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PARTICIPATORY VARIETAL SELECTION WITH IMPROVED PEARL MILLET IN WEST AFRICA

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SUMMARY

A reconnaissance survey and participatory varietal selection trials (PVS) were conducted in four major pearl millet-growing countries of the Sahel between 2001 and 2003. The studies aimed to identify farmers' preferences in improved pearl millet varieties, increase awareness, test new varieties and enhance farmers' access to the improved varieties. Farmers selected five out of 10 tested varieties, with preferred characteristics, namely, maturity cycles of 80–90 d in the Sahel and 90–100 d in the Sudanian agro-ecozones, acceptable grain yield, compact and long (30–100 cm) panicles, a large number of tillers with panicles, adaptation and an acceptable taste. Farmers indicated that their local varieties were of superior adaptation and taste. They mentioned that hindrances to uptake and sustained use of improved varieties were due to lack of awareness, traditional values, seed unavailability, early maturity, bird damage and lack of fertilizer. The strong genotype × environment interactions in the Sahel suggests that breeding should be directed towards producing varieties adapted to specific zones rather than for wide adaptation. Notably, since farmers often cultivate pearl millet without any soil amendments, it may be advisable to disseminate varieties as a package (with fertilizer and agronomic instructions) rather than as varieties alone in a PVS programme, in order to achieve the full potential of improved varieties. The PVS trials are synergistic to plant breeding in identifying varieties suitable for harsh environments, which are difficult to duplicate in the research station. However, in the absence of formal distribution seed systems in the trial countries, village- or community-based seed production of varieties selected by farmers appears critical to the sustainable adoption of selected varieties.

INTRODUCTION

Pearl millet (*Pennisetum glaucum*) is the flagship cereal crop of the Sahel, providing food grain to households living in areas with low soil fertility and erratic rainfall, averaging 300–600 mm (Ndjeunga, 2002). An estimated 11.3 million t of pearl millet grain is produced annually in Africa (ICRISAT and FAO, 1996). With a rapidly growing population, new productive pearl millet varieties able to escape or tolerate drought spells are needed in Sahelian Africa. These new varieties have been tested on-station

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for observation and evaluation by farmers, and occasionally on-farm, under farmers' management, with facilitation by researchers. The latter is known as participatory varietal selection (PVS) and has been described in previous studies, for example by Sperling *et al.* (1993), Sthapit *et al.*, (1996) and Witcombe *et al.*, (1996). Similarly, work by Maurya *et al.* (1988) and Sperling *et al.* (1993) has indicated that farmer involvement can enhances diffusion and adoption of improved crop varieties in crops like rice and beans in India and Rwanda.

PVS has also assisted in the dissemination of pearl millet varieties in Namibia, Zimbabwe and Tanzania (Holtland, 1996; Mangombe and Mushonga, 1996; Rohrbach *et al.*, 1999). In these cases, farmers selected pre-released varieties indicating their preferred traits. In Namibia, this resulted in the development of a composite pearl millet that became widely adopted by farmers (Rohrbach *et al.*, 1999). In these trials, farmers preferred traits were not necessarily high grain yield, but encompassed earliness, drought tolerance, grain size and colour (Mangombe and Mushonga, 1996).

ICRISAT (1982–1997), LCRI (2002–2003) and ROCAFREMI (2002) have developed and tested improved pearl millet varieties in West Africa. Despite these efforts, there is limited use of these varieties by farmers in West Africa. For example, as Yapi *et al.*, 2000 reported, adoption rates of pearl millet in Mali ranged from 0 to 23 % five years after the release of new varieties. Grain yields remain low on farmers' fields, fluctuating on average, between 300–600 kg ha^{-1}. Against this background, the present study was conducted in the major pearl millet growing regions of Burkina Faso, Mali, Niger and Nigeria. It aimed to identify farmers' preferred characteristics in pearl millet varieties, to increase awareness, to test new varieties and to enhance farmers' access to these varieties.

MATERIALS AND METHODS

Experimental details

We conducted a reconnaissance survey in Burkina Faso, Mali, Niger and Nigeria in 2001, and thereafter PVS trials on farmers' fields in 2002 and 2003 in the first three countries listed. A semi-structured questionnaire was utilized in the reconnaissance survey. Information on pearl millet preferences and constraints to adoption (uptake and sustained use) was collected from individual interviews with 111 farmers and also from group/informal discussions with another 104 farmers. Twelve of the 215 farmers interviewed in the survey were women. A random sample of 33 villages were covered in the major pearl millet growing regions, namely, Ouagadougou, Obritenga, Kokologho in Burkina Faso; Segou and Mopti in Mali; Maradi, Tahoua and Zinder in Niger; and Borno, Kano and Sokoto in Nigeria.

PVS trials were then conducted with a total of 184 and 144 farmers in June–October 2002 and 2003, respectively, from 22 villages in Burkina Faso, Mali and Niger (Table 1). Total annual rainfall in the years 2002/2003 was, respectively, 767/750 mm in Kodougou and 394/591 mm in Ouahigouya, Burkina Faso; 494/541 mm in Segou and 351/725 mm in Mopti, Mali; and 517/541 mm in Dogon Doutchi, Niger. In Gaya and Tera in Niger, the rainfall figures were available for year 2003 totalling 780 and

Table 1. Pearl millet varieties tested with farmers and other partners in different agro-ecozones of Burkina Faso, Mali and Niger in 2002 and 2003.

Agro-ecozone/ Country/Region	Village	Variety tested†	Partner	No. of farmers in 2002/2003	Remarks
Sudanian Burkina Faso Koudougou	Latou-Nord Kouglapaka Koulnatinga	ICMV IS 89305 ICMV IS 92222 SOSAT C88 ZATIB Kapelga (local)	INERA, Department Provincial Agricole	30/11	Flooding destroyed some fields in 2003
Sahelian Burkina Faso Ouahigouya	Pobe Mengao Bougue Garbaboule	ICMV IS 89305 ICMV IS 90311 **HKP** SOSAT C88 Balbou (local)	INERA, Department Provincial Agricole	29/30	
Sudano-Sahelian Mali Segou	Cinzana Koudougou Fanbougou	ICMV IS 89305 ICMV IS 90311 ICMV IS 92222 **SOSAT C88** **NKOXTCL** Toronio C1 (local)	IER-Cinzana	30/15	Farmers citing adaptation problems did not test the varieties typed in bold print in 2003
Sahelian Mali Mopti	Sofara Koulebala Guidiowel	ICMV IS 89305 ICMV IS 92326 ICMV IS 99001 SOSAT C88 Niou (local)	Winrock International-Mali	30/30	
Sudano-Sahelian Niger Dogon Doutchi	Kalgo Kalon mota Boutana	ICMV IS 94206 SOSAT C88 Zongo (local)	Service Agricole-Dogon Doutchi	15/16	
Sudanian Niger Gaya	Yombou Karey Goussou Sia Gawassa	ICMV IS 89305 ICMV IS 92222 SOSAT C88 **ZATIB** Guero (local)	PADEL-Gaya, Service Agricole, INRAN-Bengou	28/20	Some fields were destroyed by floods
Sahelian Niger Tera	Sirfikoira Wargountou Kokani	ICMV IS 89305 ICMV IS 92222 **HKP** SOSAT C88 Haini Kirey (local)	Moriben Farmers Cooperative	22/22	Crop failure experienced due to late planting in some fields

†Pearl millet varieties shown in bold print were sown only in 2002; others were sown in both 2002 and 2003 seasons.

496 mm, respectively. Farmers from the pearl millet-growing agro-ecological zones were selected with the assistance of local partners, based on their willingness to test the improved pearl millet varieties, availability of land and accessibility to the fields. The pearl millet varieties selected for the tests were matched to the specific zones based on recommendations in technical reports from the ICRISAT Sahelian Centre, Niger. Within a country, three to four villages were selected in each agro-ecological zone (or region), while 10 farmers were selected in each village (Table 1). Each farmer tested one to two improved pearl millet varieties alongside the local cultivar. In 2002, five farmers in a village grew the same two varieties. In 2003, farmers tested varieties of their own

choice from those evaluated in 2002. The trial farmers were fewer than expected in 2003, due to floods, late planting and loss of seeds. The variety trials were conducted under farmers' management on adjacent plots of 0.02–0.5 ha and incorporated seed treatment and hill placement of 6 g NPK fertilizer (15 % N: 15 % P_2O_5:15 % K_2O). The pearl millet fields were sown at 10 000 hills ha^{-1}. Farm visits in each village were made at pre-sowing and near harvest times with local partners within the season; focus group discussions elicited farmers' preferences for the improved varieties and constraints to their uptake and sustained use. Data on days to 50 % flowering, plant height, panicle length and grain yield were assessed in each experimental field.

Data analysis

Assessment of farmers' preferences for the pearl millet varieties and constraints to their adoption were tabulated. Agronomic data were subjected to the restricted maximum likelihood estimation (REML) analysis, as described by Patterson and Thompson (1971) using GENSTAT software. Extreme outliers were declared as missing values only when there was an explanation in the field books. Farmers within villages were considered as replications. The significance of pearl millet performance characteristics was assessed using a Chi-square test. Combined analysis was conducted across years within regions (agro-ecological zones) and countries. A combination of an evaluation site and a season (year) was considered as a macro-environment. The contribution of years, varieties and villages and their two- and three-way interactions to the variation observed in the agronomic data, were analysed using the Wald Statistic as explained by Payne *et al.* (1994) at $p < 0.05$, $p < 0.01$ and $p<0.001$. Coefficients of phenotypic correlations were computed among traits within the macro-environments.

RESULTS

Characteristics and varieties of pearl millet preferred by farmers

The reconnaissance survey indicated farmers' preferences for pearl millet as acceptable grain yields (at least 500 kg ha^{-1}), early maturity within 80–90 d from planting in the Sahelian zones and 90–100 d in the Sudano-sahelian zones, long (30–40 cm) and compact panicles (Table 2). PVS trial results conducted in 2002 and 2003

Table 2. Percentage of farmers mentioning preferred traits for pearl millet in various agro-ecological zones of Burkina Faso, Mali, Niger and Nigeria.

Trait	Burkina Faso: Sudanian	Mali: Sudano-sahelian	Mali: Sahel	Niger: Sudano-sahelian	Nigeria: Sudano-sahelian	Total: all zones
Grain yield	69	67	82	67	95	74
Early maturity	100	33	91	50	15	53
Long panicle	44	42	27	38	20	35
Compact panicle	56	33	27	15	70	34
High tillering	50	25	36	37	20	34
Drought resistance	56	8	55	23	15	28

Table 3. Preferred pearl millet varieties and characteristics† mentioned by farmers in Burkina Faso, Mali and Niger in 2002 and 2003.

Agro–ecozone/ Country/ Region/Variety	EM	GY	GS	CP	PL	TP	HM	ST	BD	AD	GTC	DM	RD
Sudanian/Burkina Faso/Koudougou													
SOSAT C88	+	+	+	+	–	+	+	–	–	–	+	–	–
ICMV IS 89305	+	+	–	+	+	+	–	–	–	–	+	+	–
Kapelga	–	–	+	–	+	–	–	+	+	+	+	+	+
Sahelian/Burkina Faso/Ouahigouya													
SOSAT C88	+	+	+	+	–	+	+	–	–	+	+	–	–
ICMV IS 89305	+	+	+	+	–	+	+	–	–	+	+	–	–
Balbou	–	+	+	+	+	–	–	–	+	+	+	+	+
Sudano–sahelian/Mali/Segou													
SOSAT C88	+	+	+	–	–	+	–	–	–	–	+	–	–
Toronio C1	+	+	+	+	+	–	+	–	+	+	+	–	+
Sahelian/Mali/Mopti													
SOSAT C88	+	+	+	+	–	+	–	–	+	+	+	–	–
ICMV IS 89305	+	+	+	+	+	+	–	–	–	+	+	–	–
ICMV IS 92326	+	+	+	+	+	+	–	–	–	–	+	–	–
ICMV IS 99001	+	+	+	+	+	+	–	–	–	–	–	–	–
Niou	–	–	+	+	+	–	–	–	+	+	+	–	+
Sudanian/Niger/Gaya													
SOSAT C88	+	+	+	+	–	+	–	–	–	+	+	+	–
ICMV IS 89305	+	+	+	+	+	+	–	–	–	+	+	+	–
Guero (Haini kirey)	–	+	+	+	+	–	–	–	+	+	+	+	+
Sudano–sahelian/Niger/Dogon Doutchi													
SOSAT C88	+	+	+	+	–	+	+	–	–	+	+	+	–
ICMV IS 94206	+	+	+	+	+	+	+	–	–	+	+	+	–
Zongo (Haini kirey type)	–	+	+	–	+	–	–	–	+	+	+	+	+
Sahelian/Niger/Tera													
SOSAT C88	+	+	+	+	–	+	–	–	–	–	+	+	–
Haini Kirey	+	–	+	+	+	+	–	–	+	+	+	+	+

†EM: early maturity of 85–90 days; GY: high grain yield; GS: acceptable grain size; CP: compact panicle; PL: panicle length > 30cm; TP: tillers with panicles; HM: headminer resistance; ST: *Striga* resistance; BD: bird damage resistance; AD: well adapted; GTC: acceptable grain taste and colour; DM: downy mildew resistance; RD: resistance to other diseases.

+: Preferred characteristic found in the pearl millet variety.

–: Characteristic that farmers found lacking in the pearl millet variety.

were consistent with the survey data (Table 3). In addition, adaptation, resistance to *Striga*, head miner, drought and lodging were important preference traits for farmers. The PVS trials permitted evaluation of 11 improved varieties with farmers, with their local varieties acting as controls. Farmers expressed preferences for the improved varieties, which had acceptable grain yield (about 400 kg ha^{-1}), were early maturing (85–90 days) and had high number of tillers (>3) with compact panicles (Table 3).

In Koudougou, Burkina Faso and Mopti, Mali, farmers indicated that SOSAT C88, ICMV IS 89305, ICMV IS 92326 and ICMV IS 99001 were not well adapted

to their regions (Table 3). Farmers explained that they lacked good germination, stout growth, resistance to lodging, drought and pests, and resilience to browsing. The lack of resistance to head miner and *Striga* was a major concern in the improved and local varieties, except for Kapelga, which exhibited some *Striga* tolerance. The varieties SOSAT C88 and ICMV IS 94206 were mentioned as having head miner resistance in Kodougou and Dogon Doutchi, respectively (Table 3). SOSAT C88 was appreciated in all regions for having acceptable grain yield, and providing grain early in the season, though farmers would prefer it to have a longer panicle. The local varieties Kapelga, Balbou, Toronio C1, Niou and Haini Kirey types (Guero and Zongo) were preferred by farmers for being especially well adapted, having stable panicle characteristics and seeds that are readily available. This contrasts with the poor availability of seeds of the improved pearl millet varieties, especially at pre-sowing time. After the 2002 trials, farmers requested 315 kg of improved seed and this increased to 1020 kg after the 2003 trials. Farmers who saved and planted seeds from the previous season (2002) were concerned that the improved varieties exhibited unstable or changing panicle and height characteristics in the following season. For example, the panicles of SOSAT C88 and ICMV IS 89305 were not compact and lost uniformity in flowering. Farmers in Niger and Mopti in Mali indicated they were inconvenienced when tying harvested SOSAT C88 panicles into bundles due to the short panicle length. They would prefer the variety to have a panicle length of ≥ 30 cm or more. In all three countries, farmers preferred the taste of their local variety in the traditional *bol* (porridge), but found the taste of porridge made from the preferred improved varieties acceptable.

Agronomic performance of the local and improved pearl millet improved varieties

In Burkina Faso, the pearl millet varieties differed significantly in all the characteristics assessed, except in grain yield at Koudougou (Table 4). The time to 50 % flowering for the improved pearl millet ranged from 54 to 61 d. The local variety Balbou achieved 50 % flowering after 61 and 65 d in 2002 and 2003, respectively, in Ouahigouya, Burkina Faso. SOSAT C88 plants were the shortest in all environments, while local Kapelga and Balbou were taller than the improved varieties (Table 4).

In Mali, the performance characteristics differed statistically, except in grain yield at Segou in 2003, and at Mopti in both seasons (Table 4). Improved varieties reached 50 % flowering after 60–71 d in 2002, and 57–66 d in 2003 at Segou. This compares with 61–65 d in 2002 and 52–53 d in 2003 at Mopti for the improved varieties. The local Toronio C1 and Niou cultivars flowered after 63–72 d (Table 4). In both years, Toronio C1 had the highest grain yield at Segou, with averages of 949 and 1183 kg ha^{-1}. At Mopti, the largest mean grain yield was observed in SOSAT C88 (1142 kg ha^{-1}) in 2002 and ICMV IS 99001 (883 kg ha^{-1}) in 2003. The local control Niou attained average grain yields of 906 and 694 kg ha^{-1} in 2002 and 2003, respectively.

In the Gaya region of Niger, the pearl millet varieties differed significantly in all the assessed characteristics (Table 5). Flooding in some fields resulted in low yields in 2003. Grain yields ranged from 809 to 919 kg ha^{-1} for improved varieties in 2002,

Table 4. Performance of pearl millet varieties in Burkina Faso and Mali in 2002 and 2003.

Agro-ecozone country/ region variety	Days to 50 % flowering		Plant height (cm)		Panicle length (cm)		Grain yield (kg ha^{-1})	
	2002	2003	2002	2003	2002	2003	2002	2003
Sudanian/Burkina Faso/Koudougou								
ICMV IS 89305	–	–	156	–	62	–	645	–
ICMV IS 92222	–	–	156	150	63	54	685	426
SOSAT C88	–	–	144	149	22	29	663	461
ZATIB	–	–	154	–	37	–	619	–
Kapelga	–	–	194	255	29	26	590	368
Significance	–	–	***	***	***	***	ns	ns
s.e	–	–	6.8	21.6	3.1	6.8	46.9	162.4
Sahelian/Burkina Faso/Ouahigouya								
ICMV IS 89305	56	61	178	216	47	46	225	973
ICMV IS 90311	60	–	176	–	47	–	132	–
SOSAT C88	56	54	165	184	27	27	262	980
HKP	55	–	177	–	47	–	254	–
Balbou	61	65	190	215	43	40	229	894
Significance	***	**	***	***	***	***	***	**
s.e	0.9	2.1	5.8	9.3	3.1	2.3	32.6	54.4
Sudano-Sahel/Mali/Segou								
ICMV IS 89305	61	66	184	183	55	–	568	458
ICMV IS 90311	61	60	171	171	42	–	549	1060
ICMV IS 92222	60	57	186	165	57	–	500	1050
NKOXTCL	71	–	203	–	36	–	878	–
SOSAT C88	60	–	183	–	32	–	598	–
Toronio C1	67	66	203	213	34	–	949	1183
Significance	***	***	***	***	***	–	***	ns
s.e	2.8	2.8	4.6	16.0	2.0	–	165.4	230.2
Sahel/Mali/Mopti								
ICMV IS 89305	62	52	228	233	55	57	1065	1006
ICMV IS 92326	65	53.	218	211	55	51	922	670
ICMV IS 99001	62	53	230	231	55	55	1105	883
SOSAT C88	61	53	163	183	28	31	1142	784
Niou	72	63	174	205	35	46	906	694
Significance	***	***	***	***	***	***	ns	ns
s.e	1.07	2.7	9.1	10.9	1.3	2.6	162.2	166.4

–: Variety not planted by farmers or data not assessed.
ns, *, **, *** denotes not significant, significant differences among the variety means within years at $p < 0.05$, $p < 0.01$ and $p < 0.001$, respectively.

compared to a mean of 756 kg ha^{-1} for the local Guero (Haini kirey) cultivar. In 2003, grain yields ranged from 367 kg ha^{-1} (Guero) to 450 and 453 kg ha^{-1} for SOSAT C88 and ICMV IS 89305, respectively. In Dogon Doutchi 2003, there were no significant differences between varieties in any traits. On average, the improved varieties took 58–65 d to 50 % flowering in the two test seasons. At Tera 2002, significant differences were observed in all traits, while flowering time and grain yields were both similar in 2003 (Table 5).

Table 5. Performance of pearl millet varieties in 2002 and 2003 in Niger.

Agro-ecozone/ region variety	Days to 50 % flowering		Plant height (cm)		Panicle length (cm)		Grain yield (kg ha^{-1})	
	2002	2003	2002	2003	2002	2003	2002	2003
Sudanian/Gaya								
ICMV IS 89305	–	–	–	245	–	58	832	453
ICMV IS 92222	–	–	–	–	–	–	809	–
SOSAT C88	–	–	–	195	–	25	903	450
ZATIB	–	–	–		–	–	919	–
Guero	–	–	–	262	–	64	756	367
Significance	–	–	–	***	–	***	**	*
s.e	–	–	–	2.8	–	2.4	71.5	54.2
Sudano-Sahel/Dogon Doutchi								
ICMV IS 94206	66	64	260	204	68	51	405	807
SOSAT C88	58	62	200	181	28	41	471	873
Zongo	72	–	264	–	73	–	327	–
Significance	***	ns	***	ns	***	ns	ns	ns
s.e	2.8	5.4	19.8	52.1	5.0	15.8	167.6	222.2
Sahel/Tera								
ICMV IS 89305	60	47	175	214	57	51	659	835
ICMV IS 92222	63	49	183	211	62	51	584	450
HKP	62	–	161	–	55	–	412	–
SOSAT C88	60	46	164	166	26	21	497	1082
Haini Kirey	78	–	203	–	70	–	596	–
Significance	***	ns	***	**	***	***	*	ns
s.e	2.2	4.8	9.4	22.9	2.4	6.5	105.3	218.2

–: Variety not planted by farmers or data not assessed.

ns, *, **, *** denotes not significant, significant differences among the variety means within years at $p < 0.05$, $p < 0.01$ and $p < 0.001$, respectively.

Table 6. Percentage of farmers citing constraints to adoption of improved varieties in different agro-ecological zones of Burkina Faso, Mali, Niger and Nigeria

Trait	Burkina Faso: Sudanian	Mali: Sudano-sahelian	Mali: Sahel	Niger: Sudano-sahelian	Nigeria: Sudano-sahelian	Total: across zones
Awareness	44	33	73	44	55	48
Tradition	50	50	73	35	45	44
Seed availability	63	8	36	42	30	39
Early maturity	63	25	55	38	15	38
Bird damage	69	0	36	13	35	23
Fertilizer availability	69	17	36	21	0	25

Hindrances to uptake of improved pearl millet varieties

The reconnaissance survey indicated that the uptake and sustained use of improved varieties is constrained by lack of awareness of the improved varieties, traditional values, seed unavailability, early maturity, bird damage and fertilizer unavailability (Table 6).

Table 7. Wald Statistic values and significance due to years (Yrs), varieties (Var), villages (Vill), respective two-way interactions† for days to 50 % flowering (Flowering), plant height and grain yield in entries assessed in 2002 and 2003.

Agro-ecozone/region Characteristic	Source of variation					
	Yrs	Var	Vill	Yrs × Var	Yrs × Vill	Var × Vill
Sudanian/Kodougou						
Plant height	7.51**	243.21***	36.69***	37.17***	13.33***	68.04***
Grain yield	30.30**	9.41**	7.34*	1.95 ns	4.48 ns	0.49 ns
Sahel/Ouahigouya						
Flowering	16.33***	103.71***	0.05 ns	17.19***	0.27 ns	2.06 ns
Plant height	42.59***	33.01***	1.00 ns	2.48 ns	0.07 ns	0.64 ns
Grain yield	124.54***	7.17*	8.39*	4.60 ns	2.64 ns	1.66 ns
Sudano-Sahel/Segou						
Flowering	6.72**	66.39***	1.15 ns	3.79 ns	0.75 ns	9.26 ns
Plant height	4.55*	121.39***	2.43 ns	12.47**	1.22 ns	8.37 ns
Grain yield	8.90**	46.04***	1.19 ns	10.44*	1.03 ns	21.24*
Sahel/Mopti						
Flowering	19.46***	407.64***	5.82*	6.09 ns	1.55 ns	12.67 ns
Plant height	4.64*	124.79***	41.32***	21.72***	16.12***	8.56 ns
Grain yield	9.67**	12.88**	1.37 ns	1.48 ns	1.41 ns	5.01 ns
Sudanian/Gaya						
Grain yield	2.96 ns	13.16***	13.51***	1.53 ns	21.49***	2.78 ns
Sudano-Sahel/Dogon Doutchi						
Flowering	11.05***	67.61***	8.38*	2.73 ns	7.80**	8.41*
Plant height	38.71***	58.91***	4.70 ns	6.02 ns	12.58**	0.49 ns
Grain yield	17.05***	5.79 ns	6.55*	2.41 ns	7.41*	6.57 ns
Sahel/Tera						
Flowering	195.69***	214.27***	3.94 ns	0.19 ns	13.54***	19.96**
Plant height	1.22 ns	71.72***	1.73 ns	4.84 ns	7.46**	9.83 ns
Grain yield	26.01***	9.12 ns	12.41**	9.21**	1.19 ns	11.83 ns

ns, *, **, *** denotes not significant, significant differences among the variety means within years at $p < 0.05$, $p < 0.01$ and $p < 0.001$, respectively.
†Three-way interactions were not significant and hence are not presented

Combined analysis across years within zones

The test years (season) had a significant effect on grain yield at all test sites, as shown in Table 7. This effect was less pronounced in Mali, as evidenced by the Wald Statistic values. Variation in plant height was strongly influenced by the genotypes (varieties). The year × variety, year × village, variety × village and year × variety × village interactions were mostly not significant. The locations (villages) within regions did not contribute significantly to the variation observed in flowering dates, except at Dogon Doutchi, Niger and Mopti, Mali.

Relationships between pearl millet performance characteristics

Coefficients of correlation were largely weak and inconsistent among traits within regions (Table 8). However, longer panicles were consistently associated with taller

Table 8. Correlation among selected characters combined within regions (zones) and years in the indicated countries.

Correlated Characters†	Burkina Faso				Mali				Niger				
	Koudougou		Ouahigouya		Segou		Mopti		Gaya	Dogon	Doutchi	Tera	
	2002	2003	2002	2003	2002	2003	2002	2003	2003	2002	2003	2002	2003
GY×PL	−0.09	−0.19	0.07	−0.03	−0.26		0.07	0.07	−0.26	0.02	−0.40	0.06	−0.08
GY×DF			−0.06		0.20	0.34	−0.41	−0.14		−0.40	−0.15	0.22	−0.24
GY×PH	−0.12	−0.18	0.15	−0.02	0.15	0.21	0.10	0.18	−0.29	0.31	0.51	0.32	−0.05
PL×DF			0.14		−0.27		−0.19	0.02		0.50	−0.37	0.45	0.12
PL×PH	−0.32	−0.47	0.19	0.45	−0.25		0.69	0.60	0.98	0.69	0.39	0.29	0.73
DF×PH			0.27		0.28	0.69	−0.08	0.06		0.29	−0.37	0.53	0.26

†GY: Grain yield; PL: panicle length; DF: days to 50 % flowering; PH: plant height

plants at Mopti, Gaya, Dogon Doutchi and Tera regions. Panicle length and flowering were moderately and positively correlated at Dogon Doutchi in 2002. Days to flowering generally increased with plant height at Ouahigouya, Segou, Dogon Doutchi and Tera regions.

DISCUSSION

Characteristics preferred by farmers in the tested improved pearl millet varieties

Grain yield and early maturity were the two most mentioned performance traits (Tables 2). Farmers indicated that short maturity cycles permit an early harvest, thereby breaking the famine and allowing harvest and sale of grain at prime market prices. Early maturity provides relative drought escape, especially at the season's end. Earliness has indeed been recognized as an important trait in finger millet and maize (Gowda *et al.*, 2000; Hintze *et al.*, 2002). Since the water requirements of millet depend on crop duration (Dancette, 1983), varieties with short maturity cycles require less water, and are thus useful in the Sahel, which is prone to erratic rainfall. On the other hand, farmers also observed that early maturing varieties were prone to insect and disease attack, as they form the first panicles in their fields (Table 2). However, they expressed the view that the advantage of earliness supersedes these disadvantages. Niangado and Ouendeba (1987) noted that although earliness is important, late maturing varieties may assist farmers in cases of late planting or replanting due to spells of drought, pests and diseases experienced at the beginning of the season. The late maturing photosensitive local varieties such as 'Maiwa' in Niger initiate flowering with the decreasing day lengths in October. This allows farmers to have a second harvest in November. Droughts within the planting season were erratic and farmers indicated that a combination of cultivating early and late varieties would improve their food security and form a better risk management strategy than either alone. This system of planting crops with different maturities is extended to up to five crops in southern Niger, where farmers crop early and late pearl millet, groundnut, cowpea and late sorghums in one field. In difficult environments, several varieties may provide yield stability (Ceccarelli *et al.*, 1994). In 2003, farmers complained about rains that washed

off pollen in varieties SOSAT C88, ICMV 89305 in Koudougou, Burkina Faso and in Gaya, Niger, both of which lie in Sudanian agro-ecozones. The trial farmers recognized that this was a season dependent experience and neighbouring farmers still requested seeds of these varieties to cultivate in 2004.

Grain yield is a key preference for farmers, as has also been indicated in previous studies (LCRI, 2002–2003). However, farmers' selection of varieties was not solely guided by grain yield alone but also by panicle length and compactness, multiple tillers with compact, well-filled and disease-free panicles, the taste of cooked grain and adaptation of the variety to their location (Table 3). After harvest, they judge good yield by the number of panicle bundles or the number of containers filled with panicles. Compact panicles assist in reducing bird and head miner damage and may result in larger yields due to high seed density per panicle. Despite appreciable grain yields from HKP in Ouahigouya (Table 4) and ICMV IS 92222 and ZATIB in Gaya, Niger (Table 5) in 2002, farmers expressed a non-preference for these varieties due to lack of adaptation. Consequently, they were not willing to sow them in the following season. As Musa (1998) indicates, PVS allows farmers to select for adaptation *in situ*. Farmers in the three countries described adaptation as good germination, stout growth, resistance to lodging, tolerance to drought and pests under farmers' conditions, and resilience to damage by livestock. The most important source of seed for sowing is from their own harvest (Ndjeunga 2002). Prior to harvesting, farmers use panicle traits and adaptation as key characteristics in the selection of panicles for seed. Panicles harvested for seed are kept separately in the granary and may be left with longer peduncles for identification.

Farmers who harvested seeds in 2002 and replanted them in 2003 found that the improved varieties changed; for example SOSAT C88, ICMV IS 89305 had less compact panicles, and less uniform panicle length and flowering time. This is due to out crossing of the improved pearl millet with neighbouring farmers' varieties, a fact also noted by Holtland (1996).

Hindrances to uptake and sustained use of improved pearl millet varieties

Farmers are largely unaware of improved early maturing varieties, partly due to insufficient or ineffective extension services. This leads to unavailability of preferred varieties, as also noted by Stoop (2002). An important aspect encountered in the field is 'traditional values', which refers to a firm conservative attitude among farmers, biasing them to use local varieties of known characteristics passed on from previous generations. However, with the continued use of preferred improved varieties, the farmers may reduce their emphasis on 'traditional value' and gradually allow more testing of new varieties. It is important to note that use of preferred improved varieties can only be sustained if community-based seed production is effective, to ensure seed availability, a fact also acknowledged by Ndjeunga (2002).

Though earliness is a preferred trait, early maturity of 85–90 d is at the same time a hindrance to adoption because of damage by birds, diseases and other pests. Birds consume pearl millet grain and can cause severe yield losses in small fields or when harvest is delayed for an extended period after maturity. Grain is borne on open

panicles; hence timely harvest is critical to minimize bird damage. Discussions with farmers indicated that bird damage could be reduced when a large number of farmers cultivate varieties of similar maturity. As noted by Bationo *et al.*, (2005), improved varieties need fertilizer to perform well, a fact which farmers are aware of. Farmers indicated that fertilizers are not always available at the time they are needed and when available the cost is prohibitive. None of the farmers in the focus group discussions used pesticides due to high costs and unavailability.

Variability among pearl millet traits across years

The significant effect of the year (season) illustrates the strong environmental influence on trait expression (Table 7). Genotype by environment (G×E) interaction in general is considered to have a negative impact on the success of breeding programmes because breeders tend to search for a few widely adapted cultivars (Ceccarelli *et al.*, 1994). Of most importance is the crossover G×E, which has also been reported in different environments, using pearl millet (Virk and Mangat, 1991). Grain yield values were drastically different for the two seasons at Kodougou and Ouahigouya in Burkina Faso (Tables 4 and 5). On the other hand, some varieties such as ICMV IS 89305, ICMV IS 92222 and SOSAT appear to have relatively stable yields across test sites. These varieties are based on the local open-pollinated varieties and possess some adaptation qualities similar to the local cultivars.

The environmental component includes rainfall amount and distribution, differences in soil fertility, pest and disease incidence, and farmers' agronomic practices. These parameters are highly variable and exert significant effects on varietal performance in farmers' fields. Coffman and Smith (1991) suggested that it may be better to breed for sustainability, i.e. fitting varieties to an environment instead of altering the environment to fit the varieties.

Correlation among pearl millet traits within macro environments

The observed weak and inconsistent correlations among traits indicate the differential phenotypic expression of the assessed trait in the same varieties largely as a result of strong environmental influences (Table 7). The relationship among panicle length, days to flowering and plant height were stronger in some locations than others (Table 6), in line with the stronger genetic control observed for these traits (Table 5).

Implications for pearl millet improvement in the Sahel

The present work illustrates the appreciable yield performance of some improved pearl millet varieties across different agro-ecological zones (Tables 4 and 5). Crop varieties do not always perform well in all environments (Atlin, 1997; Ceccarelli *et al.*, 1991, 1994). To facilitate the breeding of varieties that fit in to the target environments, breeders' may consider using PVS on advanced pearl millet lines sown in selected farmers' fields. This approach is also referred to as participatory plant breeding (PPB), which may be described as farmer selection with unfinished materials possessing a

high degree of genetic variability (Witcombe *et al.*, 1996). Indeed, farmers should be involved in the generation of variability and selecting segregating pearl millet lines. This has the potential to increase farmer acceptability of the pre-released or released varieties and assists in the retention of genetic material with particular characteristics preferred by the farmers. Sthapit *et al.* (1996) have also noted that farmer-preferred pearl millet varieties from the PVS trials could be suitable parental materials for subsequent participatory breeding, an observation endorsed by this study.

To incorporate adaptation in the development of improved varieties, there is a need to derive materials from crosses developed from farmers' varieties in the target agro-ecological zones. Past breeding efforts by ICRISAT (1982–1997) produced early maturing varieties, which are not necessarily higher yielding compared with the farmers' varieties (Tables 4 and 5), but they escape an end-season drought and provide grain early in the season. In addition to grain yield enhancement, future pearl millet improvement should address increasing resistance to pests, especially head miners and *Striga hermonthica*. Due to the strong environmental effect on grain yield (Tables 4, 5 and 7), and in view of the fact that the farmers often cultivate pearl millet without any soil amendments, it may be advisable to disseminate improved pearl millet varieties as a package rather than as varieties alone in a PVS programme in order to achieve the full potential of the improved varieties. In particular, a holistic approach, applying resources to develop and utilize better germplasm simultaneously, and improve environmental conditions, is essential in raising pearl millet productivity in the Sahel.

The PVS trials served as an effective tool in facilitating farmer to farmer exchanges among trial and non-trial farmers, and in the diffusion of improved pearl millet varieties to over 200 farmers within two years. As a consequence, the seed requests from farmers for the preferred early maturing varieties more than tripled in the two years. The accelerated demand for the introduced pearl millet varieties shows the importance of integrating clients (farmers), extension services and local organizations in a pearl millet breeding programme, further signifying the pre-requisite for strong local partnerships to successful PVS.

The PVS method is a window for introducing technology. Potential grain yield on-station is rarely achieved under small-scale farmers' condition, and hence PVS allows manifestation of on-farm genotype by environment interactions, which in turn enables selection for specific environments as earlier discussed. Our experience indicates that PVS could be improved by paper- and pencil-less interviews, which seems to put the farmers at ease. Discussions should be free but focused, encouraging farmers to seek solutions to identified constraints. This is most sustainable because they identify with answers that they produce themselves. Since PVS relies heavily on a researcher's personality and skills, training on how to conduct interviews and discussions that permit free and open response would assist researchers in conducting PVS, a fact also noted by Stoop (2002).

Farmers are aware that the improved pearl millet varieties seem to 'marry' their own varieties after 1–2 years, resulting in panicle and flowering modifications towards their landraces, which are later maturing. This phenomenon refers to the out-crossing

of the improved pearl millet varieties with the local cultivars. The unstable panicle characteristics discourage adoption of improved varieties by farmers, who considered that these varieties rapidly loose their advantageous characteristics. Thus, as also recommended by Green (1987) and Ndjeunga *et al.* (2002), the production of pearl millet seed at the village or community level is essential to promote utilization of preferred improved varieties in farmers' fields, a development that is critical in West Africa, where formal seed production is largely absent.

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