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Resistance breeding in sugarcane (*Saccharum officinarum* L.)

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Abstract

Resistance breeding in sugarcane *Saccharum officinarum* L against red rot is described in detail in this review for its utilization in the development of resistant varieties of sugarcane.

Key words : Sugarcane, *Saccharum officinarum*, resistance breeding

Introduction

Sugarcane is one of the most important industrial crops only next to the textile in India and occupying about 8 percent of the total cultivated areas of the country. It is essentially a tropical crop, but is grown successfully in a larger area in subtropical belt of the country also. About 70 percent of the cane area is cultivated in U.P. Bihar, Punjab and Haryana under subtropical climate and contribute a larger amount to the total pool of the sugar production of the country.

Trend of monoculture cultivation during sixties and seventies with varieties like Co. 312 and Co. 1148 gave the great shock to the sugar industry in the sub-tropical region when variety Co. 312 was knocked down by red rot. Red rot is a serious disease of sugarcane. It causes a rot of seed cuttings that commonly results in faulty stands of plant cane or some times complete failures, reductions in stands of stubble or ratoon crops because of the rotting of the underground parts of the stem from which the crops arise, and annual losses of sucrose in mill cane from infection of the stalks that usually follows injury by the sugarcane borer, *Diatraea saccharalis* [1-4]. Similarly, varieties Co. 453, BO 11, BO 54 and CoS 510 etc, were eliminated from sub-tropical belt of India. Now variety Co. 1148 is going out of cultivation from larger areas of Haryana, U.P. and Bihar due to red rot. In spite of this deadly disease, no systemic studies on breeding for red rot resistance have so far been carried out except to screen the genetic material and to utilize the same source of resistance in breeding programme. Therefore, systemic studies are required, to be undertaken to know about the genetical aspect of the disease for formulating an effective breeding programme to develop resistant varieties. Sugarcane breeding was started in Java in 1880 and subsequently in India in 1912. The interspecific hybridization programme, which formed the basic structure of these efforts has resulted in the evolution of varieties with wide adaptability and tolerance to disease which facilitated cultivation of sugarcane under wide environmental conditions.

The early sugarcane breeding programme were aimed at identifying varieties for sub-tropical India, to replace the poor yielding Indian Sugarcane (*Saccharum barberi*). The breeding followed by selection gave emphasis to adaptability, yield, quality improvement and disease resistant by utilizing *S. spontaneous, S. officinarum* and *S. barberi*. This resulted in the production of outstanding varieties, which were better yielding as well as tolerant to the major disease like red rot. However, recurrent epidemics of red rot resulted in the replacement of varieties, which succumb to the disease. The evolution of new races of red rot pathogen, is regarded as the major factor for the breakdown of the resistance. The lack of adequate level of resistance to the changing race picture of the fungus, is also a major cause for rapid breakdown of the newer varieties.

Breeding work done at the Sugarcane Breeding Institute (SBI), Coimbatore, represented the first attempt in improving the subtropical sugarcane. The parents employed for hybridization were genetically wider than in most other countries.

Sugarcane breeding differs from other crops due to its high polyploidy, hetreozygosity cytogenetical features like unreduced gametes, parthenogenesis and chromosome elimination.

Two main lines of breeding followed at SBI, Coimbatore, are production breeding for southern region and resistance breeding for northern region against red rot and pests. Red rot occurs in tropics as well as in subtropics. Yield and quality are the main criteria for

selection only when decline records certain levels of yield and quality of it is tested for red rot before commercial exploitation.

Breeding for red rot resistance

So far, there is no chemical control of red rot except the varietal resistance. Breeding for resistance of red rot, is therefore, the only solution of the problem. There are endemic areas in sub-tropical India for this disease, hence, breeding resistant varieties for the problematic areas is of prime importance and of great challenge to the breeders and the pathologists. However, for a successful breeding programme on red rot resistance, breeder must be well acquainted with the host parasite relationship, varietal resistance and susceptibility method of testing classes of resistance, sources of resistance, inheritance of the disease and nature and number of pathotypes/races prevailing in that zone. It is therefore, essentially an integrated programme of breeders and pathologists.

Varietal resistance

Resistance of a plant to any pathogen is a hindrance in spread of the disease in the plant to the extent of its morpho-economic survival in the presence of pathogen and environment suitable for the spread of the disease. Durable resistance is often achieved against disease that express less or non-specification of the race pathogens into specific cultivars. The control of resistance may be monogenic or polygenic with additive effect, since, varying degrees of tolerance is obtained in different genotypes against this disease from highly susceptible to complete resistance. Also, there are varieties, which are susceptible when tested artificially but maintains fairly good field resistance. In such varieties escape or avoidance mechanism prevails. In sugarcane this resistance is of two types viz., mechanical and bio-chemical or genetical. Mechanical resistance refers to the morphological structures of the plant which prevents the early or spread of the pathogen into various host tissues like thickness of cuticle, epidermis, hardiness, position of vascular bundles and compactness of the bud scales etc. [5, 6]. Presence of lignified schlerenchyma, low sugar in nodal tissues and the cross walls of the xylem vessels of the vascular bundles also restrict the pathogen entry and spread in the plant.

Biochemical resistance or protoplasmic or genetical or physiological resistance refers to counter-acting reaction in protoplasm of the host tissues to protect it in the spread of the mycelium of *Colletotrichum falcatum*. In resistant varieties there is neither quick dark red zone formation CoH 14, CoH 15 or pith formation in Co 89003. Also several phenolic compounds like ferulic acid, cinnamic acid and chlorgenic acids have been found responsible for resistance [7-10].

Resistance source

The inheritance of red rot resistance in sugarcane is indiscriminate, i.e. crosses between susceptible clones sometimes produce resistant clones [11, 12]. Also the degree of resistance of the parents makes little difference in producing the higher frequency of resistant progenies [13, 14]. Hence information whether a genotype itself is resistant or susceptible is important but the combining ability of the parents and heritability of the trait is of greater significance. The good general combiners must be utilized in the breeding programme for developing resistant clones. However, several workers [15-18] have reported sources of red rot resistance. Virk [19] have reported genotype Co7314 as a good general combiner, which transmit resistance into 50.0 to 84.6 percent progenies. *Saccharum officinarum* L as a source of red rot resistance can be utilized in the breeding program. Similar results were obtained by several workers (20-22) (Table 1).

Table 1. Information on red rot screening reaction of *Saccharum spp* [20-22]

Species	Reaction					Total canes
	R	MR	MS	S	HS	
S. officinarum	7	15	14	33	210	279
S. barberi	1	3	3	6	5	18
S. sinense	2	6	3	1	9	21
S. robustum	2	8	9	9	37	65
S. spontaneum	109	114	26	54	12	315

Source: Sugarcane Genetic Resources I-III, Sugarcane Breeding Institute, Coimbatore

Similarly in *S. occifinarium* Pargun is also a good source of resistance. Though a number of hybrid canes developed through intervarietal crosses are also resistant but breeder has to evaluate such genotype for its combining ability for red rot resistance.

In sugarcane, a breeder can identify the source of resistance by raising the seedling of crosses involving a common parent. The progenies of these crosses may be tested and the combinability of the tester may be evaluated based on the frequency of the resistant clones from these crosses at the initial stage itself. Red rot observation may be taken after two months of inoculation and disease index (0-9) may be calculated [23]. The resistance, tolerance, escape avoidance mechanisms may prevail in genotype and must be evaluated properly. Pathotype attacking Co-1148 appears to be new in India as this variety was resistance to all the strains of *Colletotrichum falcatum* from various parts of India [24]. Information on sugarcane genetics also shows the limited applicability of simple Mendelian inheritance and has emphasized the importance of important characteristics. A survey of the literature indicates that only limited information is available on inheritance.

Inheritance of red rot

Since, the disease is sensitive to environmental changes therefore, much information on this aspect is perhaps not available. However, various workers [25, 26] have reported that single gene in autotetraploid does not segregate always in a simple (a typical single gene autotetraploid) ratio so the probability of the polyploid cannot be completely excluded. The diploid behaviour might be due to the gradual chromosomal shift with meiotic irregularities like restriction and differentiation due to inversions and interchanges etc, which may change a multivalent to bivalent, resulting a polyploid to diploid segregation ratio. Choudhary [27] however observed different ratios (1:3, 3:1 and 1:5) for resistance to susceptible clones. (Table 2).

Table 2. Segregation for red rot resistance in various crosses of sugarcane (27)

Crosses	Observed frequencies		Total	Ratio	χ^2 value	P-value
	Resistant	susceptible				
CoJ64 × Co 1148 (S × S)	8	27	35	1:3	0.038	0.7-0.9
Co 1148 × Co 7717 (S × R)	34	41	75	1:1	0.48	0.3-0.5
Co 1148 × Co 775 (S × R)	39	142	181	1:3	0.832	0.3-0.5
Co 1148 × CoJ 64 (S × S)	16	70	86	1:5	0.005	0.9-0.095
Co 1148 × Co 7314 (S × R)	23	8	31	3:1	0.041	0.7-0.9
Co 1158 × Co 1148 (S × S)	11	28	39	1:3	0.213	0.5-0.7
Co 7704 × Co 1148 (R × S)	22	28	50	1:1	0.72	0.3-0.5
Co 1158 × Co 7717 (S × R)	24	26	50	1:2	0.02	0.7-0.9

Table 3. Good general combiners and better cross combinations

General combiner	Specific combiner	Remarks
Co 775	Co 11458 × Co 775	For resistance & agronomic traits
Co 1148	Co 47803 × CoS 510	For quality and red rot resistance
CoH 7803	CoH 7803 × Co775	For quality and red rot resistance
Co 7314	Co 7314 × Co 1148	For quality ad red rot resistance
Co510	Co7704 × Co 1148	For quality & agronomic traits
Co 7704	CoJ 83 × Co 62198	For quality and red rot resistance
CoJ 83	CoJ 83 × BO 91	For quality and agronomic traits

Source: Annual Research Report, HAU, RRS, Uchani

They further stated that few genes with additive effect governed the disease. Resistant to highly susceptible (HS) and intermediate (MS&S) categories were suggested to be proportionate to the number of loci having dominant or recessive alleles in a particular genotypes and interaction thereof. Meiotic irregularities were also responsible for such ratio in sugarcane.

Breeding approaches for red rot resistance

(a) Conventional approaches

(i) Selection of Parents for crosses: Parents with high general combining ability for red rot resistance should be utilized in the breeding programme. In general, it has been observed that the progenies of these crosses involving resistant parents tend to be more towards resistant or moderately resistant. Therefore, it is essential to identify the resistant and good general combiner source of resistance. Variety, Co7314 and Ço 7704 have been found as good general combiners for red rot resistance [19]. Several genotypes viz., BO 90, BO 91, BO 102, BO 104, CoJ 59 Co 7314 and CoS 767 have been reported to be resistant to red rot for endemic zone of Uttar Pradesh, Haryana and Punjab and may be utilized by the breeders in their crossing programme. The genotypes having high fibre content with good juice quality may be successfully utilized as a source of resistance particularly in Terai belt of sub-tropical India. The resistant source can be identified through the line × tester mating design in sugarcane.

A part from the good general combing breeders should also search out some specific cross combination like Co 1148 × Co 775, CoH 7803 × CoS 510, CoH 7803 × Co775, CoJ 83 × Co 62198 etc (Table 3) for red rot resistance with desirable agronomic traits. These elite crosses have been found generating resistant and desirable segregants. Therefore like other crops in sugarcane also information on general and specific combing abilities are equally important.

(ii) Population size: For effective selection programme in sugarcane it is being presumed till present that since sugarcane is highly heterozygous and complex polyploid, a large population is required to raise and to select a desirable clone. However, it has been observed that, if the general combining ability of the parents and specific combining ability of the crosses are known, then a random population of about 500-600 plants per cross will represent truly to a large population of any cross to select a genotype of desirable traits. It is because that the range of variability does not deviate significantly in a small random population for various characters then a large population of the same cross. Therefore, the version of raising a large population of only few elite crosses does not held true. Hence a small but random population of many crosses with known combinability is advocated for better results. This

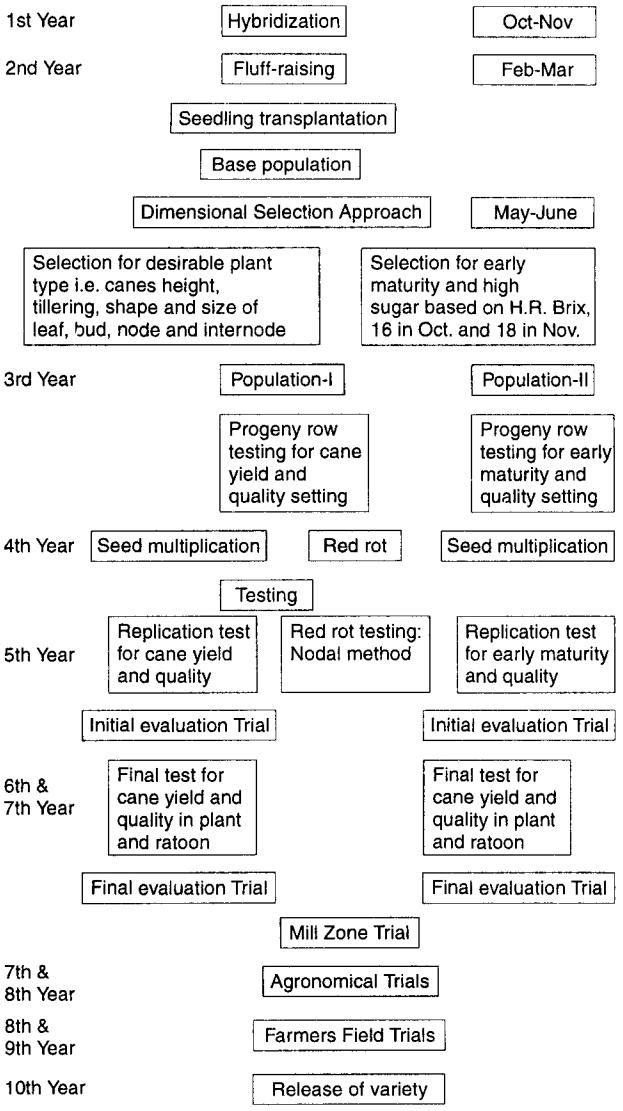
version holds true to select genotype to red rot with other agronomically desirable traits.

(iii) Selection parameters: The selection cannot be made effective without the knowledge of the degree and type of association between character. Correlation and path analysis studies in sugarcane revealed that the fibre content is positively correlated with red rot resistance, tillering, ratoonability etc. However, fibre content is negatively correlated with the total POL in sugarcane variety CoH 77. CoH 77 is a high yielding red rot resistance line with good ratoonability and high POL in juice. But the variety had shown poor POL in sugarcane only due to high fibre content and poor juice extraction. The POL in sugarcane should therefore, be the selection parameter in stead of POL in juice, To evolve a resistant and high sugared variety, it is therefore essential to reach a compromise both for fibre and disease resistance. hence, a moderately resistant/susceptible variety with high juice extraction will be more desirable than a variety with the complex resistance and high fibre content.

(iv) Pathway of selection and screening for red rot: The clonal selection in sugarcane is taken up in the first segregation population. However, for better results many workers [27, 29] have advocated selection from ratoon of the seedlings in stead of seedling stage, itself, since there is no strict positive correlation between seedling and setting for most of the traits. It is desired to keep the ratoon of the seedlings for selection programme. One or two canes of these selected clones may be put separately for red rot testing through artificial plug method. Inoculating the mixture of the available pathotypes of that zone should be used for red rot testing by artificial plug method. The progenies of these clones are evaluated for morphological and quality (H. R. brix) traits. Desirable clones coupled with red rot resistance and grouped for early and late maturity should be advanced for further evaluation. The same cycle of selection and screening is continued until promising clones are entered in final yield evaluation trials. It has been observed that high sugared and early maturing genotype, in general, are more red rot prone. However, some genotypes are otherwise maintaining field tolerance and it is, therefore, suggested to evaluate such high sugared but susceptible genotype (plug method) for their field tolerance. Such evaluation can keep the ratoon of the clones formation through plug method.

(v) Dimensional approach of selection: It can be described as follows :

The cane yield and the sugar recovery are the traits of interest from the cane growers and the sugar industry point of view respectively. Since yields and quality are negatively associated therefore, a variety containing both the traits will be an ideal one. The



past experience and results of selection in this crop indicated that a plant ideotype, combining high quality, disease resistance, ratoonability, non-lodging and high yield with high adaptability is merely a dreamful thought. The G × E interaction studies revealed the interaction effect of the greater magnitude for cane yield than the quality. Being the quality and quantitatively traits independently inherited, the selection should be exercised independently both for yield and quality in the base population (seedling ratoon of the seedlings). In these dimensional approach of selection of two different populations, i.e. for yield (Population - I) and for quality (Population - II) are formed through a specific standard criterion for each group. In the first year, the selection is restricted only to the yield and its components keeping aside the quality traits in population-1 whereas, the second population is formed based on the quality only (i.e. H.R. Brix). For population-I, the selection criterion is the plant ideotype with good

tillering, moderate cane thickness, intermediate internode, medium height, drooping foliage, non-spring leaf sheath and solid cane whereas for population-II, as specific standard is fixed for brix, i.e. more than 18% at eight months in age of the seedlings (seed to test). In second year a part of the seed (sett) of both the populations is screened against red rot. rest of the seed is planted separately in augmented design for progeny tests (setting stage-I). In 3rd year, the progenies of only release clones based on red rot resistance and yield for population -I and the quality for population-II are raised to increase the seed for further evaluation (setting stage-II). These lines are evaluated for their respective merits and their components again alongwith red rot reaction. The selection pressure is also put for ratoonability of the selected clones from the setting stage-I for both the populations. However, more selection pressure should be put on to population-I, at this stage and lines will be rejected based on the poor ratoonability and below yield level of the standard checks. In the fourth year, the selected clones from both the population are evaluated in a completely randomized block design separately for cane yield, quality red rot and insect pest resistance and ratoonability. The most promising lines showing significant superiority over respective standard shall be advanced and cross-examined. If genotype from population II excels the yield of plant and ratoon crop of population I and its checks and combiners are having desirable traits, then the only aim of breeder is fulfilled. The final recommendations to identify or to release any line thus be made based on their performance in this trial, at the farmer's field and sugar mill farms accordingly.

(b) Non conventional approaches

The sugarcane being highly heterozygous and complex polyploid although, produce enough variability for further selection through conventional breeding. However, there are enough scope for varietal improvement through non-conventional breeding method in this crop. The mutation breeding and biotechnology have emerged as most attractive methods in crop improvement programmes in recent years. In sugarcane these methods can be applied broadly as follows :

(i) Mutation: In sugarcane it is most suitable for creating genetic variability. However, induced mutation have been reported useful for disease resistance such as red rot [30, 32] and also for other morphological characters (22, 33) have reported the importance of mutation breeding in sugarcane and have developed red rot resistant mutant from a susceptible commercial variety CoJ 64. Similarly, the SBI, Coimbatore have developed a spineless mutant of Co-7717 without altering its agronomical traits. But till now it has not made any success story.

(ii) Tissue culture: In sugarcane the tissue culture was initiated in 1961, at Hawaii (USA). However, the sugarcane breeders are putting their efforts to alter the conventional breeding programme. In sugarcane, the tissue culture may be used for creation of genetic variability and micropropagation. A part from the mass propagation, which has real, significance as one of the applied areas of this technology in sugarcane, the somatic embryogenesis is also important for gene transfer. Through conventional breeding it is very difficult to produce isogenic lines. However, haploids can be produced by anther culture or pollen culture technique and by doubling the chromosome of these haploids or dihaploids can easily be produced which can be used for further breeding programmes. The intergeneric crosses can also be made possible. This technique after overcoming the barriers of sexual incompatibility and sterility of hybrids through embryo rescue, somatic cell hybridization *in vitro* selection for disease resistance, abiotic stress like drought and high salt conditions and selections for associative symbiosis and DNA recombination through genetic engineering are other possible areas of interest where this technology can be used.

Recent review of red rot resistance breeding

Choudhary [27] observed different ratios (1:3, 1:1, 3:1 and 1:5) for resistant to susceptible genotypes in response to red rot (*Glomerella tucumanensis*) in the progenies of 8 crosses involving 7 varieties. According to them the disease is governed by a few genes with additive effects, resistant to highly susceptible and intermediate categories were suggested proportional to the number of loci having dominant or recessive alleles in a particular genotype. Meiotic irregularity was also implicated in the ratios. Parent Co 7314 generated the most resistant segregants. Ramji Lal [33] inoculated 35 clones of different crosses inoculated with a mixture of 5 isolates of *Colletotrichum falcatum (Glomerella tucumanensis*). Five of the crosses appeared resistant but same clones of the same crosses showed reaction ranging from resistant to highly susceptible. Alexander [34] evaluated clones of *Saccharum officinarum, S. barberi, S. sinense, S. robustum and S. spontaneum* to red rot (*Glomerella tucumanensis*). Of these six *S. officinarum*, one *S. barberi, two S. sinene,* two *S. robustum* and 108 *S. spontaneum* genotypes resistant to red rot are listed. Virk and Satyavir [35] evaluated in 1983-86, 16 varieties of sugarcane for stable resistance to red rot (*Glomerella tucumanensis*) using plug, method and nodal methods (which involved inoculating the plants using a hypodermic syringe and placing the inoculum suspension in the axil of two adjacent leaves respectively). CoS 767, CoA 7602 and Co 7305 showed stable resistance when inoculated by both methods while CoC 671, CoM 7211, CoS 802,

Co 7321, CoC 772 and CoJ 75 only showed resistance when inoculated by the nodal method. It was concluded that the plug method was best as the environment had a smaller impact on infection using this technique than it did with the nodal method. Singh *et al.* [36[evaluated in 1986-1989, 10 varieties of sugarcane for resistance to red rot (*Colletotrichum tucumanensis*) by inoculation by the plug and nodal method, using five virulent strains of the pathogen. Only two varieties viz., UP 12 and UP 15 showed moderate resistance to all strains when inoculated by both methods. Wang *et al* [37] evaluated a total of 45 varieties in the field and in green house (high humidity for resistance to *Leptosphaeria taiwanensis* following artificial inoculation. Results from field and greenhouse studies were consistent and F 167 (control), F 170, F 175, F 177, F 178, ROC 1 and ROC 2 were highly resistant. In another experiment 42 varieties were evaluated in the laboratory for resistance to *Physolopora (Glomerella tucumanensis)* following inoculation by the borer mycelium or the drill tooth pick methods. Both methods gave consistent results and F 134, F 154 and M 94.63 (control) were highly resistant. Kalaimani *et al.* [38] evaluated 81 sugarcane (*Saccharum officinarum*) genotypes which were promising for other attributes for their reaction to *Colletotrichum falcatum (Glomerella tucumanensis*) at Cudo during 1989-91. Only two genotypes CoC 772 and C 85436 were resistant. C 82059 released in 1991 as CoC 91061 for general cultivation in Tamil Nadu and is a good substitute for CoC 671 having superior cane yield. Pandey *et al* [39] evaluated 81 genotypes for resistance to *Colletotrichum falcatum (Glomerella tucumanensis)* at Lucknow during 1982-85, 12 were resistant or moderately resistant with CoLK 7710 and CoLK 8002 the most resistant), 27 showed intermediate reactions and the remainder were susceptible. The highest yielders of the moderately resistant group were CoLK 8001 (415.6 tonnes/ha) and CoLK 8002 (402.6 tones/ha).

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