Breeding for Resistance to Stem Borer (*Chilo partellus* Swinhoe) in Sorghum

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Abstract

*Stem borer (*Chilo partellus *Swinhoe) is the most important pest of sorghum [*Sorghum bicolor *(L.) Moench]. Progress has been made in developing borer-resistant breeding lines with moderate yield and acceptable grain quality. Sorghum variety, ICSV 700, has high levels of stem borer resistance across several seasons and locations. Borer resistance is a quantitatively inherited trait governed by additive and nonadditive genes. Epistatic gene effects are more pronounced under artificial borer infestation. Cytoplasmic effects appear to be present.*

Résumé

***Sélection de sorghos résistants aux foreurs des tiges :** Le foreur des tiges (*Chilo partellus*) est le plus important ravageur du sorgho (*Sorghum bicolor*). On a fait des progrès dans la création de lignées en sélection résistantes au foreur ayant un rendement moyen et une qualité de grain acceptable. La variété ICSV 700 a montré de hauts niveaux de résistance au foreur lors de plusieurs saisons de cultures et sur plusieurs sites. La résistance aux foreurs des tiges est un caractère quantitatif contrôlé par des gènes additifs et non additifs. Les effets de gènes épistatiques sont plus marqués en infestation artificielle. Des effets cytoplasmiques seraient également présents.*

Introduction

Sorghum grain yields are generally low (500-800 kg ha^{-1}) under farmers' conditions in the tropical world. One of the reasons for low yields is crop damage by insect pests. Among the many insect pests which attack sorghum, stem borers constitute the most widely distributed and serious group throughout the world (Young and Teetes 1977, and Seshu Reddy ' Davies 1979b). Yield losses due to stem borer quite high (80%) in tropical sorghums. These insects are internal feeders, not much affected by predators and parasites, unfavorable environmental conditions, or insecticides. Host-plant resistance appears to be an economic, efficient, and a long-term solution to manage stem borers either alone or in combination with other methods of control. Research on host-plant resistance to sorghum stem borers has been done primarily with the spotted stem borer, *C. partellus*. In this paper, we review the work done on breeding for resistance to the spotted stem borer.

Screening Techniques

Development of an effective and reliable screening technique that ensures a uniform and desired level of

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ICRISAT Conference Paper no. CP 491.

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1989. International Workshop on Sorghum Stem Borers, 17-20 Nov 1987, ICRISAT Center, India. Patancheru, A.P. 502 324, India: ICRISAT.

crop is the backbone of a host-plant resistance breeding program. These requirements can be met either by selecting a location where the pest occurs regularly with adequate severity (hot-spot location) or by testing plant material under artificial infestation with laboratory reared insects. Other agronomic practices can also be used to increase the insect infestation such as planting time, use of diapausing insect population, trap crops, fertilization, and irrigation.

A three-step screening methodology was adopted for stem borer resistance testing in the All India Coordinated Sorghum Improvement Project (AICSIP) (Pradhan et al. 1971). The first step was a general screening carried out in single-row plots under natural infestation. Selected materials were then entered in multi-row replicated trials under natural infestation. The third step was confirmation of resistance in replicated trials under artificial infestation. ICRISAT employs a similar methodology (Fig.1) with some modification, and has worked with heavy natural infestation at Hisar and artificial infestation at ICRISAT Center.

Screening at a hot-spot location requires basic knowledge of insect population dynamics so that planting time can be adjusted to ensure that the susceptible stage of the crop coincides with the peak activity period of the insect. For instance, at Hisar, severe borer infestation has been recorded for 10 years (1977-87) on sorghum planted during the first fortnight of July (10-15 Jul). Early in the project

Table 1. Testing locations for stem borer resistance in AICSIP, 1977-86.[1]

	Leaf injury		Stem tunneling	
Location	Years tested	Effective years	Years tested	Effective years
Delhi	8	4	10	6
Indore	7	4	10	1
Udaipur	6	0	9	4
Navsari	5	4	6	0
Akola	6	2	9	7
Hyderabad	4	0	5	2
Dharwad	6	1	9	5
Coimbatore	4	0	4	3
Rahuri	5	2	6	0
Parbhani	1	0	7	2

1. Effective screening implies a minimum score of 5 for leaf injury (1-9 scale) and 25% tunneling on the susceptible genotype.
Source: AICIP 1977-86.

Table 2. Years of effective screening for stem borer resistance in AICSIP trials 1977-86.[1]

	Leaf injury		Stem tunneling	
Year	Locations tested	Effective locations	Locations tested	Effective locations
1977	-	-	8	1
1978	7	2	5	1
1979	7	4	8	5
1980	6	3	9	6
1981	6	4	9	3
1982	9	4	10	5
1983	5	0	7	1
1984	-	-	6	1
1985	4	0	7	1
1986	9	0	9	5

1. Effective screening implies a minimum score of 5 for leaf injury (1-9 scale) and 25% tunneling on the susceptible genotype.
Source: AICSIP 1977-86.

AICSIP concentrated testing for stem borer resistance at Delhi, Udaipur, and Indore, where natural stem borer incidence was high. Additional test locations have been added in recent years to record data on stem borer infestation on the most susceptible sorghum genotype (Tables 1 and 2). The data indicate that in any year, sufficient infestation did not occur at all locations. In 4 out of 7 years, locations were less than 50% effective in terms of leaf injury (score of 5 on a 1-9 scale), and in 7 out of 9 years, incidence of stem tunneling was insufficient at all locations. This indicates that the pest attack was often too low at some of the testing locations and/or the susceptible stage of the crop did not synchronize with the peak activity period of the insect.

Screening sorghum under artificial infestation has been accomplished by many researchers in India using laboratory reared insects. Stem borers have been reared both on natural food (Singh et al. I and on synthetic diets (Chatterji et al. 1968, Dang et al. 1970, Siddiqui et al. 1977, and Seshu Reddy and Davies 1979b). In AICSIP, laboratory reared insects have either been released as first-instar larvae (Singh et al. 1983) or as blackhead egg masses in the leaf whorls (Jotwani 1978).

ICRISAT Center's artificial rearing laboratory supports the screening of 2-3 ha of sorghum each season by raising enough first-instar larvae to provide an infestation rate of 5-7 insects per individual plant. Details of this rearing method, field infesta-

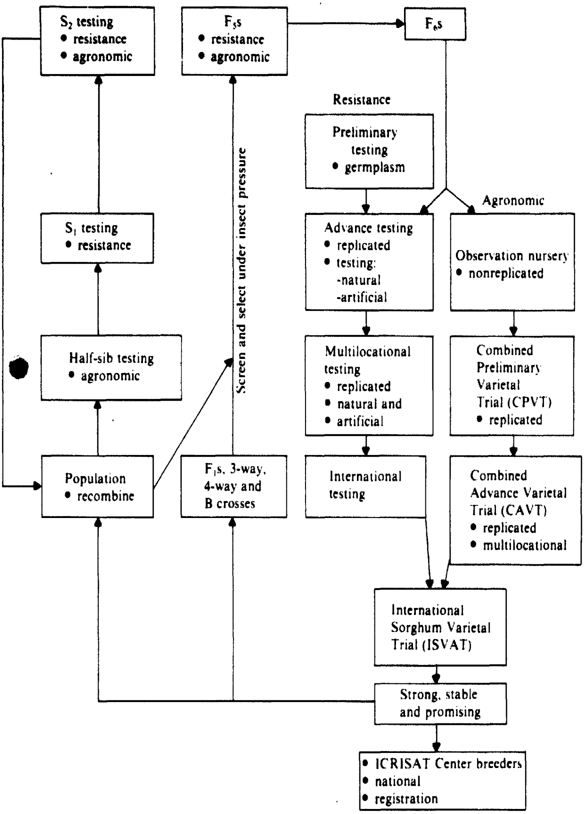

Figure 1. Screening and breeding for insect-pest resistance.

tion, and evaluation for stem borer resistance has been described by Taneja and Leuschner (1985).

Selection Criteria

Symptoms of stem borer attack in sorghum are leaf injury, tunneling of stem and peduncle, and deadheart formation. Each of these symptoms is not necessarily related to grain yield loss. Although leaf injury is the first indication of borer attack, it has no clear relationship with yield loss (Singh et al. 1983). Leaf injury score varies over time because the plant recovers by producing new leaves. However, Singh and Sajjan (1982) observed a positive relationship between leaf injury score and grain yield loss in maize.

Stem tunneling by borers is also not related to grain yield reduction in sorghum (Singh et al. 1983, Pathak and Olela 1983, and Taneja and Leuschner 1985). Stem and peduncle damage can be critical, however, under two situations: (1) if tunneling results in breakage of stem or peduncle; and (2) if tunneling interferes with plant nutrient supplies by destroying the vascular system of the stalk. These two situations depend on the critical stage of the crop at time of infestation, and borer density.

The most critical damage by the stem borer, which results in significant grain yield loss and low plant stand, is the formation of deadhearts. Taneja and Leuschner (1985) observed highly significant and negative relationship between number of deadhearts and grain yield of sorghum (r = -0.9). Singh et al. (1968) indicated that as a parameter of stem borer attack, the percentage of deadheart was the most stable criterion for differentiating degrees of resistance.

Researchers argue strongly that resistance screening should be based mainly on deadhearts, while stem tunneling and leaf injury can be subsidiary criteria. In AICSIP the deadheart parameter was used as a prime criterion for the evaluation of sorghum material for stem borer resistance until 1969. Only leaf injury and stem tunneling are being used as selection criteria at the present time. At ICRISAT, evaluations are done on the basis of deadheart incidence, with leaf injury and stem tunneling as secondary criteria.

Identification of Resistant Sources

The earliest report on sorghum cultivars resistant to spotted stem borer (*C. partellus*) is by Trehan and Butani (1949). Pant et al. (1961) and Swarup and Chaugale (1962) reported certain sorghum varieties to be relatively less-damaged by the stem borer than others. A systematic screening of the world sorghum collection for resistance to stem borers was started in 1962, in India, under the cooperative efforts of the Accelerated Hybrid Sorghum Project, Indian Council of Agriculture and Research (ICAR), the Entomology Division of the Indian Agricultural Research Institute (IARI), and the Rockefeller Foundation (Singh et al. 1968, Pradhan et al. 1971, and Jotwani 1978). This work has been continued by AICSIP and ICRISAT.

General screening of sorghum germplasm for stem borer resistance was carried out under natural infestation at Delhi from 1964 to 1969. A total of 8557 lines were screened, and 1375 lines were selected for further testing (Table 3). Evaluation of these lines was done on the basis of deadheart formation.

Retesting of selected germplasm accessi carried out at Delhi, Udaipur, and Pune 1966-76 and a number of accessions were selected for confirmation of resistance (Table 4). The resistance in selected genotypes was confirmed by artificial infestation at Delhi, Udaipur, Indore, and Kanpur (Table 5).

At ICRISAT, stem borer resistance work began in 1979 using artificial infestation (Seshu Reddy and Davies 1979). Later on, testing of the material also began at Hisar under natural infestation. Out of nearly 16000 germplasm accessions tested over several seasons, 72 genotypes have been found to be resistant (Table 6). Most of these sources are of Indian origin; however, some genotypes are from

Table 3. Screening of sorghum germplasm for stem borer resistance under natural infestation.

Year	Accessions		Selection criteria[1]	Incidence susceptible control
	Screened	Selected		
1964	3492			
1965	461	507	DH	80% (32-100%)
1967	890	74	LI, ST	ST =58%
1968	2906	794	LI, DH, ST	DH=32% ST =30%
1969	808	0	LI, DH	

1. Selection criteria: LI = leaf injury, DH = deadhearts, ST = stem tunneling.

Source: Singh et al. 1968, and Pradhan et al. 1971.

Table 4. Screening of sorghum genotypes for stem borer resistance under natural infestation in replicated trials, AICSIP 1966-76

Year	Accessions Screened	Accessions Selected	Selection criteria[1]	Incidence on susceptible control	Promising genotypes
1966	488	57	LI, DH, ST	-	IS Nos. 1034, 1099, 1151, 1499, 5479
1967	104	73	LI, DH, ST	DH-38% ST-50%	IS Nos. 1034, 1044, 1087, 1115, 1137, 1151 3950, 4522, 4569, 4776, 4912, 4994, 5030
1968	91	42	LI, DH, ST	DH-30% ST-28%	IS Nos. 1044, 5030 5606, 5615, 5656
1969	151	40	LI, ST	ST-72%	IS Nos. 1151, 4246, 4307, 4339, 4868, 4870, 5072, 5599, 5629, 5653, 5662
	100	16	LI, DH	DH-29%	IS Nos. 1005, 1019, 1509, 1522, 1594, 4522, 4780, 4793, 4797, 4833, 4866, 4870, 4897, 4912, 5615, 5701
1973	28	13	LI, ST	ST-23%	JML-2, AKL-5, Gangapuri, NCL-3, PCL-3, Aispuri
1976	23	23	LI, ST	-	VZM-2B, P 151, SPV 61

1. Selection criteria: LI = leaf injury, DH = deadhearts, ST = stem tunneling.
Source: Singh et al. 1968, Pradhan et al. 1971, and Jotwani 1978.

East Germany, Nigeria, Pakistan, Sudan, Uganda, USA, Yemen Arab Republic, and Zimbabwe. Stability analysis, of 61 resistant genotypes tested over six seasons indicated that the most stable resistant lines were IS 5470, IS 5604, IS 8320, and IS 18573 (Taneja and Leuschner 1985).

sistance Mechanisms and Associated Factors

Knowledge of resistance mechanisms and associated factors in donor parents is important in transferring resistance into elite cultivars. The role of various mechanisms and morphological and chemical factors has been emphasized by several workers. A detailed review of this has been covered by Taneja and Woodhead in their paper Mechanisms of Stem Borer Resistance in Sorghum (these proceedings).

Genetics of Resistance

Knowledge of genetics of resistance and tolerance is prerequisite to determining appropriate breeding methods to be used in developing insect-resistant cultivars. There is limited information available, however, on inheritance of resistance to sorghum stem borers. Resistance to spotted stem borer *C. partellus*, measured in terms of leaf feeding injury, percentage deadhearts, and stem tunneling is polygenic (Rana and Murty 1971, Kulkarni and Murty 1981, Pathak and Olela 1983, Pathak 1983, Rana et al. 1984, Hagi 1984, and Pathak 1985). Rana and Murty (1971) indicated that the inheritance patterns of primary (leaf injury) and secondary (stem tunneling) damage were different. Resistance to primary damage was predominantly controlled by additive and additive × additive gene effects while additive and nonadditive gene effects were important for secondary damage. Height and maturity traits were also found to be associated with different

Table 5. Confirmation of stem borer resistance in sorghum lines under artificial infestation, AICSIP 1966-1975.

Year	Number of lines		Selection	Incidence on susceptible	
	Screened	Selected	criteria[1]	control	Most promising lines
1966	5	5	DH	-	IS Nos. 1034, 1099, 1151, 1499, 5479
1968	59	36	LI, DH, ST	DH-18% ST-34%	IS Nos. 1099, 1115, 1458, 3967, 4118, 4283, 4316, 4522, 4651, 4776, 4780, 4897, 5115, 5469, 5613, 5656
	17	7	LI, DH, ST	DH-9% ST-33%	IS Nos. 1044, 1115, 1151, 4764, 4776, 4994, 5030
1969	20	6	LI, ST	ST-76%	IS Nos. 1056, 4552, 4651, 4747, 4782, 5470
1972	8	7	LI, ST	ST-87%	IS Nos. 4424, 4689, 4827, 4841, 4875, 4934, 5031
1973	98	25	LI, ST	ST-65%	IS Nos. 2122, 4329, 4799. 5251, 6046, 6101, 6119
1975	25	12	LI, ST	ST-37%	-
	12	6	LI, ST		GIB, BP 53, Aispuri, Nag-B, SPV 16 and R 147B

1. Selection outline: LI = leaf injury, DH = deadhearts, ST = stem tunneling.
Source: Pradhan et al. 1971; Jotwani 1978.

types of damage. In a diallel cross analysis in F_2 and F_1 generations, Kulkarni and Murty (1981) reported that resistance to percentage deadhearts is governed by both additive and nonadditive types of gene actions, but predominantly by additive genes. The general combining ability (GCA) effects over generations indicated that at least one parent should be a good combiner in breeding for stem borer resistance. In another diallel cross analysis, Pathak and Olela (1983) showed that resistance to deadhearts (prim-

Table 6. Sources of resistance to sorghum stem borer identified by ICRISAT, 1979-86.

Origin	IS Number
India	1044, 1082, 1119, 2195, 2205, 2375, 2376, 4273, 4546, 4637, 4756, 4757, 4776, 4881, 4981, 5075, 5253, 5429, 5469, 5470, 5480, 5538, 5566, 5571, 5585, 5604, 5619, 5622, 8320, 131(17742, 17745, 17747, 17750, 17948, 17966, 18333, 18366, 18662, 18677, 21969, 22039, 22091, 22145, 23411,
Nigeria	7224, 18573, 18577, 18578, 18579, 18580, 18584, 18585
USA	2122, 2123, 2146, 2168, 2269, 10711, 20643
Sudan	2263, 2291, 2309, 2312, 22507
Uganda	8811, 13674
E.Germany	24027
Ethiopia	18551
Pakistan	9608
YAR	23962
Zimbabwe	12308

Source: Taneja and Leuschner 1985.

ary damage) is governed predominantly by additive genes. They also found that inheritance patterns of primary and secondary damage are different. Both resistance and tolerance mechanisms for stem borer resistance exist in sorghum.

Hagi (1984) studied the genetics of resistance (percentage deadhearts) to spotted stem borer under natural and artificial infestations, and found different patterns of resistance under these two situations. Major gene effects (additive and dominant) were found to be contributing under natural infestations while epistatic effects (additive × additive, additive × dominant, and dominant × dominant) were predominantly contributing under artificial infestation, where the expression of major gene effects is masked. In turn, his studies indicated that the ovipositional nonpreference mechanism is controlled by major gene effects, while antibiosis is influenced by epistatic gene effects. The epistatic gene effects were found unstable over environments.

ak (1985) reported that susceptibility is dominant over resistance in susceptible × resistant (S×R) and susceptible × tolerant (S×T) crosses, while resistance was dominant over susceptibility in the tolerant × resistant (T×R) cross. Both resistance and tolerance mechanisms were found to be operating and independently inherited. Estimates of low heritability, genetic coefficient of variability, and expected genetic advance indicated the usefulness of recurrent selection to simultaneously improve the level of stem borer resistance, tolerance, and yield in sorghum.

Breeding for Resistance

Breeding for stem borer resistance started in 1966 in India, when a number of resistant parents were included in the breeding program (Pradhan et al. 1971). Since then a number of identified sources of ce have been utilized by crossing them with agronomically elite susceptible parents. A list of promising derivatives and their parents is given in Table 7. A borer-resistant parent, BP 53, has produced a number of promising derivatives, particularly when crossed with IS 2954. Other good resistant sources have been Aispuri, M 35-1 and Karad Local. Stem borer resistant sources have also been utilized in developing high-yielding varieties and hybrids in AICSIP (Table 8).

One of the objectives of the Stem Borer Resistance Program initiated at ICRISAT was to strengthen the sources of resistance by accumulating diverse genes from different sources. To meet this objective, a population breeding approach was chosen. A sorghum population resistant to shoot pests, (shoot fly and stem borer) has been developed using ms_3 and ms_7 male-sterility genes. So far, a total of 175 genotypes have been fed into this populations (85

Table 7. Most productive borer resistant sources and their promising derivatives.

Resistant source	Other parent	Promising derivatives
BP 53	IS 2954	Selection nos. 165, 169, 174, 177, 300, 364, 384, 434, 446, 468, D nos. 124, 167, 168, 172, 175, 244, 259, 350, 358, 365, 366, 367, 609, DU nos. 98, 135, 245, 293, P nos. 108, 151, 235, U 376
	IS 84	Selection no. 602
	IS 3691	DU 291, U 369
	CK 60B	E 302, U nos. 37, 218, 35, 373
	IS 3954	E 303
Aispuri	IS 3922	Selection nos. 829, 835, D 832
M 35-1	IS 539	DU 19
	IS 531	U 83
IS 4906	CK 60A	P 37
IS 5837	CK 60A	P 82
IS 10327	CK 60A	P 90

Source: AICSIP 1972-85.

Table 8. Stem borer resistant sources utilized in AICSIP.

Resistant source	Promising varieties/hybrids
Aispuri and its derivatives	CSV 5, SPV nos. 14, 58, 80, 96, 99, 101, 102, 104, 105, 107, 108, 110, 115, 168, 265, 270, 271, 374, 378, 475, 513, 516, 716, 727, 743, 744, CSH 7R
IS 3541 (CS 3541)	CSV 4, SPV nos. 60, 104, 122, 126, 245, 292, 297, 303, 312, 346, 351, 354, 371, 386, 741
M 35-1 (IS 1054)	CSV 7R, SPV nos. 19, 270, 364, 440, 510, 727
GM 1-5	SPV nos. 9, 33, 34, 183, 268
Karad Local	CSV nos. 2, 6, SPV nos. 8, 13, 17
BP 53 (IS 1055)	CSV 3, 26, 70, 513, 688
PD 3-1	CSH 8R

Source: AICSIP 1975-86.

stem borer resistant sources and their derivatives, 76 shoot fly resistant sources and their derivatives, and 14 elite genotypes). After six cycles of random mating under borer-infested conditions, this population has shown good improvement for agronomic features and resistance. The shoot pests resistant population is being advanced by using (S_2) cyclic recurrent selection as outlined in Figure 2.

A comparison of 135 fertile derivatives (S_2) of the shoot pest population and 130 advanced progenies from pedigree breeding was made for stem borer resistance at ICRISAT Center under artificial infestation, and at Hisar under natural infestation, during the 1986 rainy season. In general, the population derivatives showed better levels of resistance under both types of infestation compared with progenies derived through pedigree breeding (Fig.3). The population derivatives showed a good level of borer resistance, 6%, compared with only 0.6% resistance of the pedigree progenies.

Transfer of resistance into improved genotypes, initiated through the pedigree breeding approach has utilized a number of resistant sources (Table 9). Most productive are IS 1082, IS 3962, IS 5604, and IS 5622. The most promising derivatives are ICSV

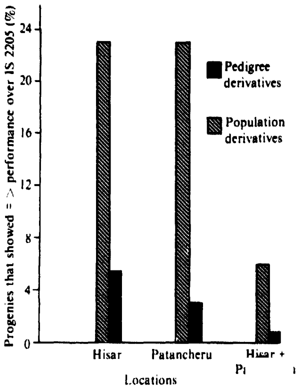

Figure 3. Performance of pedigree and population derivatives against stem borer.

Season	Steps	Number	Activity	Location
Summer	Population	1	Random mating	ICRISAT Center
Rainy	Half-sibs	2000	Agronomic evaluation	ICRISAT Center
Postrainy	S_1 progenies	1000	Evaluation - borer - shoot fly	ICRISAT Center
Rainy/ postrainy	S_2 progenies	250	Evaluation - borer - natural	Haryana Agricultural University, Hisar
			- artificial	ICRISAT Center
	Select 25-30 best progenies		Shoot fly	ICRISAT Center
			agronomic	ICRISAT Center

Figure 2. Scheme for recurrent selection.

Table 9. Stem borer resistant sources and their promising derivatives, utilized at ICRISAT Center.

Resistant source	Promising derivatives
IS 1082	PS 14413, PB 10791, PB 12446
IS 2312	PS 19338, PB 12693
IS 3962	PS 18601, PS 18822, PB 12611, PB 12631
IS 5604	PS 18527, PS 19336, PS 27623 PB 10365, PB 12040, PB 12497, PB 12687, PB 12689
IS 5622	PS 14454, PS 19295, PS 19663, PS 21113, PS 30768, PS 30769, PS 31376, PB 10337, PB 10445, PB 10446
IS 13681	PB 12049, PB 12050
Shoot pest population	PB 12339, PB 12342, PB 12346, PB 12380, PB 12387, PB 12413

700, ICSV 701, ICSV 825, ICSV 826, ICSV 827, ICSV 828, and ICSV 829 (Table 10).

Experience over the years has shown that there is very little correlation between selections made for stem borer resistance under natural and artificial conditions. This may be due to the differential expression of resistance mechanisms in these two types of infestations. Some mechanism(s) may not be operating under both types of infestations. Similar observations were made by Haji (1984) in his genetic studies conducted in relation to natural and artificial infestations. This apparent dichotomy needs scrutiny, particularly as any correlation may influence future breeding strategies for borer resistance.

Table 10. Performance of improved lines for stem borer resistance.

	Resistance index[1]	
	Natural	Artificial
ICSV 700	0.50	1.250
ICSV 701	0.65	0.625
ICSV 825	1.05	1.320
ICSV 826	0.90	0.625
ICSV 827	0.13	1.380
ICSV 828	0.94	0.710
ICSV 829	0.96	0.700

1. Resistance index = $\frac{\text{\% of deadhearts in a particular line}}{\text{\% of deadhearts in resistant control (IS 2205)}}$

Conclusions and Recommendations

The effectiveness of a host-plant resistance breeding program largely depends on the development of a reliable screening technique, reliable criteria for measuring resistance, identification of stable sources of resistance, knowledge of the inheritance of resistance per se, the resistance mechanisms, and finally the selection of breeding procedures to incorporate resistance into agronomically superior backgrounds.

Although considerable work on host-plant resistance to stem borer has been accomplished in India and elsewhere, there is still a scope for further improvement. Intensified efforts are needed in the following areas:

- Natural borer infestations at specific locations should receive a thorough examination of population dynamics, planting time, use of overwintering population, fertilizers, and other factors affecting these populations.
- Feasibility of artificial infestation should be considered by national programs according to the facilities and support available.
- Determine breeding should be carried out under natural or artificial borer infestations, or under both types.
- Deadhearts should be given prime consideration as a selection criterion for resistant types. Stem tunneling and leaf injury should be used as secondary parameters.
- Tolerance should be considered as a factor in breeding for borer resistance.
- Cultivars with multiple resistance should be developed according to regional needs.
- More genetic information needs to be generated on individual resistance factors/mechanisms/resistance.
- Resistant parents need to be developed to use in the further development of resistant hybrids.

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