

## REVIEW PAPER

# AN OVERVIEW ON THE SELECTION STRATEGIES IN SUGARCANE BREEDING PROGRAMMES

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## Abstract

*New sugarcane varieties identified for commercial cultivation are developed through a systematic selection procedure. As in most crops, G x E interactions reduces the selection efficiency and increase the complexity of the selection programme. Several breeding programmes demonstrated that family selection when followed by mass (individual) selection was superior in terms of genetic gain for the most important characters such as Commercial Cane Sugar yield, Cane yield, and Net Merit Grade. A liberal form of family selection is generally practiced and more clones are identified from the best families. The availability of objective data on family performance combined with the estimates of BLUP (Best Linear Unbiased Predictor) is essential for getting an overall improvement in the selection efficiency.*

**Key words:** Sugarcane – parental selection - Family selection – individual selection – selection index.

## Introduction

In a sugarcane improvement programme, identification of an elite clone for commercial cultivation is greatly dependant on the exploitation of genetic variability and more likely the efficiency of the selection procedure. Different methods of selection were developed to suit diversified needs of different countries. A selection cycle in sugarcane involves about four to six stages and takes 12-15 years to complete. Sugarcane breeder has to rely on the initial variability created during hybridization as subsequent stages are planted clonally. Only few clones are evaluated in advanced stages and as such there is no

opportunity for sexual recombination or to create new variability that the breeder can exploit.

## Parental selection and Cross Prediction Methods

Information on the breeding value of the parents as revealed by the progeny evaluation tests (Ramdoyal and Domaingue 1994) is the main criteria in the selection of parents besides the agronomic characters, disease reaction and flowering behavior of the parental clones. Hybridisation records provide important guidelines in the choice of parent clones in planning the cross combinations. As early stage data were based on indirect measurements, that is, visual assessment to estimate cane yield and brix to estimate sucrose content, efforts to estimate the breeding value of the parents was hampered due to lack of objective data on family or clonal performance.

The breeding information relied heavily on the percent of clones from a cross that are advanced to later stages. Specific crossing strategies could be designed, if we can identify genetically diverse parents in the present population. The coefficient of inbreeding can be used to express the level of homozygosity in an individual, while the coancestry between two individuals measures the genetic diversity between varieties. It is computed based on their pedigree, traced back to 6-8 generations. Promising ROC varieties of Taiwan were studied for its inbreeding coefficient and coancestry and it revealed that their parents were generally related as full or half sibs with some common ancestors.

## Information Technology system and molecular approaches in parental choice

In the Mauritius cane breeding and selection programme, a customized information technology system takes care of combining abilities in screening for proven crosses and for the judicious choice of clones of good combining abilities (Ramdoyal and Domaingue 1994) in

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experimental crosses or proven parent crosses. Parent clones are coded for agronomic traits, morphological attributes, disease reaction, flowering characteristics and breeding performance. Databases of the parental clones through a sound information technology system help in increasing the efficiency of parental choice and in sorting out parents for the crossing programmes aiming at specific objectives. For designing crosses for a specific agro-climatic zone, the system requires that at least one of the parents is adapted to the specified zone and resistant to major diseases prevailing in that zone. The present day developments in the field of molecular genetics and biotechnology, molecular characterization of parent varieties is feasible. This will provide useful information on existing genetic diversity and will allow a more rational use of the parental gene pool. Once the feasibility of marker assisted selection for traits of interest in the parent gene pool e.g. sugar content, adaptation and yield is established, it will help breeders in the early identification of superior parents for use in crosses and allows a faster recycling of new parents in the gene pool.

#### Univariate and Bivariate Cross Prediction Methods

A breeder is successful, if he is able to identify the best crosses in terms of their potential to produce commercially acceptable varieties. The earlier sugarcane workers used the frequency distribution curves of agronomic traits, by measuring random samples of seedlings/cross, to assess the merit of each cross. A visual grade score was applied to represent the relative worth of individual seedlings so that the family mean of such ratings bears a close relation with the mean cane yield per family. George (1962) reported that very poor genetic combinations could be discarded on the basis of their average performance. The potential of univariate and bivariate cross prediction techniques was assessed by Badaloo (1997) in two environments and over the seedling, the first and second clonal generations. The mean and square root of the phenotypic variance of each cross were used to calculate the predicted proportion of genotypes that are expected to be or less than the set target (PROB) for each trait. The PROB was compared to the observed proportion of genotypes that exceed the target (OBS) and the family mean (MEAN). Bivariate prediction was based on the methodology of Pooni and Jinks (1978) and Brown and Caligari (1988). Highly significant positive correlations between the predicted and the observed proportions of genotypes that are

expected to transgress the set target for most traits at each generation and at both sites. Breeders are interested in the relative ranking of crosses for characters of importance. There were highly significant correlations between the predicted and observed ranks for all traits studied. A rapid and reliable information on the parental clones could be generated based on replicated evaluation of testing sixty random seedlings per cross using a randomized complete block design which will be useful to the breeder in the choice of parents. In addition, family performance based on objective data collection will enable the evaluation and ranking of crosses in terms of their potential to produce desirable genotypes and the subsequent application of family or combined selection.

**Table 1.** Predicted and observed rank correlation coefficients at seedling stage

Trait	Correlation	
	BRES	PSES
Breeder's preference	0.86	0.76
Cane yield	0.94	0.82
Growth habit	0.97	0.96
Leaf stripping ability	0.96	0.92

Significance Levels 0.39 @ 5% and 0.55 @ 1%

BRES Belle Rive Experiment Station PSES Pamplemousses Experiment Station

Source: Ramdoyal & Badaloo (1998)

These findings have led to the large-scale application of the prediction methods on a larger number of crosses in the Mauritius breeding programmes since 1998. Selection records of the past, inherent parental characteristics and information on the breeding value of the parents, development of a customised information technology system based on relational databases, has led to an overall improvement in the efficiency in planning of crosses. The use of cross prediction as a new tool in increasing efficiency of the breeding programme has been emphasized.

#### Mating systems

The main mating systems available are the proven cross and the proven parent approaches both based on progeny performance and proven variety performance (Heinz and Tew 1987). Crosses with high advancement (proven crosses) were usually replanted in large numbers to

increase genetic gain by exploiting specific combining ability. The proven parent approach is based on the intercrossing of female and male parents of high breeding performance (Ramdoyal et al. 1998) and aims at increasing the probability of selecting superior genotypes with acceptable commercial attributes. As selection rates are subject to large environmental effects when single stools are grown in large seedling and first clonal populations, it is useful to determine relative selection rates in the clonal selection stages (Berding and Skinner 1987). The use of new elite clones as parents in crossing (experimental crosses) resulted in an increased rate of genetic progress in Hawaii (Tew 1987). The sugarcane breeders at India followed the well tested procedure of screening small populations in experimental crosses and later enlarging them into 'semi-bulk' and 'bulk' crosses if found promising for raising large populations. The practice of repeating past crosses that have given high percentages of selection and the continuous testing of increasing numbers of seedlings from such genetic combinations with the hope of selecting superior genotypes is believed to be unreliable. Greater advance and response to selection will be achieved from the selection of seedlings arising from new parent combinations as suggested by George (1959).

#### **Simulation of selection systems in seedling population**

Selection rates from original seedlings are generally high (10% to 30%) to reduce the possibility of discarding the superior varieties which may not express their full potential in highly variable original seedlings. There are several possible combinations of selection rates, plot sizes, replications and locations, and it is difficult to choose the optimum combination (Skinner 1961). Simulation of selection systems in Australia showed that many combinations give approximately similar results, although some may be inferior. Extensive simulation experiments is desirable because only a small proportion of possible combinations can be tested in practical selection experiments and because long-term experiments involving more than one stage of selection have large standard errors (Skinner et al. 1987).

Selection in the original seedlings is the least effective of all stages of selection because broad sense heritabilities are low for most characters, and it is too time-consuming and expensive to assess varieties for many important characters. However, it is a vital stage of selection because it provides the base population for the remaining and more effective stages of selection. Most cane breeders agree that selection should be very liberal, but many different approaches to selection have been developed.

#### **Family Vs Individual selection**

Individual selection is commonly practiced in original seedlings. However, a combined system of individual and family selection is already practiced in several countries. Environmental effects are very large in original seedling population, and it is necessary to select a fairly high proportion of the original seedlings in order to avoid discarding the superior ones. In addition to increased selection rates, family selection provides a method for achieving progress when large environmental effects occur.

#### **Heritability estimates in Individual and Family selection**

Estimates of broad sense heritability, response to selection, and correlations between characters in sugarcane have been extensively studied. The estimates of broad sense heritability and repeatability for stalk numbers, stalk diameter and brix during early stages of selection were given by James and Miller (1975).

Estimates of broad sense heritability on an individual and on a family basis are presented in Table 2. On an individual basis, heritabilities are low for most characters apart from rust resistance, smut resistance and brix. In the early stages, selection on an individual basis should be based largely on highly repeatable characters such as brix and disease resistance. However, selection for important characters with low heritability is effective in improving the population, despite low efficiency for individual clones. The heritabilities on a family basis are relatively high for many characters, indicating that effective selection on a family basis can take place.

**Table 2.** Heritability in the broad sense on an individual (and family) basis.

Character	Country			
	Australia	Hawaii	Fiji*	Argentina
Cane t/ha	0.17 (0.75)		(0.48)	0.10
Brix t/ha	0.16 (0.76)		(0.43)	
Net merit grade	0.20 (0.80)		(0.25)	
Brix	0.65 (0.90)	0.27 (0.53)	(0.55)	
Stalk number	0.26 (0.90)	0.13 (0.51)	(0.53)	0.06
Stalk diameter		0.30 (0.71)	(0.70)	0.44
Stalk length	0.32 (0.84)	0.21 (0.40)	(0.54)	0.24
Volume		0.10 (0.39)		
Rust resistance	0.51 (0.93)			
Smut resistance		0.56 (0.84)		

\* In the Fijian experiments, sucrose percent was measured, not brix.  
Source: Skinner et al (1987)

### Merits and demerits of individual and family selection

Environmental effects are usually large in original seedling populations. In this situation, both mass (individual) selection with high selection rates and family selection are appropriate. The heritability estimates for different characters studied in different countries clearly illustrates that estimates of broad sense heritability are low for most characters on an individual basis but might be quite high on a family basis (Table 2). For family selection, whole family is selected or rejected as units using the mean phenotypic value of the family. Progeny testing, based on the mean phenotypic value of the progeny, can be regarded as a modified form of family selection. In clonally propagated crops like sugarcane, modified family selection can be based on selection rates instead of mean values.

Individual selection for the most important characters (tonnes cane, tonnes Brix and net merit grade) is expected to be inefficient, about 80% of the variation being due to environmental effects with only 16 to 20% due to genotype. While family selection for these characters would be relatively effective, 75 to 80% of the phenotypic variation between families being due to genotype. Latter (1964) considered that, when heritability is in excess of 0.5, individual selection is superior to family selection. On this basis, individual selection would be superior for

Brix and rust resistance in Queensland, with family selection more efficient for weight of cane, weight of brix and net merit grade.

Family selection operates on the mean, whereas production of superior varieties depends on the variance as well as the mean, and possibly on other factors such as the type of distribution. Considering the merits of individual and family selection in sugarcane, families have had no commercial success in any country, commercial varieties being individuals (clones). Families have little or no direct commercial value, a family being valuable only if it includes superior individuals. A comparative study on systems of selection was made by Ramana Rao et al. during 1984. The base population had 2000 progenies drawn from 17 matings. The findings were that coefficient of variability was highest for stalk weight and lowest for brix. Six families were superior to their respective better parents for stalk weight while none for brix. Hence the potential for family selection for stalk weight was greater than for brix in this population. Stalk weight and brix were considered as target traits for the study of selection methods because they represent the principle components of sugar yield (stalk weight as principle component of cane yield and brix as index of sucrose). Three criteria viz., mean, mean + CD and per cent gain over base population were



used for family selection. Top twenty of the base population was selected based on individual merit for each of the two target traits. Gain by individual selection over mean of the base population far exceeded that from family selection. The selection of the best families based on their mean performance and further selection of individual clones based on their sugar yield in early stages would improve the efficiency of selection and increase heritability in the genetic populations being tested was suggested by Shanthi et al. (2008).

Statistical methods appropriate for rare superior individuals are not well developed, and it is not safe to assume that mean and variance alone describes the proportion of superior varieties in a family. If two families have similar high means and variances, one may contain superior varieties whereas the other may not, its high variance being due to some very poor individuals. Family selection based on mean and variance involves measuring each individual in a family, a costly procedure in original seedlings. Provided fairly high selection rates are used, it is probably more efficient to practice individual selection in single-planted original seedlings, using the selection rates (instead of means and variances) for family selection. Furthermore, selection rates integrate for each family all of the factors (mean, variance and type of distribution) likely to be important in production of superior varieties.

#### **Stage II and Stage III trials**

Selections from original seedlings are planted in one row plot which are 2 to 5 m long. Selection is usually conducted in the plant crop only, but ratoon crops may also be selected. Hogarth (1977) found that broad sense heritabilities were still very low (about 0.20) for yield characters at this stage, so that selection for yield should be liberal.

Selections from stage II trials are usually planted in two or three row plots. With larger plots, the effects of competition between varieties are narrowed and environmental variation is also reduced relative to genotypic variation. Hogarth (1973) showed that broad sense heritability for yield of cane on an individual basis was about 0.50 on a single site at this stage. Stage III trials are usually ratooned and it would be suitable for regional testing at more than one site if sufficient resources are available (Skinner 1972). Evidence of genotype x environment interaction for yield of cane is

reported from several countries, so there is a high probability that good genotypes will be discarded when selection is conducted on only site.

#### **Stage IV and Stage V trials**

The final two stages of the selection pathway involve testing varieties in replicated variety trials. A coordinated system of replicated variety trials covering the whole country is in practice in many countries. Randomized complete block designs are used with three or four replications and each trial is harvested in three successive years (plant, first and second ratoon). Replicated trials which can sample only a limited number of locations and seasons have serious limitations. Despite this, they provide the best clones for selecting new commercial varieties. They may be valid for selection purposes, despite poor prediction of commercial varieties.

#### **Varieties x Location interaction**

The major task of a sugarcane breeder is to select varieties that are consistently high in performance over a range of environments in different locations and different seasons. This selection is often inefficient due to G x E interaction that is the failure of the varieties to have the same relative performance in different locations. The optimum number of locations and years for variety trials depends on the size of the varieties x locations and varieties x years interactions. Multi-location varietal evaluation trials in a systematic sugarcane breeding programme would involve planting about 20 varieties in replicated design in several locations and replanting the trials with the same varieties on the same locations for 3 or 4 years, harvesting all trials as plant cane, 1st and 2<sup>nd</sup> ratoons (Skinner 1972). Determining the optimum number of locations is again important in early selection stages. The normal practice in different countries is to provide several locations to one to eliminate all but one or two varieties before large scale testing in mill areas. Large G X E interaction would make the latter procedure inefficient because most of the gains in selection would be lost when the selected varieties are planted in mill areas and the discarded group would include most of the potentially valuable commercial varieties. If the trial is conducted in several sites and seasons, the yield of all varieties at a site (general mean) can be used to provide a measure of that environment. The regression of the yields of individual varieties on these environments was used to measure adaptation and stability of varieties (Finlay and

Wilkinson 1963).

### Selection from ratoon crops

Ratoon evaluation is generally included in all selection programs because of the economic importance of the ratoon performance. Selection from ratoon crops in early stages is commonly practiced in many countries. It is very essential to balance the advantage of selection from ratoon performance against additional land requirements and the number of years required to select commercial varieties. Selection based on one or two ratoon crops increases the efficiency of the selection programme as varieties with prolonged ratooning ability can increase profits without increasing yields because of the lower cost of the ratoon crops.

### Simulated selection to optimize family selection

To investigate optimum selection intensities for family and individual clone selection (Kimbeng et al. 2001) an experiment was carried out in central Queensland. Families (replicated family plots) and random clones within each family plot were assessed for various characteristics, including cane yield, sucrose content, visual grade and brix in the plant crop of stage I trial. These clones were evaluated in stage 2 (first clonal stage) in the plant and the first ratoon crops. Response to selection in stage 1 was judged on the performance of corresponding clones in stage 2. The main objective was to simulate optimum rates of combined family and individual clone selection in stage 1.

The results confirmed that while family selection was effective in identifying families with a high proportion of elite clones, it was more efficient when combined with visual selection (Table 3). The efficiency improved further when clones with good visual grade were subjected to a brix test. Inferior clones were rejected on the basis of visual grade and brix, and considerably fewer clones were evaluated in stage 2. Enforcing a strict selection for brix led to the loss of a considerable number of elite clones. But when the cut-off point for brix was allowed to vary, depending on the visual grade, (for example a clone with low brix is accepted when the visual grade is high), the number of elite clones that would have been discarded dropped dramatically.

Based on the results from the simulations, individual clone selection rates of 40, 30, 25 and 10% were optimum

for families selection rates of 10, 20, 30 and 40%, respectively, when selecting families (Based on Net Merit Grade) in the plant crop and clones (based on visual appraisal) in the first ratoon crop. Individual clone selection based on brix was the best by taking into consideration the visual grade of the clone. These selection rates should be applied with some caution

**Table 3.** Gain from different selection strategies in Stage I as measured by performance in stage II

Selection strategy*	Appraised Stage I	Evaluated Stage 2	With NMG>9.0 Stage 2**	Gain %
Individual clone	2444	340	51	15.0
Family (F)	944	944	88	9.3
F + Visual grade	944	360	54	15.0
F + Visual grade + Brix	944	240	43	17.9

\* Only the top 40% of families are shown here.

\*\* Clones with NMG > 9.0 are considered to be elite clones and are selected to the next stage.

Source: Kimbeng & Cox (2003)

because they probably depend on the germplasm base and, as such, may differ in other programs.

### Factors influencing selection methods

The different factors which can influence selection systems adopted by sugarcane breeders are listed briefly

#### Size of the initial population

The approach of testing a very large number of seedlings and repeating the crosses over and over again in order to explore a large total population has been advocated by Hawaiian breeders (Warner 1953). Breeding programmes at Barbados and Mauritius showed that the extremely useful variants always appeared among the first few hundred seedlings tested in a cross. Sugarcane breeders at Coimbatore followed the well tested procedure of screening small populations in experimental crosses and later enlarging them into "semi-bulk" and "bulk" crosses if found promising for raising large populations.

### **Sample size of the population**

Precise and rapid evaluation of family performance progeny size of the cross is very important. Skinner (1972) found a sample size of 75 is sufficient to determine the cross performance. Wu et al. (1978) in their study with polycross progenies found that a sample size of not less than 40 would estimate the mean with acceptable variance in respect of stalk number, diameter, stalk length and brix percent. In India, a sample size of 40-50 seedlings was found to be essential for the estimation for most of the traits while the size has to be stepped up to 100 for yield, stalk number and stalk weight (Bhagyalakshmi and Ethirajan, 1988). A progeny test with small number of individuals is routinely used to estimate the selection rate for the evaluation of proven crosses in sugarcane breeding programs in Australia. Approximately 70 seedlings / cross were found to be sufficient to predict superior crosses and increase the incidence of elite clones in Hawaiian breeding programme (Tai et al. 2003).

### **Selection criteria**

In view of the enormous initial population, some amount of culling is imposed in seedling stage in order to reduce the population to a manageable size and increase the frequency of desirable clones in clonal generations. Defects for which seedlings/clones are eliminated in different countries are poor vigour, defects in agronomic characters and susceptibility to pests and diseases. In Hawaii, seedlings showing mosaic are eliminated and in India juvenile testing for red rot disease is practiced in early clonal stages to avoid susceptible types getting forwarded. Selection response for a complex character like yield depends on its association with component characters. Path analysis studies in sugarcane by Bhagyalakshmi (1985) indicated that stalk number and weight alone had direct effect on yield and all other components had only indirect effect through stalk weight. Brix percent showed low or no association with yield or its components indicating the probability of getting selections combining high yield and quality is very less.

### **Selection intensity**

The intensity of selection refers to the proportion of individuals that are saved for subsequent stages. In sugarcane, selection intensity seems to vary in different countries and with different stages of selection and the

number of character selected for. Skinner (1972) opined that 20 to 30 percent selection at seedling stage was effective in retaining superior clones. Bhagyalakshmi (1985) reported that the frequency of superior clones was based on stalk weight at 25 % level. Selection for brix at 25 percent in stage I retained high yielding clones indicating that selection for both yield and quality is possible though at a lower frequency in inter-varietal progenies.

### **Competition**

Skinner (1961) found that in small plots of sugarcane, genetic differences in competitive ability for yield were much larger than true genetic differences in yielding ability. The genotypic correlation between true yielding ability and competitive ability was estimated to be 0.39 % by Skinner (1961) and 0.47 by Skinner and Hogarth (1978). Competition inflates the phenotypic and genotypic variances. These results indicate that selection in small plots should be very liberal.

### **Number of characters selected**

The demands on a crop variety are always complex in the sense that high levels of expression are required for a considerable number of characters (Simmonds 1969). For example, selecting at 10% for seven independent characters would demand not less than ten million plants for an expectation of one superior variety. It is impossible for any plant breeding program to operate efficiently on this scale. Superficially it may seem reasonable to select 10% of the varieties for as many as seven characters, but in practice the number of characters which can be selected severely is very small. In practice, the breeder does not usually select a certain proportion of the varieties on the basis of each character separately but rather selects a reasonable proportion after considering all characters. However, the implication of the above example cannot be avoided, gain from selection for any particular character often being much smaller than expected, and some characters included in selection showing no measurable improvement.

### **Selection index and Grading**

Construction of selection indices based on the information derived from an appropriate set of families on the inter-relationships amongst characters which determine the cane and sugar yields is essential and direct

measurements provide a more efficient way to enhance improvement in multiple traits. Since several characters are considered during selection, index method is the main method effectively applied in sugarcane (Miller et al. 1978).

### Rank based selection indices

Wijesuriya et al. 1997 developed rank indices in an experiment with nine biparental families. The characters, stalk length, H.R. brix and rind hardness were chosen for selection at initial stages. Stalk length, purity, brix and fibre % were selected to construct the index for intermediate stages. The indices constructed for initial and intermediate stages of selection are as follows:

#### Index for selection at initial stages

$$I_{\text{INT}} = 0.3 (\text{rank of stalk length}) + 0.4 (\text{rank of H.R. brix}) + 0.3 (\text{rank of rind hardness})$$

#### Index for selection at intermediate stages

$$I_{\text{INTER}} = 0.3 (\text{rank of stalk length}) + 0.2 (\text{rank of purity}) + 0.2 (\text{rank of brix}) + 0.3 (\text{rank of fibre \% (fresh weight)})$$

The constructed indices are of the form  $I = a_i R_i$  where,  $a_i$  is the economic weight and  $R_i$  is the rank given for the  $i^{\text{th}}$  trait to identify phenotypic superiority.

### Statistical methods to estimate family performance

Several methods have been proposed to estimate the potential of sugarcane families to produce superior individuals (elite genotypes), including factors for superior performance (FSP) by Arcenuax et al. (1986), the probability of exceeding a target value (PROB) (Milligan and Legendre 1991) and a univariate cross prediction method (Chang and Milligan 1992). The factors for superior performance (FSP) are easy to use, but a FSP value can only be obtained after the original seedlings have been carried through all stages of selections. The univariate cross prediction method requires extensive data collection. Tai et al. (2003) adopted multiple regression analysis to select the best predictive model for the progeny performance based on the selection rate. Results indicated that the frequency distribution of selection rates was markedly skewed

toward higher performance in both small progeny tests and the regular seedling program.

The Best Linear Unbiased Predictor (BLUP) to estimate the breeding value allows data from a diverse range of mating designs, relatives, and precisions to be combined into a single breeding value for each trait and genotype. The real advantage of the BLUP over other statistical models is that, it can handle large, highly unbalanced data sets generated from routine progeny evaluation trials.

### Gains from family selection for the selection index

Breeders at the BSES (Bureau of Sugar Experiment Stations), Australia generally select the top 30 – 40% of families based on family mean data. Differential selection rates are used within families, whereby more clones are selected out of the top 10% families, with progressively fewer clones being selected for the next 20% to 40% of families. Kimbeng et al. (2001) analyzed data from four years (1992-1995) of the family selection and reported that more clones were selected from the top families than was actually necessary. Different combinations of rates for family and individual clone selection within families were investigated. Seedlings from 114 full-sib families were evaluated at the BSES's Central Sugar Experiment Station during 1991. Families and random clones within families were assessed for different traits in the plant and first ratoon crops. Selection response in stage I was estimated on the mean performance of plant and first ratoon crops of the corresponding clones in stage 2. It was reported that individual clones was most efficient when clones had qualified a visual yield grade (VYG) test were also selected for brix. Net Merit Grade (NMG) is a selection index incorporating tonnes cane per hectare (TCH), commercial cane sugar (CCS) and other agronomic characters of economic importance. Family selection intensities of 10, 20, 30 and 40%, appeared to be optimized when combined with individual clone selection rates of 40, 30, 25, and 10%, respectively. Results indicated that the gains from family selection for Net Merit Grade (NMG) was mostly greater than at higher selection intensities and decreased as the selection intensity approached 100% (Table 4). Thus, family



**Table 4.** Effect of family selection for the selection index, NMG in stage 1 as measured by performance of clones in stage 2

Rate of family selection in stage 1	Gain from selection %				Elite clones that would have been discarded *%
	TCH	CCS	TSH	NMG	
10	12.68	0.64	13.40	15.15	77.03
20	8.82	0.86	9.60	10.90	66.22
30	7.75	0.80	8.58	9.82	51.35
40	5.80	0.94	6.79	8.15	40.54
50	2.82	0.91	3.77	4.87	35.81
60	3.12	0.93	4.04	5.17	24.32
70	2.90	0.65	3.52	4.34	18.24
80	2.38	0.66	3.00	3.76	9.46
90	1.73	0.45	2.17	2.70	2.70
100	0.00	0.00	0.00	0.00	0.00

\* Clones with Net Merit Grade > 8.9

Source: Kimbeng, et al. (2001).

selection was effective in identifying families with a high proportion of elite clones. Kimbeng et al. (2000) suggested that families with moderate to low NMG that have high CCS but low TCH and vice versa can be targeted for routine family selection.

#### **Selection via simulated individual BLUP based on family genotypic effects**

A new selection strategy for the initial stages of sugarcane improvement, based on the methodology 'simulated individual BLUP (BLUPIS)', which promotes a dynamic allocation of individuals selected in each full-sib family, using BLUP as a base for both the genotypic effects of the referred families and plot effects was proposed by Resende and Barbosa (2006). Australian sequential selection (among families selection followed by mass selection) (Kimbeng and Cox 2003), and modified sequential selection (Bressiani, 2001) use family information and are therefore superior to mass selection. The optimum selection strategy would be through genotypic values predicted by individual BLUP that would use simultaneously information on family and

individual for selection. BLUPIS determines the number of individuals to be selected per family, the total number of clones to be advanced, and the number of families that contribute to selected individuals. By this way, a smaller number of better clones are advanced, increasing the efficiency of the selection process and reducing costs of the improvement program.

This review has emphasized the selection principles and selection methods practiced in the sugarcane breeding programmes in different countries. Decisions on the selection strategy to use and the number of clones to be promoted to advanced stages will ultimately depend on the available resources. However, as stated by Cox and Stringer (1998), selection in the early stages should be designed to make genetic improvement and some form of liberal family selection may be warranted as superior clones can be found in relatively poor families also. Family selection combined with individual clone selection for visual grade and brix was very effective in increasing genetic gain. Constant and sustained efforts are required to refine the techniques for the judicious choice of parents and further identifying crosses that have the greatest potential for producing commercially acceptable genotypes.

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