Impact of Improved Sorghum Cultivars on Genetic Diversity and Yield Stability

10

UK Deb, MCS Bantilan, BVS Reddy, PJ Bramel and N Kameswara Rao

Impact of Improved Sorghum Cultivars on Genetic Diversity and Yield Stability

UK Deb[1], MCS Bantilan[2], BVS Reddy[2], PJ Bramel[3] and N Kameswara Rao[3]

10.1. Introduction

The genetic diversity of a crop species is fundamental to its improvement and survival. Low levels of genetic diversity in cultivars increasingly render them vulnerable to unexpected pests and diseases, resulting in major production losses. History has been witness to numerous epidemics caused by low levels of nuclear and cytoplasmic genetic diversity. These include the blight that affected temperate potatoes in the northern hemisphere in the 1840s and the southern corn leaf blight epidemic of maize in the USA in 1970 (McIntyre et al. 1997).

It is largely believed that the Green Revolution led to a reduction in genetic diversity. For example, Pretty (1995) states “the introduction of modern varieties and breeds has almost always displaced traditional varieties and breeds”. Cooper et al. (1992) inferred that the Green Revolution not only destroyed diversity, but as new seeds replaced old traditional varieties and their wild relatives, the future raw material for plant breeding programs was lost. High-yielding cultivars developed by national and international breeding programs and multinationals are reported to be the major cause of genetic erosion (Fowler and Mooney 1990; FAO 1996). Shiva (1991) states that the food supplies of millions are today “precariously perched” on the “narrow and alien genetic base” of the semi-dwarf wheat, and that “science and politics were wedded together in the very inception of the Green Revolution” which left the Punjab of India “ravaged by violence and ecological scarcity”. Some researchers believe that the Green Revolution has increased variability in crop production (Hazell 1989; Mehra 1981; Barker et al. 1981; Griffin 1988) and thereby increased threats to food security. If this is the case, then it has serious consequences for sustainability in production and food security.

This chapter quantifies and estimates different types of genetic diversity indices—average, weighted and recommended – and the impact of germplasm research on yield increase and yield instability. Finally, it determines the relationship between adoption of improved cultivars, genetic diversity and yield instability.

10.2. Analytical Techniques

10.2.1. Quantification of Genetic Diversity

Genetic diversity in a crop can be measured in different ways such as pedigree analysis and molecular markers (for example, restriction fragment length polymorphosis – RFLPs).

1. Centre for Policy Dialogue, House 40/c, Road no. 11, Dhanmondi, Dhaka 1209, Bangladesh.
2. International Crops Research Institute for the Semi-Arid Tropics, Patancheru 502 324, Andhra Pradesh, India.
3. Formerly of the International Crops Research Institute for the Semi-Arid Tropics, Patancheru 502 324, Andhra Pradesh, India.

Deb UK, Bantilan MCS, Reddy BVS, Bramel PJ and Kameswara Rao N. 2004. Impact of improved sorghum cultivars on genetic diversity and yield stability. Pages 225-234 *in* Sorghum genetic enhancement: research process, dissemination and impacts (Bantilan MCS, Deb UK, Gowda CLL, Reddy BVS, Obilana AB and Evenson RE, eds.). Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics.

Determining genetic diversity through molecular markers is prohibitively expensive and is only done by biotechnologists.

One way of determining genetic diversity in a crop is to analyze its parentage (Cox et al. 1985; Souza et al. 1994). Souza et al. (1994) distinguished between latent and apparent genetic diversity. Latent genetic diversity within a crop may influence disease vulnerability and stability across variable environmental stresses, while apparent genetic diversity is shown by the development of specific resistance genes. A narrow genetic base may increase a crop’s latent vulnerability to disease and pest epidemics, especially those to which a crop or cropping region has been newly or increasingly exposed.

A Coefficient of Parentage (COP) summarizes genealogical similarities between pairs of cultivars. According to St Martin (1982) and Souza et al. (1994), each cultivar has a COP of 1 within itself, and each pair of cultivar without any common parentage has a COP of 0. Assuming each parent contributes equally to the progeny, then with unrelated parents the COP between parent and offspring is 0.5.

The pedigree of all varieties and hybrids was traced in this study to compute genetic diversity. However, this was not possible in the case of privately researched sorghum hybrids. Of the 122 notified cultivars, the pedigree of 77 cultivars could be traced. Since, this analysis is based only on these 77 cultivars, the estimates underestimate the level of diversity. To overcome this limitation, a further analysis was done for all the 182 cultivars under a restricted assumption that a cultivar with unknown parentage is not related to any other cultivar, ie, it has no common parentage. Since this would overestimate the actual level of diversity prevailing in farmers’ fields, the actual level of diversity would be somewhere between the two estimates.

A matrix (77 × 77) of COPs between each of 77 important Indian cultivars (varieties and hybrids) was prepared.

The converse of genealogical similarity is diversity. Souza et al. (1994) define Coefficient of Diversity (COD) as (1-COP), whereby the higher the COD value, the greater is the genetic diversity within the cropping system. The COD indicates the degree to which a single cultivar and its related germplasm dominate a cropping region.

Souza et al. (1994) distinguished between various types of diversity:

- Average annual diversity within particular years
- Temporal diversity (comparing diversity at the start and end of periods)
- Recommended diversity based on variety recommendations from local research systems.

This analysis examines all these types of diversities:

- Average diversity: Based on the average COD of each variety grown in a given region in a given year
- Weighted diversity: Based on a weighted average of the COD of each variety weighted by the proportion of the area sown to each variety in a given region in a given year
- Recommended diversity: Based on the average COD of each cultivar recommended by either the public or private research system or notified by the seed certification agency, that can be grown in a given region in a given year.

Algebraically, if P is the matrix of the COP values between each of the cultivars, then the average diversity is calculated as:

$$d_a = 1 - G_i P G_i' \qquad ...(10.1)$$

where,

G_i is a row vector of weighting values and G_i' is its transpose. Any cultivar grown in a region in year i receives a weight of n^{-1} (where n is the number of cultivars grown in that year), while other cultivars receive a weight of 0.

The weighted diversity value d_w, is calculated as:

$$d_w = 1 - A_i P A_i' \qquad ...(10.2)$$

where,

A_i is a row vector of the proportion of the area sown to each cultivar in year i and A_i' is its transpose.

The recommended or notified diversity value d_r is calculated as:

$$d_r = 1 - R_i P R_i' \qquad ...(10.3)$$

where,

R_i is a row vector of weighting values and R_i' is its transpose. Any cultivar recommended in a region in year i receives a weight of n^{-1} (where n is the number of cultivars grown in that year), while other cultivars receive a weight of 0.

10.2.2. Estimation of Instability in Sorghum Yield

Production variability (instability)[4] may arise due to variability in area, yield and/or interaction between area and yield. Since variability in yield is the main source of production instability (Weber and Sievers 1985; Hazell 1985), this analysis focuses exclusively on yield variability and instability in sorghum yield during two periods – 1966/67 to 1980/81 and 1981/82 to 1993/94. Critics opine that HYVs have decreased genetic diversity and increased variability in production. The objective was to test this hypothesis.

Instability in sorghum yield has been measured using the Cuddy-Della Valle index, referred in equation 9.1 in Chapter 9, adopted in recent years as a measure of variability in time-series data.

To test the differences in CV between two time periods, Z statistics was computed[5].

$$Z = (CV_2 - CV_1)\ \{[(1 + 2CV_1)/2](1/n_1 - 1/n_2)\}^{0.5}/CV_1 \qquad ...(10.4)$$

where,

CV_2 and CV_1 are the CVs of periods 2 and 1, respectively

n_1 and n_2 represent the number of years during period 1 and period 2, respectively.

The change in CV for each district was tested using the Central Limit Theorem to compute

$$Z^* = \Sigma Z_i/m^{0.5} \qquad ...(10.5)$$

where,

Z_i are the standard normal test statistics for each observation of equation and m is the number of observations in the sample.

10.3. Improved Sorghum Cultivars Released

Table 10.1 shows the total number of improved sorghum cultivars released in select countries in Asia and Africa. A complete list of all these cultivars (varieties/hybrids) along with their pedigree, yield potential, year and purpose of release are given in Appendixes I and II.

---

4. Variability and instability are extensively used as synonyms in this study.
5. For details, see Kendal and Start (1969) and Anderson and Hazell (1989).

India. The first sorghum hybrid CSH 1 was released in 1964. Today, about 182 improved cultivars of sorghum are available for cultivation for grain, forage or dual purpose. Of these, 122 are notified either by the National Seed Release Committee or by the State Seed Release Committees. The rest are products of private seed companies, sold as “truthfully labeled seed”.

Table 10.1. Number of sorghum cultivars recommended for release in select countries in Asia and Africa.

Country	Up to	Varieties	Hybrids	Total
India	1998 (April)	101	81	182
China	1997	0	24	24
Indonesia	1997	13	0	13
Pakistan	1997	7+(4)[1]	0	11
Thailand	1997	7	0	7
Iran	1997	3	3	6
Myanmar	1997	21	0	21
Nigeria	1998	4	0	4
Egypt	1998	5	3	8

1. Figure in parenthesis is the number of cultivars submitted to the seed release committee for recommendation.

Of the 122 notified cultivars, 16 are derived from ICRISAT supplied materials. It is difficult to know the parentage of private hybrids due to proprietary reasons. However, private seed companies in India have collaborations with ICRISAT, and have acknowledged that their hybrids contain part of the genome from ICRISAT material. Details of collaborations with private seed companies in India are discussed in Chapters 4 and 7.

China. China has released 24 improved sorghum cultivars, of which 7 are ICRISAT-derived ones. After 1987, China released 10 cultivars, of which 7 were derived from ICRISAT-supplied materials. This indicates the potential of ICRISAT material in the future development of sorghum hybrids in China.

Pakistan. Pakistan has recommended a total of 11 improved cultivars for release. Four varieties (D.G. Pearl, Sarokarthuho, Red Janpur and Bagdar) are pure line selections from local landraces. Two of them (PARC SS1 and PARC SV1) are ICRISAT-derived varieties, two (Pak SSII and DS 75) are from Purdue University’s germplasm collection and one (Jowar 86) is from national program breeding materials. Variety PARC SH1 was directly introduced from India (CSH 6) through international trials. PARC SS2 too was directly introduced (IRAT 204) from ICRISAT through international trials.

Thailand. Thailand has released seven improved cultivars. Two varieties (Early Hegari and Late Hegari) were introduced in the early 1960s from USA. Hegari is still popular in Thailand. The other five cultivars are from materials derived from the national breeding program. Suphan Buri 1 released in 1993 had ICRISAT-supplied germplasm as a parent in the crosses.

Myanmar. Myanmar has released 21 varieties, of which 11 are directly from ICRISAT-supplied breeding lines (seven varieties) or direct germplasm introductions from ICRISAT (four varieties). After 1982, all the 7 varieties released were direct introductions from ICRISAT breeding lines.

Indonesia. Indonesia has released 13 improved sorghum varieties – two are pure line selections from local landraces and the others direct introductions. Pedigrees of these cultivars could not be traced. However, ICRISAT has had substantial collaboration with Indonesia since 1980.

Iran. Iran has six recommended sorghum varieties – Speed Feed, Jumbo, Sugar grace, Payam, Kimia and Sepeeden. The first three, originating in Australia, have been released for forage while the other three (local selections) are used for grain.

Egypt. Egypt has eight recommended cultivars (5 varieties and 3 hybrids). These are Giza 114 (released in 1962), Giza 15 (1978), Giza 113 (1994), Dorado (1993), NES 1007, Hybrid 1, Hybrid 2 and Hybrid 3 (1996). Giza 114 and Giza 15 are pure line selections from local varieties, while Giza 113 is derived from a cross between a local and an exotic variety. The three varieties have been released for grain purposes and the hybrids for dual purpose. None of these is from ICRISAT materials.

Nigeria. After 1995, Nigeria released four improved cultivars (ICSH 89002NG, ICSH 89009 NG, ICSV 111 and ICSV 400) from collaborative research with ICRISAT. All were direct selections from ICRISAT breeding lines after adaptive research trials. Before 1995, several other varieties and hybrids were developed and released by the Nigeria NARS. The first two were hybrids developed in Nigeria in a partnership program, based on ICRISAT-bred parents developed at Patancheru, India. The other two were developed by ICRISAT-Patancheru.

10.4. Genetic Diversity in Sorghum in India

Various types of genetic diversity indices – average, recommended and weighted – were quantified based on the data and analytical methods discussed in the earlier section. The results of estimated genetic diversity for India are reported in Tables 10.2 and 10.3. The results are presented in five-year intervals from 1966 to 1994. The recommended diversity and average diversity among improved sorghum cultivars in India has increased remarkably over time. The numerical values of the average and recommended diversities of sorghum in India was the same since all the recommended sorghum cultivars are grown in India, even though the area under a majority of them is very limited. Since the estimation of average and recommended diversities does not consider the area covered by the cultivars, these are to some extent overestimates of the actual diversity in the farmer's field. Therefore, the study calculated the weighted diversity in sorghum cultivation in India as a whole and for seven major sorghum-growing states (Andhra Pradesh, Gujarat, Karnataka, Maharashtra, Madhya Pradesh, Rajasthan and Tamil Nadu). Estimates of the weighted COD are given in Table 10.3. The level of weighted diversity was much higher in 1994 than in the early 1970s in all the 7 states.In the absence of information about parentage, and thereby genetic diversity, one can try to understand the level of diveristy in any crop cultivation by counting the number of cultivars grown by the farmers. The number

Table 10.2. Coefficient of diversity (average and recommended) in sorghum in different states of India.

Year	Diversity index[1]
1966	0.25
1971	0.92
1976	0.95
1981	0.97
1986	0.98
1991	0.99
1994	0.99

1. The Diversity index here is based on 182 cultivars.

Source: Based on authors' calculation.

of recommended sorghum cultivars grown in a country can also be an indicator of this purpose. Table 10.4 reports the diversity in sorghum cultivation (measured as the total number of improved cultivars) in important sorghum-growing countries of Africa and Asia. It is evident that the number of improved cultivars has increased over time. The number of improved cultivars are generally high in those contries where adoption is relatively high.

Table 10.3. Coefficient of diversity (weighted) in sorghum in different states of India.

States	1966	1971	1976	1981	1986	1991	1994
Results based on 77 cultivars							
Andhra Pradesh	0.00	0.00	0.48	0.25	0.32	0.36	0.74
Gujarat	0.00	0.00	0.34	0.56	0.25	0.27	0.28
Karnataka	0.00	0.00	0.41	0.45	0.47	0.60	0.69
Madhya Pradesh	0.00	0.00	0.46	0.46	0.44	0.55	0.64
Maharashtra	0.00	0.00	0.46	0.52	0.48	0.45	0.50
Rajasthan	0.00	0.00	0.34	0.56	0.25	0.27	0.36
Tamil Nadu	0.00	0.00	0.32	0.38	0.50	0.63	0.69
India	0.00	0.00	0.47	0.48	0.45	0.55	0.72
Results based on 182 cultivars							
Andhra Pradesh	0.00	0.00	0.84	1.00	1.00	1.00	1.00
Gujarat	0.00	0.00	0.36	0.94	1.00	1.00	1.00
Karnataka	0.00	0.00	0.49	0.91	0.99	0.99	1.00
Madhya Pradesh	0.00	0.00	0.53	0.94	0.98	1.00	1.00
Maharashtra	0.00	0.00	0.54	0.92	0.98	1.00	1.00
Rajasthan	0.00	0.00	0.36	0.94	1.00	1.00	1.00
Tamil Nadu	0.00	0.00	0.36	0.94	1.00	1.00	1.00
India	0.00	0.00	0.56	0.94	0.99	1.00	1.00

Source: Based on authors' calculation.

Table 10.4. Diversity in sorghum cultivation (measured as the total number of improved cultivars).

	Number of improved cultivars				Number of improved cultivars		
Country	1980	1990	1998	Country	1980	1990	1998
Africa				**Asia**			
Botswana	7	7	11	China	7	16	24
Burkina Faso	2	4	5	India	50	111	182
Egypt	3	3	8	Indonesia	9	11	13
Ethiopia	1	5	7	Myanmar	10	18	21
Kenya	4	8	10	Pakistan	6	7	11
Malawi	-	1	3	Thailand	2	4	7
Mali	-	-	4				
Mozambique	3	8	9	**Latin America**			
Niger	-	-	2	El Salvador	2	4	4
Nigeria	-	-	4	Mexico	1	6	9
Senegal	1	1	1	Nicaragua	-	2	2
Sudan	-	1	6				
Swaziland	-	2	3				
Tanzania	4	5	6				
Uganda	8	8	10				
Zambia	1	7	9				
Zimbabwe	-	2	6				

10.5. Instability in Yield

The impact of sorghum germplasm research on yield increase (productivity) and instability (variability over years) in yield in India was calculated using the mean yield of sorghum and instability indices (using the Cuddy-Della Valle Index). During period 1 (1966/67-1980/81), the percentage of HYV sorghum area to the total sorghum area in India was less than 20% while during period 2 (1981/82-1993/94) it was above 20%, indicating that HYV sorghum cultivation was less intensive during period 1 compared to period 2. Therefore, these two periods can be called the early HYV period and late HYV period, respectively. The coefficient of genetic diversity among the improved cultivars was very low during period 1; it increased significantly during period 2. Therefore, period 1 can also be treated as a period of low genetic diversity while period 2 was a period of genetically diversified sorghum cultivation.

Table 10.5 compares the level of and changes in average yield and relative variability in sorghum yield between the two periods in different states of India. During period 1, the highest productivity was recorded in Karnataka (985 kg ha^{-1}) followed by Tamil Nadu (943 kg ha^{-1}) and Madhya Pradesh (729 kg ha^{-1}), while yield was low in Gujarat (499 kg ha^{-1}) and Rajasthan (300 kg ha^{-1}). During period 2, the highest productivity was in Tamil Nadu (1113 kg ha^{-1}) followed by Karnataka (957 kg ha^{-1}) and Maharashtra (902 kg ha^{-1}). The lowest yield level was in Rajasthan (412 kg ha^{-1}) followed by Gujarat (551 kg ha^{-1}) and Andhra Pradesh (661 kg ha^{-1}). Yields levels in all the states except Karnataka (where productivity fell by 28 kg ha^{-1}) increased during period 2 compared to period 1. Average yield in India during period 1 and 2 was 582 kg ha^{-1} and 748 kg ha^{-1}, respectively. The coefficient of variation in yield decreased in all the states except Gujarat. It may be mentioned here that the study districts of Gujarat contributed only 2.7% of total sorghum production and 4.9% of total sorghum area in India during 1991-1994. The coefficients of variation in sorghum yield in India during these two periods were 11% and 13%, respectively. This implies that food security has been strengthened over time through reduction in year-to-year yield fluctuations.

To examine the differences in changes in CV for yield between the two periods, the Z statistics was computed for each of the 146 study districts. A summary of the analysis (Table 10.6) shows that although 26% of the districts in India showed significant increases in CV, they comprised only 14% of the total sorghum area in India. On the other hand, 39% of the districts experienced significant decreases in CV; they comprised 42% of the total sorghum area in India. This implies that during period 2 (1981/82-1993/94), reduction in yield fluctuations ensured food security in most of the major sorghum-producing areas in India.

Table 10.5. Average yield and relative variability in sorghum yield in different states of India.

	Period 1(1966-80)		Period 2 (1981-93)		Change (%)	
States	Yield (kg ha^{-1})	CV (%)	Yield (kg ha^{-1})	CV (%)	Yield (kg ha^{-1})	CV (%)
Andhra Pradesh	521	23.02	661	21.66	26.84	-5.91
Gujarat	499	31.55	551	42.51	10.38	34.76
Karnataka	985	26.65	957	23.08	-2.91	-13.40
Madhya Pradesh	729	24.08	896	19.52	22.76	-18.96
Maharashtra	609	29.50	902	26.51	17.99	-6.71
Rajasthan	300	58.62	412	50.77	37.47	-13.40
Tamil Nadu	943	28.13	1113	26.24	17.99	-6.71
India	582	10.59	748	13.02	28.47	22.97

Source: Authors' calculations are based on data obtained from the Government of India.

Table 10.6. Districts and sorghum area (%) with a statistically significant change in yield variability according to the computed Z* statistics.

	Districts (%)		Area (%)	
States	Increased CV	Decreased CV	Increased CV	Decreased CV
Andhra Pradesh	25	30	20	43
Gujarat	69	6	76	0
Karnataka	7	36	1	29
Madhya Pradesh	14	50	10	51
Maharashtra	5	45	3	50
Rajasthan	48	43	64	20
Tamil Nadu	33	44	25	52
India	26	39	14	42

Source: Authors' calculations are based on data obtained from the Government of India.

10.6. Relationship between Improved Cultivars, Genetic Diversity and Yield Instability

The relationship between the spread of improved cultivars and weighted index of genetic diversity in different states of India are presented in Table 10.7. The rates of adoption and genetic diversity in all the states except Rajasthan have increased over time. Given this situation, improved cultivars were neither adopted at a significant rate, nor was there any increase in genetic diversity among improved sorghum cultivars. The overall situation with the exception of Rajasthan implies that sorghum breeders were using different parental materials to develop new improved cultivars rather than depending only on few parental materials. The breeders were successful in utilizing a large genetic pool to increase the diversity rather than counting on only few materials in a narrow genetic pool.

The relationship between genetic diversity and yield instability can be observed from Table 10.8. Genetic diversity in sorghum cultivation has increased in Andhra Pradesh, Karnataka, Madhya Pradesh and Tamil Nadu while the index of yield instability has decreased in these states. In Maharashtra, genetic diversity at the end of periods 1 and 2 were almost similar. The variability situation was also similar during these two periods. In Rajasthan, genetic diversity as well as relative variability decreased. In other words, an increase in genetic diversity in all the major sorghum-producing states of India except Rajasthan has resulted in a decrease in variability in sorghum yield.

Table 10.7. Relationship between adoption of improved cultivars and coefficient of weighted diversity among sorghum cultivars.

	Adoption rate (%)			Genetic Diversity Index (COD)		
States	1968	1981	1993	1966	1981	1994
Andhra Pradesh	0.56	20.28	46.76	0.00	0.25	0.74
Gujarat	0.15	7.78	53.16	0.00	0.56	0.28
Karnataka	3.03	22.76	22.97	0.00	0.45	0.69
Madhya Pradesh	0.92	29.17	49.48	0.00	0.46	0.64
Maharashtra	8.47	30.02	68.09	0.00	0.52	0.50
Rajasthan	0.42	4.64	1.52	0.00	0.56	0.36
Tamil Nadu	1.35	27.65	99.31	0.00	0.38	0.69
India	3.68	23.39	52.42	0.00	0.48	0.72

Source: Authors' calculations are based on data obtained from the Government of India.

Table 10.8. Coefficient of weighted diversity and instability in sorghum yield in different states of India.

States	Genetic Diversity Index (COD) 1981	1994	Change in COD (%)	Index of yield instability Period 1	Period 2	Change in instability index (%)
Andhra Pradesh	0.25	0.74	196.00	23.02	21.66	-5.91
Gujarat	0.56	0.28	-50.00	31.55	42.51	34.76
Karnataka	0.45	0.69	53.33	26.65	23.08	-13.40
Madhya Pradesh	0.46	0.64	39.13	24.08	19.52	-18.96
Maharashtra	0.52	0.50	-3.85	29.50	26.51	-6.71
Rajasthan	0.56	0.36	-35.71	58.62	50.77	-13.40
Tamil Nadu	0.38	0.69	81.58	28.13	26.24	-6.71
India	0.48	0.72	50.00	10.59	13.02	22.97

Source: Authors' calculations are based on data obtained from the Government of India.

10.7. Conclusion

The number of improved sorghum cultivars and their rate of adoption in all the study countries have increased over time. Genetic diversity among improved sorghum cultivars in India has increased. This indicates that sorghum breeders in India were using different parental materials to develop new cultivars rather than relying on a few parental materials. The impact of sorghum germplasm research on yield instability measured for different states shows that instability in sorghum yield fell during period 2 compared to period 1. Period 1 saw the low adoption of HYVs accompanied by low genetic diversity among the improved sorghum cultivars. Period 2 was characterized by high adoption accompanied by high levels of genetic diversity among the improved sorghum cultivars. Therefore, it can be concluded that sorghum germplasm research in India has contributed to increases in genetic diversity, thereby helping reduce instability in sorghum yield.

10.8. References

Barker RE, Gabler E and Winckelmann D. 1981. Long-term consequences of technological change on crop yield stability: The case for cereal grains. *In* Food security for developing countries (Valdes A, ed.). Boulder, USA: Westview Press. 351 pp.

Cooper D, Vellve R and Hobbelink H. 1992. Growing diversity: Genetic resources and local food security. London, U.K.: Intermediate Technology Publications.174 pp.

Cox TS, Kiang YT, Gorman MB and Rodgers DM. 1985. Relationships between coefficients of parentage and genetic similarity indices in soybean. Crop Science 25:529-32.

FAO (Food and Agricultural Organization of the United Nations). 1996. The state of the world's genetic resources for food and agriculture (background documentation for the International Technical Conference on Plant Genetic Resources, 17-23 Jun 1996, Leipzig, Germany. Rome, Italy: FAO. 336 pp.

Fowler FJ and Mooney P. 1990. The threatened gene: Food, policies and the loss of genetic diversity. Cambridge, U.K.: The Lutterworth Press. 278 pp.

Griffin K. 1988. Alternative strategies for economic development. Paris, France: Organization for Economic Cooperation and Development. 267 pp.

Hazell PBR. 1985. Sources of increased variability in world cereal production since the 1960s. Journal of Agricultural Economics 36(2):145-159.

Hazell PBR. 1989. Changing patterns of variability in world cereal production. Pages 13-34 *in* Variability in grain yield (Anderson JR and Hazell PBR, eds.). Baltimore and London: The John Hopkins University Press.

McIntyre CL, Tao Y, Jordan DR and Hanzell RG. 1997. Application of molecular markers to sorghum breeding in Australia. International Sorghum and Millets Newsletter 38:11-14.

Mehra S. 1981. Instability in Indian agriculture in the context of the new technology. Research Report No. 25. Washington D.C. USA: International Food Policy Research Institute. 55 pp.

Pretty. 1995. Regenerating Agriculture. London: Earthscan Publications.

Shiva V. 1991. The violence of the Green Revolution. U.K., London: Zed Books.

St Martin SK. 1982. Effective population size for the soybean improvement program in maturity groups 00 to IV. Crop Science 22:151-152.

Souza E, Fox PN, Byerlee D and Skovmand B. 1994. Spring wheat diversity in irrigated areas of two developing countries. Crop Science 34:774-783.

Weber A and Sievers M. 1985. Observations on the geography of wheat production instability. Quarterly Journal of International Agriculture 24(3):201-211.