Genetic Resources and Crop Evolution **51:** 513–517, 2004.

Geographical patterns of diversity in pearl millet germplasm from Yemen

Narsimha Reddy*, Kameswara Rao and Irshad Ahmed
*International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru, Andhra Pradesh 502 324, India; *Author for correspondence (e-mail: kn.reddy@cgiar.org)*

Received 23 August 2002; accepted in revised form 11 January 2003

Key words: Climate, Elevation, Geography, Landrace, Variation

Abstract

Yemen differs considerably from many other countries in its extreme variation in elevation. A set of 229 pearl millet germplasm accessions collected from diverse elevations of Yemen was characterized for 12 morpho-agronomic characteristics at ICRISAT, Patancheru, India. Analysis of variance revealed highly significant differences ($P < 0.001$) among elevational zones for flowering, plant height and seed weight when evaluated in the post-rainy season and for panicle length and thickness when evaluated in the rainy season. The differential performance of accessions for flowering and plant height during the rainy and post-rainy seasons at ICRISAT, Patancheru reflected the photoperiod and temperature sensitivity of the accessions. Shannon-Weaver diversity indices indicated high diversity from low elevations for flowering and plant height. The results of the present study imply that environmental factors such as elevation, temperature and rainfall are the important determinants of variation patterns of pearl millet in Yemen and pearl millet germplasm from high elevations of Yemen is a good source for early maturity, cold tolerance, short plant height and large seeds.

Introduction

Pearl millet (*Pennisetum glaucum* (L.) R. Br.) is the most important food and forage crop in Yemen. Regionally, Yemen differs considerably from other countries for its diversity in elevation, rainfall, temperature and soil. Its climatic conditions range from tropical through subtropical to moderate, and there are regions with no rainfall at all to others with abundant rain (Anonymous 1992). About 50–60 per cent of total cultivated area in Yemen is under sorghum and millet. These crops are grown under almost desert conditions at low elevations in coastal regions of Tehama with < 300 mm rainfall, as well as on bench terraces of high elevation craggy mountainous areas with elevations over 3000 m and rainfall as high as 1200 mm. The International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru, India, in collaboration with Agriculture Research and Extension Authority (AREA), Dhamar, Yemen, launched an expedition in 1992 to collect pearl millet germplasm threatened with extinction due to cultivation of cash crops, improved varieties, urbanization, etc. (Appa Rao et al. 1993a). Information on the distribution patterns of genetic variation of a crop species is very important for planning future germplasm collection missions and for efficient utilization of collected germplasm in crop improvement programmes (Hayward and Breese 1993). Therefore, an effort was made in the present study to assess patterns of diversity distribution in relation to the elevation of collecting sites of pearl millet germplasm in Yemen.

Materials and Methods

An expedition to collect pearl millet germplasm was undertaken in October and November 1992 in the Hudaydah, Taiz, Lahij, Sana'a, and Ibb regions of Yemen (Figure 1) (Appa Rao et al. 1993b). From the total of 248 samples collected from different elevations, a set of 229 accessions was evaluated for 12 characters at ICRISAT, Patancheru (17°25′N latitude and 78°00′E longitude) in Alfisols during rainy (June to October) and post-rainy (November to March) seasons of 1993. The rainy season is characterized by relatively long days. On the other hand, the post-rainy season is cool and dry with relatively short days (Appa Rao et al. 1996). The mean minimum and maximum temperatures were 21.8 °C and 30.8 °C, respectively in the rainy season and 14.2 °C and 30.4 °C in the post-rainy season. The photoperiod decreases from 13.93 h in June to 12.47 h in October in the rainy season and increases from 11.91 h in December to 12.7 h in March in the post-rainy season. The accessions were grown in two rows, 4- m long with a spacing of 75 cm between rows and 10 cm between plants within a row. Fertilizer was applied at a rate of 100 kg nitrogen and 40 kg phosphorus ha^{-1}. Life-saving irrigations were given during the rainy season, while the crop was irrigated at regular intervals during the post-rainy season.

Observations were recorded on flowering, plant height, and panicle length and thickness during both the rainy and post-rainy seasons. Seed characters including 1000-seed weight, seed color and shape, were recorded during the post-rainy season, and the panicle shape was recorded during the rainy season, following the Descriptors for Pearl millet (IBPGR and ICRISAT, 1993). The elevation of collection sites for the landraces used in this study ranged from 30 to 3260 meters above sea level. Considering this wide range in variation and to give proper representation of accessions from each elevational zone, collection sites were classified as low elevation (< 600 m), medium elevation (600–1600 m), and high elevation (> 1600 m). This classification resulted in 126 low elevation, 82 medium elevation, and 21 high elevation accessions. These groups are roughly comparable to Yemen's three natural climatological zones: tropical, subtropical and moderate (Anonymous 1992). The tropical zone is characterized by an elevation ranging from 0–400 m, mean annual temperature of 25–31 °C and mean annual rainfall of 80–300 mm. Similarly, the subtropical zone ranges in elevation from 400–1800 m with a mean annual temperature of 22 °C and mean annual rainfall of 400–1200 mm and the moderate zone with elevations > 1800 m and mean annual temperature of 16 °C and mean annual rainfall of 1000–1200 mm are distinct from one another (Anonymous 1992). Agronomic traits were analyzed for basic statistics, such as minimum, maximum, mean and standard deviation for total collection and also for each elevational zone. Estimating Shannon-Weaver

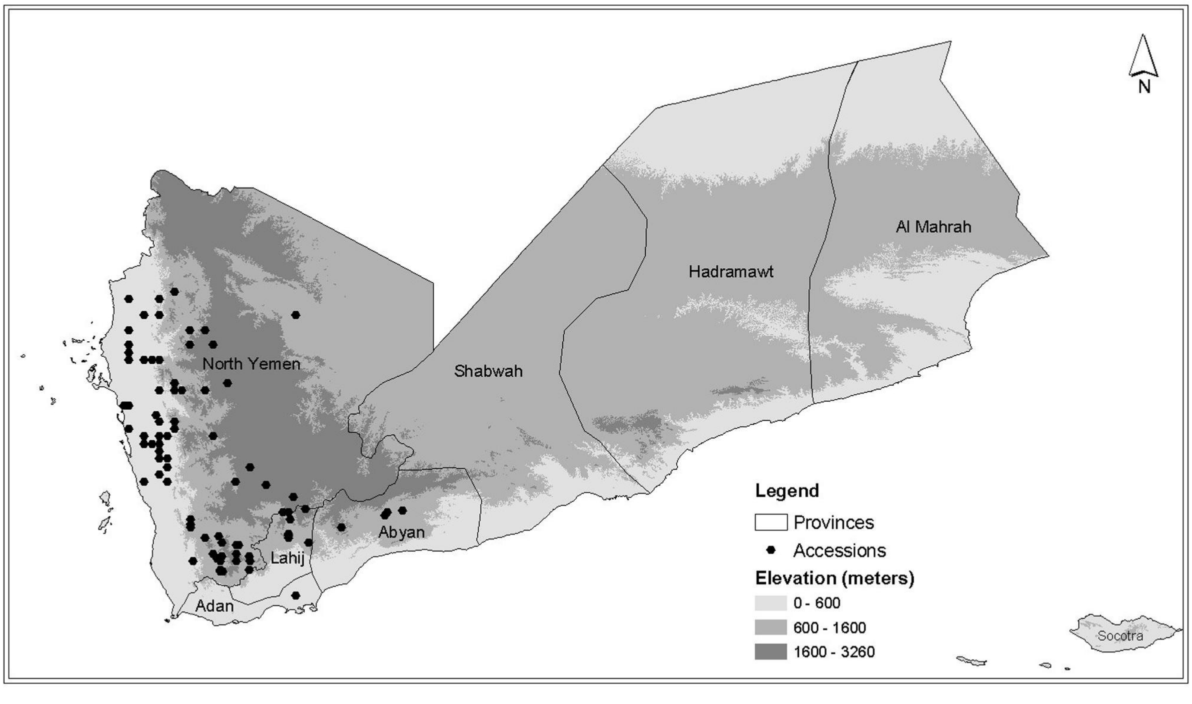

Figure 1. Map showing pearl millet germplasm collection sites at different elevations in Yemen.

Diversity Indices (SDI) studied diversity in the germplasm from each elevational zone for all characters with the formula given below (Poole 1974).

$$H' = \sum_{i=1}^{n} p_i \log_e p_i$$

where, n is the number of phenotypic classes (for qualitative characters n varied for each trait, and for quantitative traits n equaled 8, the number of frequency classes) and p_i is the proportion of the total number of entries in the $_i$th class. The indices are standardized by dividing each value of H′ by $\log_e$ n (SDI = H′/$\log_e$ n) to keep the value in a range from 0–1. in order to estimate the importance of phenotypic diversity. SDI were calculated based upon the frequency distributions of the three qualitative characters and of the nine quantitative characters after transforming the data into eight phenotypic classes by using mean and standard deviation. Frequency distribution of accessions within different modalities of each character was estimated to separate the best sources of trait specific germplasm for crop improvement.

Results and Discussion

Germplasm collected from Yemen showed wide variation for flowering, plant height, panicle length, thickness, shape, and, seed color, size, and shape. Analyses of variance revealed highly significant differences ($P < 0.001$) between the three elevational zones for flowering, plant height and seed weight when evaluated in the post-rainy season and for panicle length and thickness when evaluated in the rainy season indicating unequal distribution of variation between three elevational zones (Table 1).

The phenotypic diversity measured by Shannon-Weaver diversity indices for different morpho-agronomic characters in three elevational zones revealed great diversity in low elevation accessions for flowering and plant height when evaluated in both the rainy and post-rainy seasons when compared to accessions from medium and high elevations (Table 2). Arnold (1959) and Ferere (1984) reported that pearl millet requires a high optimal temperature of 33 to 34 °C for rapid vegetative growth. The temperatures prevailing at low elevations were close to reported optima, which could result in the proliferation or retention of diverse pearl millet types. In contrast, germplasm from high elevations exhibited less variation, probably due to genetic bottlenecks or the intensive selection practiced by farmers for cultivation in the relatively cooler sub-optimal climate. SDI for panicle length in both rainy and post-rainy season and for all seed characters including seed weight recorded in the post-rainy season indicates occurrence of highly diverse pearl millet for these characters in medium and high elevations.

Time to flowering varied from 53–137 days and 53 to 95 days when evaluated in the rainy and post-rainy seasons respectively (Table 1). In the collection three modalities/groups were distinguished, accessions that flowered in less than 50 days as early, those flowered in more than 90 days as late and rest as medium. The frequency distribution of different modalities from different elevational zones when evaluated in the rainy season showed reduction in the frequency of early and late flowering accessions with the increase in the elevation of collection sites and none of the accessions from higher elevation flowered early (Table 3). Interestingly, the flowering behavior of

Table 1. Variation for quantitative characters of pearl millet germplasm from different elevational zones in Yemen.

Character	Total collection				Low elevation				Medium elevation				High elevation				
	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD	F. probability
Flowering-R[1]	53	137	81	14.66	53	137	83.37	15.95	56	131	77.66	12.82	65	120	82.10	10.61	0.020*
Flowering-PR[2]	53	95	70	12.18	53	95	76.74	11.27	53	90	62.82	7.96	53	85	60.62	7.14	<0.001**
Plant height-R	210	380	303	39.58	210	380	309.64	38.76	220	380	293.90	39.10	240	360	304.05	40.79	0.019*
Plant height-PR	80	250	159	36.42	110	250	172.58	34.63	80	240	145.24	33.04	100	210	135.24	26.05	<0.001**
Panicle length-R	16	50	23	4.38	16	50	22.48	4.60	16	46	24.45	4.05	17	30	23.90	3.21	0.01**
Panicle length-PR	11	65	20	5.82	11	65	19.55	6.55	12	38	19.68	4.85	13	31	19.00	4.67	0.89NS
Panicle thickness-R	18	35	24	3.08	18	35	23.29	3.01	19	35	24.66	3.11	19	28	23.14	2.71	0**
Panicle thickness-PR	12	32	22	3.77	12	32	21.80	3.60	14	30	21.71	4.09	15	25	20.43	3.37	0.3NS
Seed weight-PR	4	12	8	1.20	4	11.5	7.53	1.22	6	10.5	8.16	1.04	6.5	11.5	8.29	1.23	<0.001**

[1] and [2] Rainy and Post-rainy season; * and ** Significant at p = 5% and 1% level respectively; NS = Non-significant.

Table 2. Shannon-Weaver diversity indices (SDI) for different characters of pearl millet germplasm collected from different elevational zones in Yemen.

Character	Low elevation	Medium elevation	High elevation
Flowering-R[1]	0.61	0.50	0.48
Flowering-PR[2]	0.60	0.60	0.59
Plant height-R	0.69	0.65	0.58
Plant height-PR	0.68	0.63	0.57
Panicle length-R	0.58	0.59	0.61
Panicle length-PR	0.56	0.63	0.71
Panicle thickness-R	0.66	0.65	0.55
Panicle thickness-PR	0.62	0.68	0.67
Seed weight-PR	0.70	0.72	0.66
Panicle shape	0.31	0.60	0.59
Seed color	0.43	0.51	0.37
Seed shape	0.14	0.27	0.14

[1] and [2] = Rainy and Post-rainy season respectively.

majority of the accessions was almost opposite when evaluated in the post-rainy season. In the post-rainy season, the frequency of early flowering accessions increased with increasing elevation and conspicuously, none of the accessions from medium and high elevation flowered late.

For plant height, the accessions were distinguished as short (< 150 cm), medium (150–300 cm) and tall (> 300 cm). None of the accessions was short and majority (62%) of accessions from high elevation grew tall when evaluated in the rainy season. In contrast, in the post-rainy season, the frequency of short accessions increased from lower elevations (23%) to higher elevations (81%) and no accession grew tall at higher elevations (Table 3).

Differential behavior of accessions revealed in the present study mainly for flowering and plant height during rainy and post-rainy season can be attributed to the sensitivity of accessions to temperature and photoperiod (Bidinger and Rai 1989). Pearl millet being a short day plant, frequency of early flowering accessions increased with the increasing elevation when evaluated in the relatively cool and short day post-rainy season. Averaged over 30 years, minimum and maximum temperatures of all collection sites decreased from 20.6 °C to 17 °C and 31 °C to 27.5 °C

Table 3. Frequency distribution of different modalities of pearl millet germplasm from different elevational zones in Yemen.

Character	Frequency % Modality	Low elevation	Medium elevation	High elevation
Flowering-R[1]	Early (<60 days)	3.17	2.44	0.00
	Medium (60–90 days)	68.25	93.90	95.24
	Late (>90 days)	28.57	3.66	4.76
Flowering-PR[2]	Early (<60 days)	8.73	37.80	47.62
	Medium (60–90 days)	89.68	62.20	52.38
	Late (>90 days)	1.59	0.00	0.00
Plant height-R	Short (<150 cm)	0.00	0.00	0.00
	Medium (150–300 cm)	45.24	58.54	38.10
	Tall (>300 cm)	54.76	41.46	61.90
Plant height-PR	Short (<150 cm)	23.02	67.07	80.95
	Medium (150–300 cm)	76.98	32.93	19.05
	Tall (>300 cm)	0.00	0.00	0.00
Panicle length-R	Small (<20 cm)	23.02	6.10	14.29
	Medium (20–40 cm)	76.19	92.68	85.71
	Long (>40 cm)	0.79	1.22	0.00
Panicle length-PR	Small (<20 cm)	60.32	58.54	57.14
	Medium (20–40 cm)	38.89	41.46	42.86
	Long (>40 cm)	0.79	0.00	0.00
Panicle thickness-R	Thin (<20 mm)	2.38	2.44	4.76
	Medium (20–30 mm)	94.44	95.12	95.24
	Thick (>30 mm)	3.17	2.44	0.00
Panicle thickness-PR	Thin (<20 mm)	26.19	24.39	38.10
	Medium (20–30 mm)	73.02	75.61	61.90
	Thick (>30 mm)	0.79	0.00	0.00
Seed weight-PR	Small (<6 g)	23.81	0.00	0.00
	Medium (6–8 g)	68.25	51.22	57.14
	Large (>8 g)	7.94	48.78	47.62

[1] R = Rainy season [2] PR = Post-rainy season.

respectively with increasing elevation indicating nearly optimum temperature at low elevations for pearl millet growth (Hijmans et al. 2002). Ong and Monteith (1985) reported that development can be slow by low light and growth can be retarded when the temperature is too high or too low. Ong and Everard (1979) reported that each short day results in 1.4 days reduction for anthesis leading to early flowering in pearl millet. Results of Bidinger and Rai (1989), who reported early flowering in pearl millet under 12 h photoperiod and delay in flowering under long photoperiod (14–16 h) are in conformity with the results of present study.

The frequency of accessions with long panicles (> 40 cm) decreased with increasing elevation, and none of the accessions from high elevation produced long panicles in both rainy and post-rainy seasons (Table 3). However, irrespective of evaluation season, the frequency of thin panicles increased with increasing elevation. These observations are in general agreement with those of Pearson and Coaldrake (1983), who reported similar relationships when pearl millet was grown at low elevation in western Australia.

All accessions that produced small seed (1000 seed weight < 6 g) are from low elevations and none of the accessions from medium and high elevations produced small seed. In contrast, frequency of large seed (1000 seed weight > 8 g) accessions increased considerably with the increasing elevation. The increased seed weight of accessions from higher elevations may be attributed to the low temperature at higher elevation, which probably helped longer seed filling resulting in larger seed. Ong and Monteith (1985) also reported the production of larger pearl millet seeds at relatively low temperatures because of a longer seed filling period.

The results of the present study imply that environmental factors such as elevation, temperature and rainfall are the important determinants of variation patterns of pearl millet in Yemen. These factors are very useful in predicting the genetic characteristics of the collected samples. Results also reveal that pearl millet germplasm from high elevations of Yemen is a good source for early maturity, cold tolerance, short plant height and large seeds. In breeders view, this type of material is very useful in plant breeding programs. However, these types are poorly represented in ICRISAT's pearl millet collection, and need to be further collected. Natural selection pressure for adaptation to different elevations coupled with farmers' selection for cultivation under a wide range of growing conditions could account for observed diversity patterns. Relationships observed between agronomic performance and environmental factors specific to collection sites also highlight the need to have accurate and complete records of passport information, in particular, latitude, longitude, elevation, temperature and rainfall to maximize the value of collected germplasm. The results further suggests for studies on effect of climatic factors on performance of germplasm accessions.

References

Anonymous 1992. The Europa world year book 1992. 33rd edn. Europa publications, Kenya to Zimbabwe, Vol. 11.

Appa Rao S., Mukred A.W., Mengesha M.H., Amer H.M., Reddy K.N., Alshurai A. et al. 1993a. Collecting crops germplasm in Yemen. Progress Report 72. Genetic Resources Unit, ICRISAT. Patancheru.

Appa Rao S., Mukred A.W., Mengesha M.H., Amer H.M., Reddy K.N., Alshurai A. et al. 1993b. Collecting crops germplasm in Yemen. Plant Genetic Resources Newsletter 94–95: 28–31.

Appa Rao S., Prasada Rao K.E., Mengesha M.H. and Gopal Reddy V. 1996. Morphological diversity in Sorghum germplasm from India. Genetic Resources and Crop Evolution 43: 559–567.

Arnold O.Y. 1959. The determination and significance of base temperature in a linear heat system. Proceedings of the American Society for Horticultural Science 74: 430–455.

Bidinger F.R. and Rai K.N. 1989. Photoperiodic response of paternal lines and F1 hybrids in pearl millet. Indian Journal of Genetics and Plant Breeding 49: 257–264.

Ferere M 1984. Ecological zones and production of sorghum and millet. In: Virmani S.M., Sivakumar M.V.K. and Kumble V. (eds), Agrometeorology of sorghum and millet in the Semi-Arid Tropics. ICRISAT, Patancheru, India, pp. 33–39.

Hayward M.D. and Breese E.L. 1993. Population structure and variability. In: Hayward M.D., Bosemark N.O. and Romagosa I. (eds), Plant Breeding: Principles and Prospects. Chapman & Hall, London, pp. 16–29.

Hijmans, Robert J., Gaurino L. and Rajas E. 2002. Diva-GIS. Version 2. A geographic information system for the analysis of biodiversity data. Manual. International Potato Center, Lima, Peru.

IBPGR and ICRISAT, 1993. Descriptors for pearl millet [*Pennisetum glaucum* (L.) R. Br.]. IBPGR, Rome, Italy and ICRISAT, Patancheru, India, pp. 43.

Ong C.K. and Everard A 1979. Short day induction of flowering in pearl millet (*Pennisetum typhoides*) and its effect on plant morphology. Experimental Agriculture 15: 401–410.

Ong C.K. and Monteith J.L. 1985. Response of pearl millet to light and temperature. Field Crops Research 11: 141–160.

Pearson C.J. and Coaldrake P.D. 1983. *Pennisetum americanum* as a crop in eastern Australia. Field Crops Research 7: 265–282.

Poole R.W. 1974. An introduction to quantitative ecology. McGraw-Hill, New York.