yield, high sucrose and disease tolerant crosses. This strategy gives attention to high yielding varieties in low yielding and low sucrose families with high variance, and also gives priority to varieties that show high yield estimates in the first ratoon crop, as they are likely to ratoon well. All varieties infected with smut are discarded.

Variety observation trials

This is the first stage where individual varieties are assessed. The strategy is to identify varieties with high cane, sucrose and sugar yields, that also ratoon well. The strategy aims to eliminate smut susceptible varieties through the smut inoculation trials (SITs) that are done parallel to the yield trials.

Advanced variety trials

The strategy at the AVT stages is to assess and select individual varieties with high cane, sucrose and sugar yields and desirable agronomic characteristics, and to test the varieties for adaptability to early and late season harvesting. The strategy involves testing for ratooning ability, and the crops are harvested up to the third ratoon. Further tests for resistance or susceptibility to smut are done in SIT trials, and susceptibility to eldana is also measured.

Pre-release variety trials

This stage assesses varieties for yield and sucrose content over a wide range of soils found in the South-East Lowveld of Zimbabwe. The strategy is to test for adaptability to early, mid and late season planting and harvesting at four sites with different soil types, and tests for ratooning ability of the varieties in the early, mid and late season planting and harvesting associated with these soil types. Stability analysis is used to assess varieties for wide adaptability and potential response to the varying growing conditions found in the industry. Maturity and age at harvest is also used to assess varieties for sucrose content when harvested at less than 12 months of age. Those varieties with exceptionally low sucrose contents at young ages will be tested further for the possibility of increasing their sucrose content using ripeners.

Strategies for future consideration

Various researchers have acknowledged the challenges of the early selection stages (Galvez and Empig, 1977; Lyrene, 1977; Mariotti, 1974, 1977; Roach, 1980; Shimabuku and Higa, 1977; Thomas, 1979). These challenges are caused by the genotype x environment interaction and the effect of competition on selection efficiency. Future strategies need to aim at addressing these challenges.

Molecular markers

Molecular genetics is likely to play a major role in the future as a selection strategy (Butterfield, 1995; Berding *et al.*, 1997). Molecular markers are small segments of DNA that are correlated with a particular trait. A marker can be used to screen a group of individuals for selection of those that have the marker. The use of markers will allow the elimination of all seedlings that do not have the marker, before the plants go into the first selection stage. This will reduce the number of varieties that go into field trials and make evaluation more precise. To utilise molecular markers to increase the probability of selecting a new variety, the number of seedlings raised must be increased. This would increase the number of plants with the marker going into the first stage selection. For success, a facility dedicated to mass screening for markers is required. Another strategy for using molecular markers would be to screen the parents before crosses are made. By ensuring that at least one of the parents in each cross has the marker, the proportion of progeny carrying the marker would be increased. This would be a more efficient strategy, and would require the screening of only a few hundred parents each year.

Physiological parameters

Work is being done to identify and quantify physiological parameters (Zhou *et al.*, 2003). Two new strategies can potentially be developed by combining the use of physiological parameters, modelling and existing selection strategies. Physiological parameters will allow modelling of canopy development suited to different environments. This understanding of canopy development can then be used in the selection process, where varieties that match the canopy development described by the model are likely to be suitable for, or easily adapted to, a particular environment. The other strategy is to identify physiological parameters for canopy development that are correlated to yield, and use the parameters as a selection criteria.

Replicating single lines

The biggest challenge for most selection programmes is how to accurately identify superior genotypes at early selection stages because of genotype x environment interaction. For those environments where stools grow large enough to provide sufficient seedcane (irrigated areas), replication can begin at the single lines stage with smaller plot sizes. This strategy would be an improvement on the current unreplicated single lines used in the selection programme to identify superior genotypes.

Summary

The main strategies used in the ZSAES plant breeding programme are designed to address the challenges of selection in unreplicated and replicated trials. In unreplicated stages, the strategy is to select more varieties from the superior families, while selection based on individual variety performance takes place in the replicated stages of the programme. The use of molecular genetics (genetic markers) and physiological parameters may help increase the numbers of genotypes that can be assessed. The strategy of replicating at the single line stages could improve the accuracy of identifying superior genotypes at early selection stages. However, this strategy will work only where the single stools grow large enough to provide sufficient seedcane for replicated trials.

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