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Participatory variety development for sorghum in Burkina Faso: Farmers' selection and farmers' criteria

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ABSTRACT

Sorghum (*Sorghum bicolor* (L.) Moench) is the staple crop of Burkina Faso in West Africa where guinea race landraces are grown in low-input cropping systems. National and international breeding programs have had little success in disseminating modern varieties based on high yield potential caudatum or kafir race breeding materials, mostly introduced from other countries. It has been argued that the breeding objectives were not sufficiently oriented towards the farmers' needs and preferences, and that they did not target the prevailing growing conditions of Burkina Faso. The objectives of the present article are (i) to identify and examine farmers' selection criteria for sorghum varieties in the Centre-West of Burkina Faso, (ii) to compare these criteria with the breeder's agronomic observations and standard practices, and (iii) to show how the criteria of both farmers and breeders can be effectively integrated into the early stages of a pedigree breeding program. These objectives take into consideration gender differentiation, consistency of selection criteria and the interrelationship of measured quantitative traits, as well as the impact of these traits and criteria on the final selection. The present paper is based on a pedigree breeding program that was carried out over three years (2001–2003) in two villages of Burkina Faso. Options for integrating farmers' selection expertise with that of the breeders' were examined. Participatory selection was initiated with 53 F3/F4 progenies in field trials managed by farmers using rating and voting exercises. The breeders measured and analysed the agronomic data while the farmers evaluated a large number of progenies by means of their three most important selection criteria and a general appreciation. Farmers' initial choices remained consistent in the selection exercises (voting) performed in subsequent years. The farmers' methods for defining traits turned out to be more multivariate than the breeders' formal understanding of these same traits. This was especially so for the criteria of grain quality, earliness, and productivity for which the farmers' definition encompasses factors such as flour yield and stability across environments. However, rating results between farmer groups were variable. A disagreement between female and male ratings was especially found for the grain quality traits. The results clearly show that farmers can effectively select for traits on the basis of progeny and single plants while pursuing specific agronomic aims such as adaption. Subsequent yield improvement schemes will thus be more efficient in terms of selection intensity related to grain yield. The study is showing the way for breeders to adjust their selection criteria to suit the basic needs of small-scale farmer in semi-arid regions of sub-Saharan Africa.

1. Introduction

Sorghum [*Sorghum bicolor* (L.) Moench] is a staple crop of semi-arid sub-Saharan Africa. In West Africa, farmers grow mainly guinea race landraces that are specially adapted to the harsh and unpredictable conditions of the sub-Sahelian zone (Lacy et al., 2006). These plants characteristically grow to 4 m in height and produce loose panicles. They are photoperiod-sensitive, so that flowering occurs at the end of the monsoon season, which is usually towards

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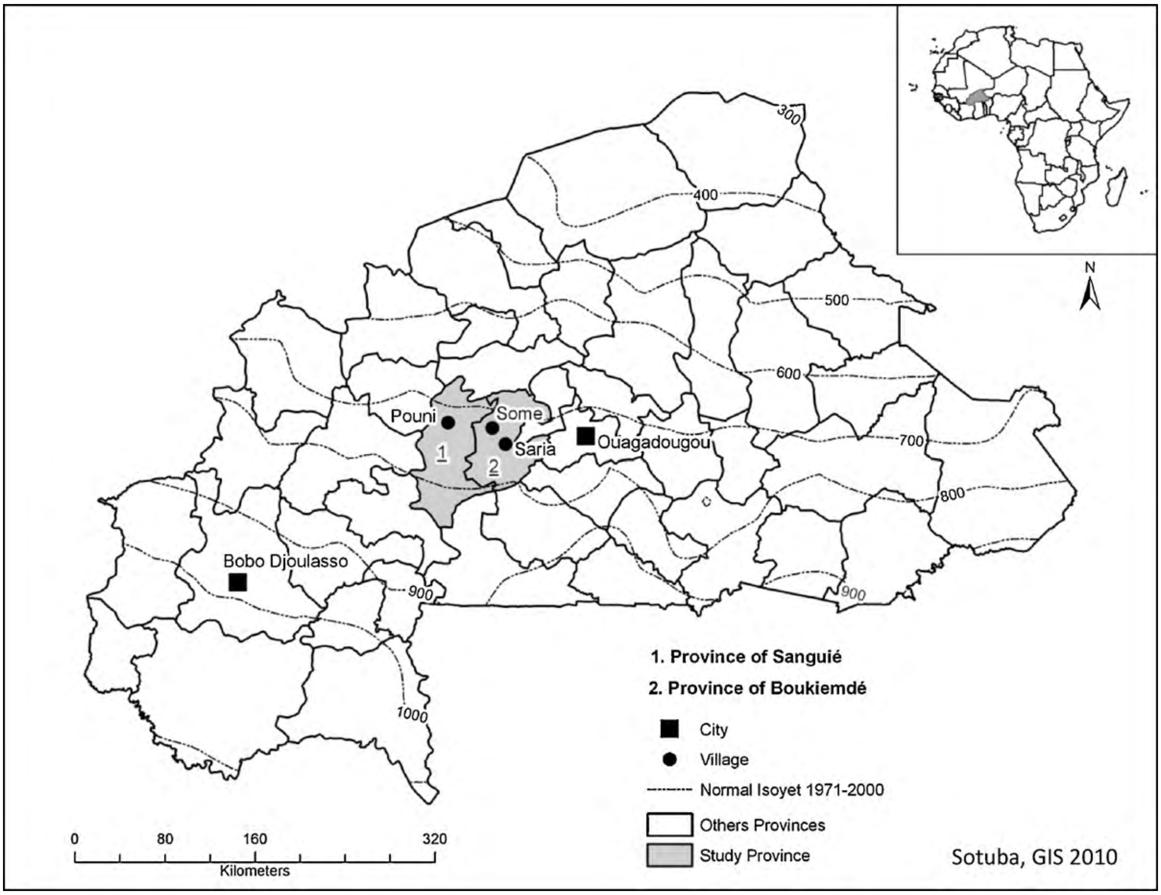

Fig. 1. Geographical location of the experimental sites (Somé and Pouni village) and the Saria research station in Burkina Faso.

the end of September (Zongo, 1991; Vaksmann et al., 1996). In Burkina Faso, sorghum is cultivated in diverse soils and climate conditions with diverse production objectives across more than 1.3 million hectares representing mainly low-input cropping systems. Past breeding projects in Burkina Faso that attempted to improve yield by introducing 'modern' varieties, based on photoperiod insensitive genotypes from caudatum and kafir races, failed to make any measurable impact (Ouédraogo, 2005). Trouche et al. (1998) provides a detailed account of the advantages and inconveniences of the breeding materials used by the latter breeding programs. In the mid-eighties, it was estimated that less than 5% of farmers in West Africa were growing modern varieties (Matlon, 1985). In Mali, for example, Yapi et al. (2000) has shown that the increase in adaptation of improved sorghum varieties of around 15% in the early 1990s was for the most part attributable to varieties derived from selections in local germplasm and not improved varieties based on exotic materials. The local germplasm is preferred in Mali because of its good adaptability to the environment and to the local farming system, and because farmers are familiar with the food quality produced by these grains. The staple crops of many other developing countries reveal a similar resistance to the introduction of new or improved varieties (Ceccarelli and Grando, 2007; Virk and Witcombe, 2007).

Studies focused on participatory variety selection (PVS) and participatory plant breeding (PPB) show that breeders' selection criteria and their way of assessing cultivar performance – mainly quantitative and statistically based – often differs widely from the methods traditionally implemented by farmers (e.g. Sperling et al., 1993; Ceccarelli et al., 2000; Mekbib, 2006). Even among farmers and farmer groups themselves, these criteria can vary considerably depending on gender, environmental concerns and economic status (Sperling et al., 1993; Defoer et al., 1997; Weltzien et al., 1998). Bellon (2002), who analysed the ways in which farmers in Mexico assess maize varieties, points out the importance of a selection program that takes into consideration "subjective" traits, that is, traits that are mainly a "function of human perception". To date, breeding objectives in countries where traditional cropping systems are dominating, have not been appropriately oriented towards the perceptions of farmers, specifically their needs and preferences for the difficult growing conditions of their regions (Almekinders and Elings, 2001; Witcombe et al., 2006; Mekbib, 2006). To overcome this predicament, participatory plant breeding methods have been proposed to bring about a more decentralised breeding approach and the integration of farmers, and their complex selection criteria, into a plant improvement program already from the early stages (Courtois et al., 2001; Mulatu and Zelleke, 2002; Ceccarelli and Grando, 2007; Thapa et al., 2009). Thapa et al. (2009), for instance, believe that farmers' criteria can be integrated using their overall preference scores while selecting for cultivars, as these overall scores take into consideration, and balance out the effects of all pertinent traits. Other authors hope to achieve better adoption rates for improved varieties by quantifying farmers' selection criteria and adjusting the breeders' criteria (Defoer et al., 1997). Mekbib (2006), on the other hand, proposes combining farmer breeding with formal breeding in an integrated scheme specifically designed for the centres of crop origin and diversity.

With the goal of enhancing germplasm and preserving local agrobiodiversity, decentralised participatory plant breeding was deemed the best approach for working with sorghum farmers in Burkina Faso with the goal of enhancing germplasm and preserving local agrobiodiversity. This research was a collaborative effort between the Centre de Coopération Internationale en Recherche

Table 1
Trial conditions and ANOVA results (coefficient of variation CV, repeatability REP, *F*-value and trial means) of three agronomic traits observed in field trials in the Somé and Pouni villages between 2001 and 2003.

Trial				Grain yield				1000-grain weight				Heading date			
Location and year	Sowing date	No. of entries	Rainfall[a] July → October (mm)	Mean (kg ha^{-1})	CV (%)	REP (%)	*F*	Mean (g)	CV (%)	REP (%)	*F*	Mean (days)	CV (%)	REP (%)	*F*
Somé 2001	29/6/2001	64	540	1242	22.5	20.9	1.55^{+}	20.7	4.1	76.6	7.67**	82	2.8	59.1	3.97*
Pouni 2002[b]	26/6/2002	49	448	2237	–	–	–	21.0	–	–	–	–	–	–	–
Somé 2002	26/6/2002	49	626	1615	21.5	41.1	2.50**	20.9	4.8	79.9	7.84**	82	3.4	53.6	3.34**
Pouni 2003[c]	6/7/2003	28	637	1351	26.8	59.1	3.84**	20.1	5.8	39.3	1.77**	76	–	–	–
Somé 2003	5/7/2003	32	568	1777	25.0	7.3	1.14	21.2	6.0	57.5	3.02**	76	2.1	34.6	1.81^{+}

[a] Meteorological stations in between 15 km and 20 km distance to Somé and Pouni village.
[b] ANOVA not performed as trial was not randomised.
[c] Statistical parameters for heading date non-estimable from original data.
$^{+}$ *F*-Test significant at the 0.10 level.
* *F*-Test significant at the 0.05 level.
** *F*-Test significant at the 0.01 level.

Agronomique pour le Développement (CIRAD) of France, the Institut de l'Environnement et de Recherches Agricoles (INERA) of Burkina Faso, together with a number of development projects and farmer organisations (vom Brocke et al., 2005). In Burkina Faso, men and women are both actively involved in sorghum cultivation, from seed selection and sowing to harvesting. In the Centre-West region, farmers grow predominantly landraces of guinea race origin (Barro-Kodombo et al., 2010). They have little or no experience with modern varieties or with formal or participatory research. The objectives of this paper are to identify relevant farmer selection criteria, including differentiation by gender, consistency of germplasm evaluation, final impact on selection decisions, and the interrelationship between quantitative traits as observed by breeders. The farmers' selection criteria and their traditional ways of assessing traits will be compared to the breeders' standard practices. Options for integrating farmers' and breeders' criteria in the early stages of a pedigree breeding program will be explored.

2. Materials and methods

2.1. Study sites and choice of farmers

In the first year of the study (2001), selection work was conducted solely at Somé in the Boulkiemdé province. The village of Pouni (Sanguié province) was included into the PPB project the following year with the aim of reaching more farmers and diversifying the soil and cropping conditions of the experiments. Both provinces are located in the Centre-West of Burkina Faso, which falls within the Sudanian climatic zone (Fig. 1). A comprehensive description of the geographical features of this region and its farming systems can be found in Van Staveren and Stoop (1985) and Ouédraogo (2005). Farmers possessing suitable fields were approached by the local farmer organisation (Tenga Wende) in consultation with a local NGO (PDL-SAB, Projet de Développement Local-Sanguié et Boulkiémdé) and the extension service. Details of the institutional framework and the roles and responsibilities of the various partners are given by vom Brocke et al. (2005). Participants for trial evaluations were invited by the two aforementioned organisations on the basis of interest for new sorghum varieties. Women participation was especially asked for as they are also involved in sorghum cultivation in the study region. Participants were all small-scale farmers for whom sorghum represents their staple crop.

2.2. Genetic materials

Trials were initiated in 2001 in the village of Somé using 53 segregating sorghum progenies (F3 and F4 lines), seven previously released modern caudatum race varieties, two local guinea landraces from the INERA gene bank, and two guinea landraces provided by farmers as village checks. The F3 and F4 lines, which were derived from crosses between exotic caudatum and local guinea material (developed by breeders on the research station using criteria given in Table 2), displayed a phenotypic resemblance to the guinea race. In the same year, a breeder carried out pedigree selection on the same progenies in an on-station nursery using the same selection criteria. The number of experimental sites in the study was limited by the seed quantities resulting from the pedigree selection. Selected lines were only included in subsequent years, hence the decreasing number of entries:

Trials of 49 entries conducted at Somé and Pouni in 2002: nine F4/F5 lines of the 2001 farmers' selections together with an additional 17 F4/F5 lines from the same crosses (but selected on-station in 2001 not by farmers but by the breeder), five caudatum varieties with superior grain quality, and 18 local guinea landraces (including four village checks provided by four different farmers). The 17 breeder-selected progenies were added to the trial in 2002 to save any promising progenies from being discarded due to exceptional climatic conditions or trial management problems of the preceding year.

A trial of 28 entries was conducted at Pouni in 2003: twenty F5/F6 lines derived from farmer selections at Pouni in 2002, two caudatum varieties, and six local guinea landraces (including the same 2002 village checks).

A trial of 32 entries conducted at Somé in 2003: twenty-five F5/F6 lines derived from farmers' 2002 selections at Somé, the same two caudatum lines as in the Pouni trial, and five of the six landraces included in the Pouni trial.

2.3. Experimental design for evaluation and selection

An incomplete block design with two replications (alpha lattice) in each village with one replication per farm formed the basis of all field trials. Row length was 8 m and spacing was 0.8 m (two rows per plot) and spacing between hills was 0.4 m with three plants per hill. The same F3/F4 lines were sown in an unreplicated breeding nursery on the Saria INERA research station (Boulkiemdé province) in 2001, with a breeder carrying out selection. The field trials were managed by the farmers themselves according to their customary practices: ploughing the field with animal traction after 10–15 mm rainfall after onset of the monsoon season and sowing after a following rainfall (that was 2–5 days after in 2001–2003), followed by generally two rounds of weeding before the stem elongation stage. It should be mentioned that farmers wished to implement fertilisation in accordance with national recommendations for sorghum

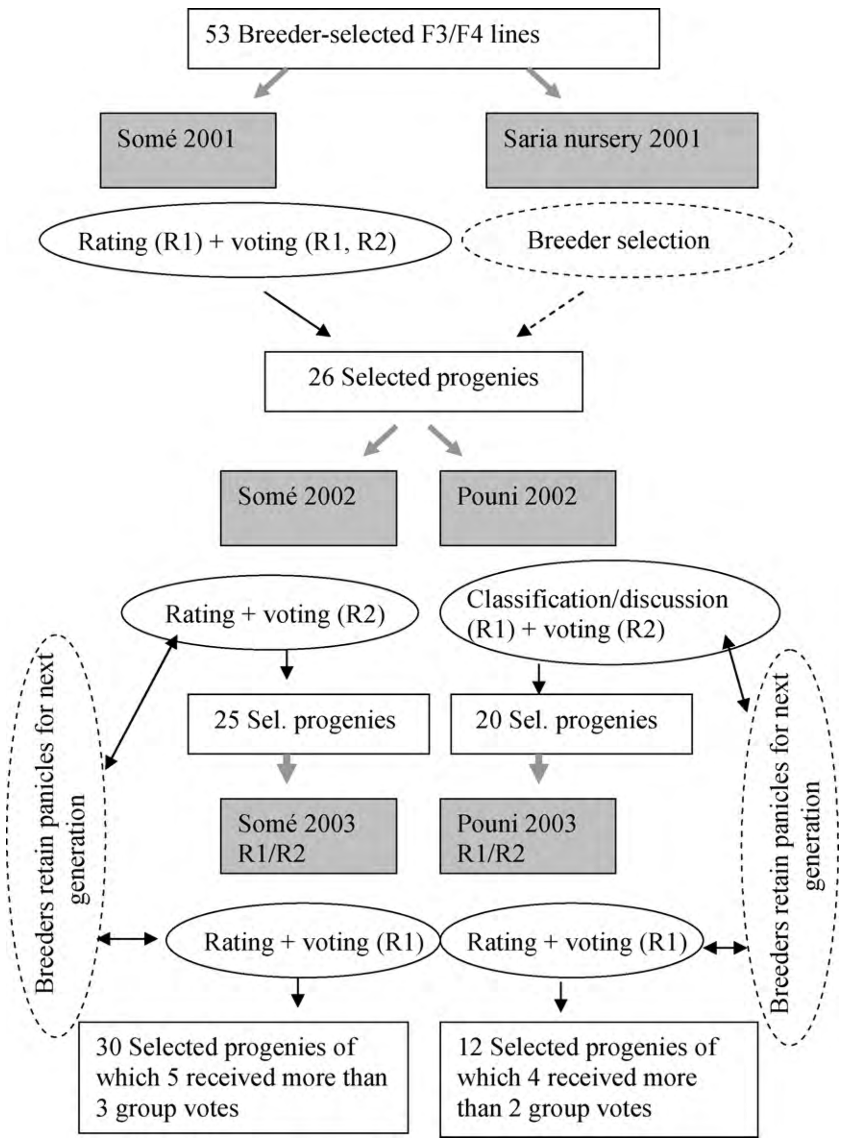

Fig. 2. Scheme of participatory approach applied to variety development using the pedigree selection method in Somé and Pouni villages of Burkina Faso during 2001 and 2003 (R = replication).

cultivation in the target zone, which is 100 kg ha^{-1} of the cotton compound fertiliser NPKSB (14-23-14-6-1) and 50 kg ha^{-1} of urea at the stem elongation stage. Compost application was largely determined by availability. In 2001 no compost was available. In 2002 the recommended amount of 2500 kg ha^{-1} compost was applied (organic matter to rebuild soil organic matter so as to induce efficient use of mineral fertilisers for the predominant ferric lixisol soil types). In 2003, one-fourth of the latter amount was used. Guidelines were established with farmers in an effort to synchronise replications (similar dates of operations, same amounts of compost, similar plant densities, etc.). Sowing dates for trials are given in Table 1.

2.4. Progeny evaluation by farmers and single plant selection procedure

Methods and tools for collaboration between farmers and scientists were designed to encourage constant feedback and adjustments. Participatory evaluation of the trials was carried out in village workshops just before harvest when differences in cycle length of entries were still visible in the trials. The farmers – from the experimental villages as well as other neighbouring villages – were organised into groups of two to five. Each group was accompanied by a researcher, a technician or a literate farmer. Depending on the number of staff available at the time, anywhere between 30 and 60 farmers (separated into male and female groups of 5–10) would participate in the evaluations. In 2001 at Somé there were two female groups and two male groups. In 2002 there were five female groups and seven male farmer groups to evaluate the trials at Somé and two male groups and three female groups at Pouni. In 2003 at Somé there were three female groups and two male groups and at Pouni there were two male and female groups each to evaluate the material. The workshops revolved around the following key elements:

1. A group discussion (men and women) for identifying farmers' selection criteria that will see a new variety accepted. These criteria were then ranked by importance, with the farmers being encouraged to explain their choices. The criteria established in the very first workshop of 2001 formed the basis for all future evaluations.

Table 2
Selection criteria of breeders of the INERA/CIRAD sorghum improvement program at Saria in early segregating generations and late generations.

Selection criteria of breeder, no given order of importance
Early selection generation (F2–F5)[a]:
The cycle (visual observation of the maturity of the panicle also in respect to the agro-climatic zone and the date of sowing)
Good panicle size (or weight) with adequate compactness (semi-loose to semi-compact)
The quality of the grain (vitreous to semi-vitreous grain, large to medium size, low pigmentation, no testa or mould)
Leaf diseases resistance
Plant height between 1.8 m and 3 m with lodging resistance
Stay green (plants with high proportion of dried leaves will be excluded)
Late generation (F6–F8)[b]
Grain-yield performance (kg ha^{-1}),
1000-grain weight (as an indicator for grain size)
Plant height
Days to flowering
Leaf diseases and grain mould
Decortication yield and tô quality for the best F8 lines

[a] Evaluated in unreplicated nurseries at the research station.
[b] Evaluated on-station in replicated field trials, compared to existing elite lines and improved local varieties.

2. In the replication with the more homogenous plant stand, entries were rated on a 0–3 scale: poor, average, good and excellent. These ratings were applied to the three most important selection criteria that emerged from the preliminary discussions. A 'general appreciation' rating of the entry was included in 2002 and 2003 to illustrate farmers' selection priorities more clearly. During the evaluations farmers were explicitly asked to make judgments about the entire plot and not just single (preferred) plants of the entry.
3. As a third step, farmers selected, either individually or in groups, their five most preferred entries, a process referred to as 'voting'. The farmers voted for a maximum of five to six entries by attaching labels to their favourite plant within the entry. Different colours were used for men and women. Only in 2003 did farmers directly select for a preferred entry during the rating exercise, i.e. after having rated an entry they were asked if they wished to retain the entry in order to further develop it into a variety. One or several panicles from the most preferred entries labelled by the farmers were retained for the next generation. The evaluation and selection approach from 2001 to 2003 is visualised in Fig. 2.

2.5. Agronomic data

In each experiment, a technician from the local farmer organisation, together with the experimenting farmer, annually monitored the following agronomic traits: vigour at emergence (score), number of hills emerged and harvested, heading date (days to 50% heading), plant height (cm), numbers of panicles harvested, panicle weight (kg ha^{-1}) as well as grain yield (kg ha^{-1}) and the general measurement breeders use for grain size, which is 1000-grain weight (g). These observations also correspond to the traits observed by breeders in the later stages of a breeding program at the Saria research station (Table 2).

Table 3
The most relevant plant characteristics (traits) for a new variety as explained by farmers from Somé village, Burkina Faso in 2001.

Plant characteristics ranked by decreasing importance
Earliness, i.e. flowering by the end of the rainy season
Grains suitable for the preparation of quality tô (white colour, little discolouration, hardness, vitreous grain, large grains)
High productivity (high flour yield, panicle characteristics, e.g. compactness)
Drought resistance (leaves stay green after rain stop)
Suitability as fodder (most leaves remain green at maturity stage)

2.6. Data analysis

Analysis of variance (ANOVA) of agronomic data corresponding to the lattice design from the five individual test environments was performed using the program PLABSTAT (Utz, 2005). For qualitative data (farmer ratings), a valid model is the proportional odds model (Mc Cullagh and Nelder, 1989), where the logit of the probability for a rating to be less or equal to *j* is equal to a variety effect α_i, plus a farmer group effect β_k, plus an intercept μ_j dependent on *j*.

$$\ln\left[\frac{p_{ij}}{1-p_{ij}}\right] = \mu_j + \alpha_i + \beta_k,$$

where ln() is the natural logarithm.

This type of analysis has been recommended by Coe (2002) using the logistic regression modelling of the GENSTAT program. In the present study, the model was adjusted using the procedure GENMOD of SAS/Stat software (Version 9.1), on farmer ratings translated into numerical values ranging from 0 (poor) to 3 (excellent). It was thus possible to adjust for the propensity β_k of each farmer group to give high ratings, while testing for differences between varieties by a χ^2-test in an analysis of deviance. Interaction between farmer groups and varieties is part of the model error and could not be tested; however, when farmer groups are gathered in categories (e.g. gender) it was possible to test for the existence of categories × variety interaction again with an analysis of deviance. Alternatively, farmer ratings were analysed using an analysis of variance (GLM procedure of SAS), which gave very similar results on the 2002 evaluations, where both analyses were performed. The analysis of variance appeared as a valid alternative to the more demanding logistic regression, as the intercepts μ_j of the proportional odds model were evenly spaced, and the variances of the ANOVA residuals were sufficiently homogenous for most of the variables and also the residuals followed a normal (grain yield and general appreciation) or near normal (quality and earliness rating) distribution for the 2002 ratings. The intended proportional odds model could not be adjusted to the farmer ratings of 2001 and 2003 in Somé and Pouni as the number of participating farmer groups was too low (4 farmer groups). An analysis of variance was therefore performed instead. Mafongoya and Kuntashula (2005) used a similar approach to analyse farmer ratings for soil fertility in *Tephrosia* species.

For each variety *i*, a variety score $\mu_0 + \alpha_i + \beta$ was estimated for each of the four criteria "earliness", "grain quality", "productivity" and "general appreciation", where β stands for the mean of the different farmer groups effects β_k. The scores estimated on Somé 2002 data were used to compute principal components on standardised variables using SAS/Insight software in order to summarise and visualise a possible pattern in farmer ratings for the different traits in the material evaluated.

Table 4
Effect of entry, gender group and farmers within gender group on farmers' ratings of productivity, earliness, grain quality and general appreciation in Somé and Pouni villages between 2001 and 2003.

Trait	Source of variation	Somé 2001		Somé 2002		Somé 2003		Pouni 2003	
		F-Value	Pr > *F*	χ^2	Pr > χ^2	*F*-Value	Pr > *F*	*F*-Value	Pr > *F*
Productivity	Gender	5.64	0.0002	1.65	0.1983	3.92	0.0506	14.53	0.0004
	Farmer (gender)	11.78	<0.0001	90.79	<0.0001	8.25	<0.0001	0.13	0.8791
	Entry	1.84	<0.0001	317.94	<0.0001	5.39	<0.0001	5.48	<0.0001
	Entry × gender	0.51	0.1017	38.47	0.8354	1.70	0.0275	1.37	0.1606
Earliness	Gender	1.89	0.0943	16.56	<0.0001	2.65	0.1072	2.78	0.1011
	Farmer (gender)	2.60	0.0225	145.80	<0.0001	7.48	0.0002	6.59	0.0027
	Entry	2.66	<0.0001	229.28	<0.0001	4.16	<0.0001	4.86	<0.0001
	Entry × gender	0.67	0.4812	55.52	0.2124	1.11	0.3468	1.12	0.3577
Grain quality (2001)/grain hardness (2003)	Gender	0.39	0.4062	7.80	0.0052	0.02	0.8802	1.57	0.2176
	Farmer (gender)	31.56	<0.0001	117.54	<0.0001	4.17	0.0131	0.49	0.6192
	Entry	1.45	<0.0001	291.18	<0.0001	2.67	0.0032	3.43	0.0003
	Entry × gender	0.60	0.3603	43.11	0.6731	2.01	0.0330	1.75	0.0568
General appreciation	Gender	–[a]		0.00	0.9979	3.03	0.0850	0.00	1.0000
	Farmer (gender)			97.84	<0.0001	7.38	0.0002	1.30	0.2821
	Entry			332.47	<0.0001	5.02	<0.0001	4.00	<0.0001
	Entry × gender			60.21	0.1111	1.26	0.1987	1.40	0.1466

Note: effects were tested with a proportional odds model in Somé 2002, where enough data were available, and with an analysis of variance in the other situations.
[a] Trait not observed at this site.

Relations between the farmer selection data and agronomic data were explored using simple descriptive statistics, such as tabulations and correlation coefficients with their confidence intervals. Pearson correlation coefficients were calculated using the software XL-STAT (Version 7.5). The final selection decision is expressed as the frequency of votes that an entry received.

3. Results

3.1. Quality of agronomic observations

Table 1 shows the basic statistical parameters for the three most important agronomic traits measured in the Somé and Pouni trials between 2001 and 2003. Significant differences among entries were observed for most of the traits for each year. The majority of the trials had significant ($p < 0.05$) effects of replications, except for grain yield at the 2001 Somé trial (data not shown). The relatively low C.V. values and relatively high repeatabilities for the observed traits were satisfying and indicate that sufficient differences among entries exist to perform selection. Rainfall was below the annual average for the region, between 450 mm and 700 mm at the two sites.

3.2. Identification of farmer selection criteria

Earliness was ranked as the most important selection criteria by farmers during group discussions in 2001, followed by high grain quality and high productivity (Table 3). The same criteria/traits were confirmed by the farmers in 2002, although no order of importance could be agreed upon this time (farmers ascertained they each have different priorities). These varying reactions towards the ranking of plant traits might be explained by the post-flowering drought conditions of 2001, which gave early-flowering entries a considerable advantage and thus became the most important selection criterion for that year. Table 2 shows that breeders focused their selection on similar traits in their breeding program. These traits will be evaluated visually in unreplicated nurseries until fixation of the traits. Replicated field trials on-station are conducted in a later generation (F6–F8). Evaluations not only focus on yield performance, but also on the quality of tô (sorghum flour and water processed to a thick porridge and eaten as a staple food).

The three most important plant traits listed in Table 3 were used by farmers for the field evaluations. During group discussions, male and female farmers stressed that other criteria existed for grain quality that could only be assessed during grain processing and tô. Such criteria include ratio of flour/bran, breakage of grains during decortications, as well as taste, texture and conservational properties of the tô. The significant entry effect on all three rated traits noted in Table 3 and the general appreciation in all years and all sites clearly show that farmers successfully differentiated the test entries using these traits (Table 4).

3.3. Farmer ratings for important selection criteria

The three selection criteria used for rating the entries as well as the general-appreciation ratings in 2002 Somé evaluations were all strongly inter-correlated. This is best exemplified by the PC analysis in Fig. 3. The PC1 axis, which accounts for 86% of the original multivariate variation, displays high correlations with all the four variables, ranging from 0.87 for earliness to 0.97 for general appreciation. The PC2 axis values are positively associated with the score for earliness ($r = 0.48$) but have a negative association with the one calculated for grain quality ($r = -0.30$). These results indicate a light trend of lower appreciation of grain quality for those entries with

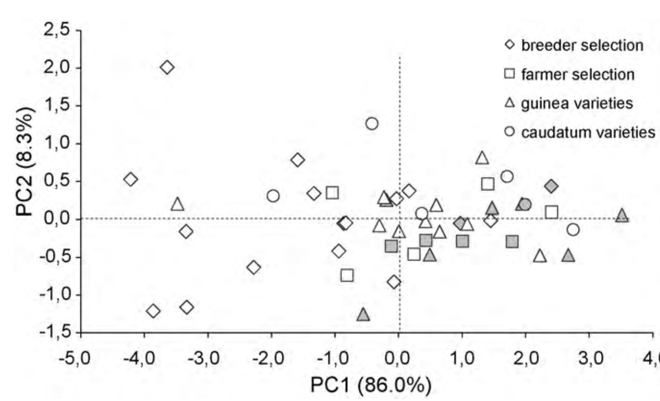

Fig. 3. Scores for principal components PC1 and PC2 calculated from the correlation matrix of entry scores of three plant traits (earliness, grain quality, productivity) and general appreciation of 49 sorghum entries tested at Somé in 2002. A darker symbol indicates farmers' voting choices in this trial.

Table 5
Coefficients of correlations between farmers' ratings (individual ratings) of productivity, earliness, grain quality and general appreciation in Pouni and Somé village in 2003.

	Trait	Productivity	Earliness	Grain hardness
Pouni 2003	Earliness	0.62**		
	Grain hardness	0.62**	0.41**	
	G. appreciation	0.75**	0.62**	0.79**
Somé 2003	Earliness	0.85**		
	Grain hardness	0.52**	0.64**	
	G. appreciation	0.80**	0.87**	0.73**

** Significant at $p < 0.01$.

higher ratings for earliness. This tendency can also be observed in evaluations carried out in 2001 in Somé, where earliness ratings showed only moderately significant correlations, with grain quality and productivity ratings of 0.34 and 0.49, respectively. In 2003, this relationship became more prominent, especially for the evaluations at Somé (Table 5).

Different farmer groups rated the same entry very differently. Most of the entries received all four possible ratings for all three or four traits. The farmer group effect and individual farmer effect for most of the evaluated traits of farmers' 2001 and 2003 ratings and for scores generated from the farmers' 2002 ratings from Somé, showed significant *F*- and χ^2-values (Table 4). Table 6 shows that women tend to rate entries less severely than men. A significant gender effect was found for the appreciation of grain quality and earliness in the 2002 evaluations and for productivity in 2001 and 2003 (Table 4). Generally, the men were more stringent in assessing for productivity and earliness compared to the women, with the exception of Somé 2001, where the women accorded lower ratings than the men (Table 6). Interactions between gender and entry were found only for the rating of grain hardness, which replaced grain quality criteria for the 2003 evaluations. Results show a disagreement between men and women's appreciation of this particular trait.

3.4. Relationship of farmers' ratings with voting results

On the whole, the farmers' voting corresponded to their rating of the identified criteria, further confirming the relevance and the repeatability of the identified criteria. In 2001, farmers mostly voted (3–4 group votes) for entries which had the best ratings for earliness, grain quality and productivity (average ratings higher than "2.25", data not shown), as was the case for four entries. Entries which received between 1 or 2 group votes represent the whole range of possible ratings for earliness and a tendency towards higher productivity and grain quality (ratings better than "1.3 and 1.5, respectively", data not shown). Fig. 3 indicates that most of farmers' voting in 2002 corresponds to entries with better scores (as revealed by the PC1), as most of the voted entries are among the entry points located on the bottom right site of the PC plot. For the 2003 evaluations, earliness and grain hardness seemed to affect farmers' voting choices. A high correlation between rating results and number of votes was noted in Pouni for grain hardness ($r = 0.90$, 0.79–0.95), which stands in contrast to the Somé evaluations with only 0.58 (0.29–0.77). On the other hand, earliness tends to show a closer relation to farmers' voting in Somé ($r = 0.84$, 0.70–0.92) than Pouni ($r = 0.55$, 0.22–0.77).

3.5. Relationship of farmers' ratings and voting with agronomic observations

Farmer productivity ratings had the highest correspondence with formal yield measurements, as measured across all evaluations, with correlation coefficients ranging from 0.41 (0.18–0.60) at Somé 2001 to 0.70 (0.44–0.85) at Pouni 2003 (Table 7). For the farmers, grain size is one of the indicators of grain quality for tô (Table 3). Breeders commonly use 1000-grain weight as a measurement for grain size (Table 2). Correlation coefficients between grain quality rating and 1000-grain weight were however generally very low and not significant, which is not surprising considering the complexity of grain quality. The negative correlations between the earliness rating and days to heading indicate a greater appreciation

Table 6
Means of ratings by women groups (WG) and male groups (MG) and standard deviations (sd) for three different plant traits and general appreciation of entries tested in Somé and Pouni village between 2001 and 2003.

Trait[a]	Somé 2001			Somé 2002			Somé 2003			Pouni 2003		
	WG	MG	sd	WG	MG	sd	WG	MG	sd	WG	MG	sd
Productivity	1.2	1.5	*1.1*	1.8	1.5	*1.0*	2.1	1.9	*1.0*	1.9	1.4	*1.1*
Earliness	0.9	1.2	*0.9*	2.0	1.5	*1.0*	2.0	1.8	*1.0*	2.0	1.7	1.2
Grain quality	1.6	1.5	*1.0*	1.9	1.5	*1.0*	2.0	2.2	*0.9*	1.5	1.6	*1.1*
G. appreciation	–[b]			1.8	1.5	*1.1*	1.9	1.7	*1.1*	1.4	1.4	*1.1*

[a] Rating scale: 0 = poor, 1 = average, 2 = good or 3 = excellent.
[b] Trait not observed at this site.

Table 7
Correlations between farmer-ratings and agronomic observations calculated for the total of all farmer group ratings in five different test sites between 2001 and 2003.

Site	No. of group ratings	Earliness/heading date	Productivity/grain yield	Grain quality/1000-grain weight
Somé 2001	4	−0.486*	0.406*	0.324*
Somé 2002 (repl 1)	12	0.026	0.423*	0.130
Somé 2002 (repl 2)	4	−0.302	0.514*	0.174
Somé 2003	4	−0.185	0.585*	–[a]
Pouni 2003	5	−0.113	0.703*	–[a]

[a] Trait not observed.
* Significant at $p \leq 0.05$.

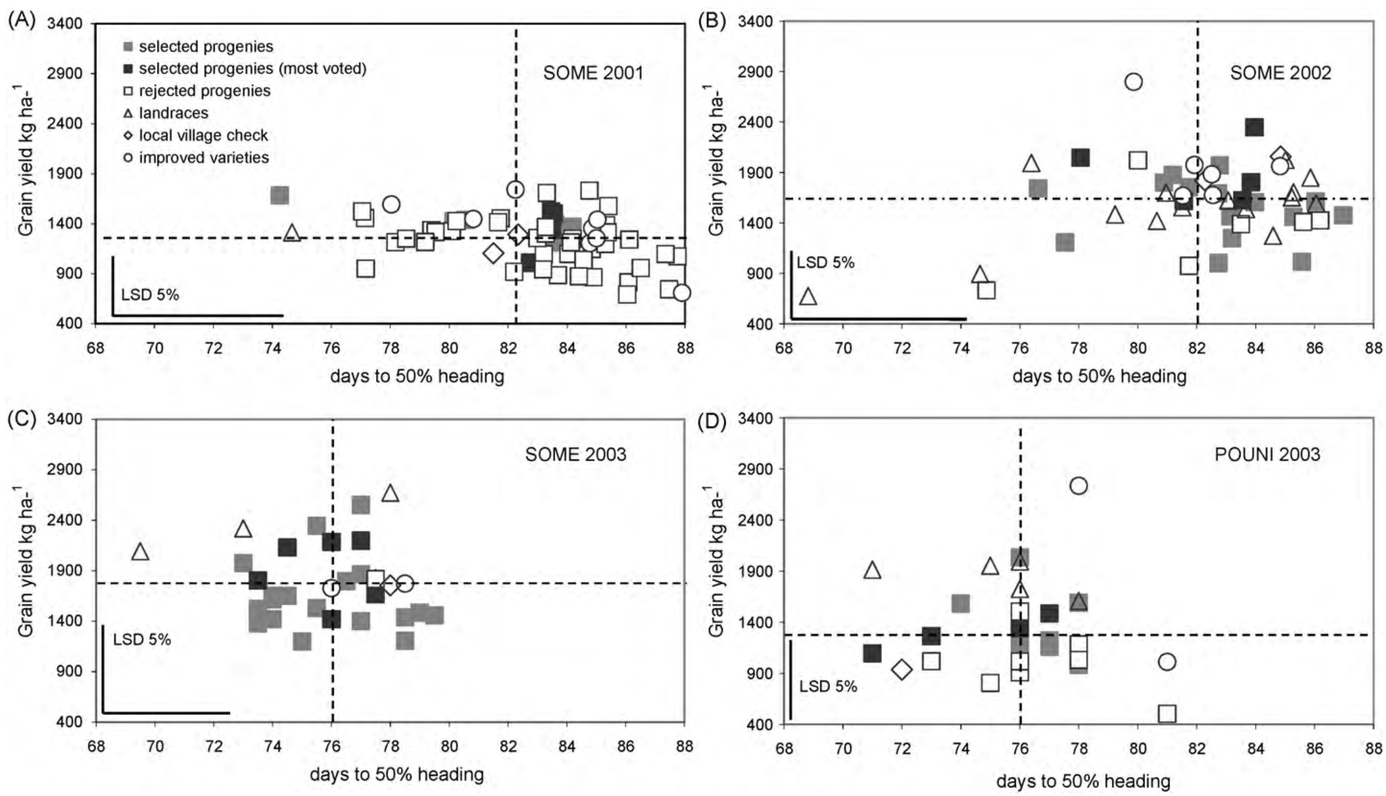

Fig. 4. Grain-yield performance and heading dates for different entry groups tested in Somé 2001 (A), Somé 2002 (B), Somé 2003 (C) and Pouni 2003 (D).

of entries with earlier maturity; however, correlations are often low and non-significant (Table 7).

Voted entries had a wide range of cycle length, from 73 days to 50% heading to almost 88 days to 50% heading across all years (Fig. 4). This corresponds to a flowering time between mid and late September. Farmers more often voted for entries which have more than average grain-yield performance, although correlations between number of votes and grain yield of entries in the evaluated replications are not significant, except for the 2003 Somé trial ($r = 0.65$, $p \leq 0.05$).

3.6. Progeny selection by farmers

Farmers voted for around 20% of the F3/F4 progenies in the first year of the trials (2001). At the same time, the breeder selected 26% of the progenies from the 2001 on-station nursery using the selection criteria mentioned in Table 2, but only 28% were in common with the farmers' on-farm selections. The farmers tended to select plant architecture typical for local varieties (taller stems, drooping panicles, etc.), whereas the breeders focused on plants of average height with more erect panicles that were loose in appearance (data not shown). All farmer-selected progenies of 2001 were reselected in 2002, as were 30% of the breeder's on-station selections, which was also added to the 2002 trials. Table 8 shows frequencies of votes per entry (VE) and entry group (VEG). Compared to the breeder's selections, farmer-selected progenies received on average more votes per progeny and, according to the proportional odds model, had a 50% higher probability of being rated better than "average" (3) for general appreciation in the Somé village (data not shown). At the Pouni site, the entry group of farmer-selected progenies received twice as many votes as the breeder's preferences (Table 8). In Somé (2003), all but one of the 25 F5/F6 progenies were reselected. In 2003 (Pouni), twelve F5/F6 progenies from the 20 progenies tested were selected by farmers of which nine presented reselections from the 2002 Pouni trials. These results indicate that farmers select consistently with the same or similar criteria year after year.

On average, the 2001 selected progenies tended to have better yield performance than the other material groups, as indicated by the individual performance of the different entry groups visualised in Fig. 4A. In 2002, productivity of farmers' most selected progenies tended to exceed the trial mean as well as the most voted landraces at Somé (Fig. 4B). In the final selection year (2003) grain-yield performance of the progenies most selected by farmers corresponded with the mean performance of the trial and was superior to the village check, which had the same performance as the rejected progenies (Fig. 4C and D).

4. Discussion

4.1. Specificity of farmers' selection criteria

In the present study, farmers indicated that "earliness of a variety" is one of their most important traits. However, farmers' perception of earliness as a positive or beneficial plant trait does not simply equate to a short growing period, as a breeder would normally interpret it. Farmers in Burkina Faso instead define earliness as the ability of a plant to reach flowering at the end of the rainy season so as to avoid major drought stress during the grain filling period. This view is supported by the relatively low correlation coefficients between the field observations for heading date and the earliness appreciation in the different years. In 2001 and 2002, farmers' votes leaned towards later-maturing progenies (around the 20 September), which corresponds to the climatic cycle of the rainy season of the region. The preference for later-maturing progenies also fits in with the farmers' preferences of local sorghum varieties which are short-day varieties with medium or high photoperiodic sensitivity (Barro-Kodombo et al., 2010). On the other

Table 8
Results from voting exercise in Somé and Pouni 2002: number of entries per entry group in field trial, percentage of farmer votes per entry group (VEG), average quantity of votes per entry (VE) with standard deviation (sd) and number of rejected entries (RE). G = guinea race, C = caudatum race.

Entry group	Nbr.	Votes Pouni[a]				Votes Somé[b]			
		VEG (%)	VE (Nbr.)	sd	RE (Nbr.)	VEG (%)	VE (Nbr.)	sd	RE (Nbr.)
Local varieties (G)	18	57	8.5	6.2	1	49	9.6	5.0	0
2001 “breeders’ selection”	17	14	2.2	2.7	8	21	4.1	5.0	6
2001 “farmers’ selection”	9	26	7.9	3.3	0	19	7.1	3.6	0
Modern varieties (C)	5	4	2.0	3.7	2	11	7.2	6.4	0

[a] Exercise performed in replication 1.
[b] Exercise performed in replications 2.

hand, maturity times in the overall selected progenies, including the 2003 selection year, have a much wider range. These selection decisions reflect the necessity of traditional production systems in sub-Saharan Africa, where shorter and longer cycle varieties can both be useful (Lacy et al., 2006). In Burkina Faso, varieties with a short growing cycle are planted in villages or house fields – mainly due to better bird control – while later-maturing varieties are allocated to farmland or bush fields. Selection decisions can thus vary depending on availability of fields and human resources for managing two sowing dates.

The weak association between farmers’ quality ratings and breeders’ 1000-grain weight measurements confirm the complexity of this trait from a farmer’s point of view (and the breeder’s also). Basically, farmers believe they can only make a final decision on the grain quality of a variety after having processed and tasted the end-product, i.e. as tô. After having studied the technological and cooking qualities of different sorghum varieties, Fliedel (1995) concluded that a variety’s decortication properties determine to a great extent its tô quality. This has been confirmed by the present study, where farmers preferred more vitreous and harder grains. Farmers also indicated that grain colour contributes to a better grain quality appreciation, a white grain colour being preferred on account of it being associated with a light-coloured tô. Even though breeders’ selection criteria for grain quality are relatively detailed in the early generations, they only partially respond to farmers’ demands. This is reflected, for instance, in the fact that decortication properties such as grain hardness do not form part of a breeder’s conventional plant selection program.

Farmers’ appreciation of productivity, which is based on panicle characteristics, does partly correspond to the quantitative measurable trait of grain yield per unit area. In the provinces of Boulkiemdé and Sanguié, farmers typically harvest and store panicles, threshing them for daily use. This constant observation and threshing of panicles has thus endowed the farmers with a keen sense of judgment for grain-yield potential. This supports the findings of Ceccarelli et al. (2000), who demonstrated that farmers’ perceptions of productivity and yield data are positively associated. Trouche et al. (2009), on the other hand, found variable correlations between farmers yield rating and productivity in sorghum in Nicaragua. The authors attributed the observed deviations to farmers’ limited experience with the sorghum crop, especially with modern plant types. Evaluations with more experienced farmers resulted in more significant positive correlations. Another interesting productivity trait that emerged during group discussions was flour yield, a trait rarely assessed by sorghum breeders. In the eyes of farmers, especially the women, flour yield is related to both the ease with which decortications can be carried out and the yield that results from this process. Formal grain-yield measurements may therefore not provide a full picture. During the culinary testing of eight of the 2002 tested entries (local varieties, F4/F5 progenies and improved caudatum varieties) we found that entries had different levels of loss (10–40%) during decortication and cleaning, and that the guinea race varieties had better decortication yields than the caudatum (vom Brocke, unpublished data). According to the farmers, the trait of grain hardness is an indicator of flour yield. The views of the women who evaluated this trait in 2003 could be summed up as thus, “*A hard grain which does not break easily while removing the husk will give more flour.*” Consequently, it appears that farmers’ perception of yield potential also encompasses some of their concerns for the grain properties. This connection of yield and grain quality to farmers’ selection is illustrated by the components of the PC1 axis in the PC analysis.

4.2. The effect of gender and farmer group genotype assessment

Concordance between women and men’s perceptions of criteria was generally observed, with the exception of grain hardness. This is not surprising as this trait is directly linked to tô preparation and (in rural areas) women are concerned with household food preparation. Divergent prioritising of maize germplasm between the sexes has been reported by other studies, such as that of Defoer et al. (1997) and Mulatu and Zelleke (2002). Contributions of female and male farmers in a participatory selection program are not only complementary but a precondition for addressing the overall needs of the household. In view of the importance of grain quality for culinary aspects as well as productivity in the form of flour yield, it is recommended to integrate women as early as possible in the selection and evaluation process of any future program. This, however, is not always easy, as female participation can be hampered by cultural constraints. Practical recommendations on how to involve women in field evaluations are given by Christinck and Weltzien (2005).

The disparity of perceptions among the different farmer groups in Table 4 confirms the diversity of opinions within the farming community. This disparity indicates that these differences are not random, but that certain groups of farmers have specific preferences. This lack of concordance among farmers is not greatly surprising when one considers that cultivar preferences are associated with differing socio-economic and production situations among farming families (Weltzien et al., 1998; Crossa et al., 2002; Mulatu and Zelleke, 2002). On the one hand, the relation between farmers’ socio-economic situations and their preferences and selection criteria needs to be better understood, on the other hand, the biases of a small, unrepresentative group of participants must be avoided, e.g. farmers related by family and sharing a similar social background. Suitable methods and tools for identifying and classifying groups of farmers representative of the target region should underpin any future PPB programs in Burkina Faso. This classification of farmers could be achieved with quantitative methods, as proposed by Crossa et al. (2002), and be integrated into a diagnostic framework, as suggested by Christinck and Weltzien (2005) that not only identifies the target groups but also the target environments. As an example, a future program would involve women who are directly involved in the processing and cultivation of sorghum, farmers who are using and not using draft animals, farmers who possess various types of fields, and farmers who are pursuing commercial activities, e.g. women who prepare and sell sorghum beer. If a survey cannot be carried out to identify key farmers for each target group, as was the case with the present study, a sufficiently large number of farmers from different households will help avoid misleading evaluations. To ensure a sufficiently high number of female and male farmer groups, a minimum of 50–60 participants would be necessary for any future program which intends to apply the kind of statistical analysis used in this study for the 2002 Somé evaluations. As it was mentioned in the description of the statistical methods, the intended proportional odds model could not be adjusted to the situations with only 4 or 5 farmer groups of 2001 and 2003 in Somé and Pouni. In regions where women and men are both actively involved in agriculture or processing, female participation should be proportional. The number of participants proposed here is similar to that suggested by De Groote et al. (2002), who believe that at least 50 farmers need to participate in an evaluation in order to address the high variability among farmers' evaluations in maize trials.

4.3. Consistency of farmers' selection

The study revealed several aspects that underline the feasibility of involving farmers in sorghum pedigree selection schemes in Burkina Faso. Farmers were able to evaluate a relatively large number of progenies with relatively little agronomic differentiation for the targeted traits. They were also able to focus selection on a small number of progenies. Pedigree selection involves the identification of the best families (lines) followed by a selection of superior individuals in the form of plants and panicles within these lines. The latter is the usual practice for Burkinabè farmers, as more than 90% of farming households in Burkina Faso produce their own seed (Delaunay et al., 2008). This is primarily achieved through single plant selection in the field following accurate criteria. Involving farmers in the pedigree selection method would therefore present no serious problems.

The farmers confirmed their initial choices by continuing to reselect these choices in subsequent years while rejecting around 40% of the breeder's selections added in 2002. This pattern points to selection criteria used by Burkinabè farmers but not by breeders. These criteria are related to the plant type as the most obvious difference noted was the difference in plant architecture. That the breeders' on-station selection and farmers' on-farm selections differ on a number of points was also pointed out by Ceccarelli et al. (2003).

4.4. Implications for formal breeding

Seeing that mean grain-yield performance of selected progenies tends to be higher than that of rejected progenies in all the selection years, farmers are obviously aiming to improve this trait. Farmers' selection methods, however, are not strongly directional, as was borne out by the workshops where farmers showed a tendency to select for entries with visually inferior performance in the belief that it could perform under specific conditions. This is similar to findings of previous studies, where authors observed that farmers, when asked to assess crop performance during experimentation, considered all possible environmental factors in years to come, and not just the prevailing conditions (Sperling et al., 1993; vom Brocke et al., 2003; Weltzien et al., 2005). Whereas breeders rely on a simple nursery at the research station for monitoring yield data through the observation of panicle characteristics in early selection generations, farmers' selection decisions are influenced by a concern for yield stability across contrasting climatic conditions, in different areas and different years. These long-range concerns of the farmers would help account for some of the spatial and temporal variations found in the target region. In view of the fact that grain yield is only quantified during advanced generations of a conventional breeding program, farmers' perception of yield stability should be included as an evaluation trait in a participatory selection program. A scale would need to be developed for scoring this trait.

There is nothing to stop breeders from quantifying certain farmer traits and using them in a selection program. Grain hardness can be monitored either using techniques developed by Fliedel (1995), which only require 10 g of seed, or by collaborating with expert women farmers. Since grain hardness and grain vitrosity determine decortication properties and are correlated to flour yield, observing these traits would be crucial for the early stages of a pedigree program, that is, before standardised flour yield measurements are carried out in more advanced generations.

The trait of photoperiod sensitivity, which is crucial for adaptation to climate variability in the Sahel and is clearly a trait demanded by farmers, deserves special mention. Breeders typically evaluate and select this trait only in the later stages of a breeding program, that is, as soon as the lines are homogeneous and ready for yield testing by means of a specific experimental design with at least two sowing dates as demonstrated by Vaksmann et al. (1996). In early generations, on the other hand, breeders will monitor cycle length by visual observation of the maturity of the panicle or by the date of heading in relation to the agro-climatic zone and the date of sowing. The discrimination of the cycle length, especially in the context of an earlier sowing date during the 'long days', will account for the entry's photosensitivity. In other words, more differences in cycle length among entries appear and evaluations for this trait are more efficient, as demonstrated by Clerget et al. (2007). Bearing this distinction in mind, photoperiod sensitivity could be better evaluated with farmers in a decentralised breeding program where earlier sowing is more likely. Farmers can start sowing earlier than the breeders because they generally need less rain and fewer rainfalls to prepare their field and to sow with animal traction or by hand. At the research station, on the other hand, two rainfalls are usually needed for soil and field preparation before sowing can begin with the agricultural machinery. Additionally, in a PPB program the breeder would have the option of requesting a farmer to delay the sowing of a trial site in order to reinforce the evaluation of photoperiod sensitivity in the early stage of selection. This would partly depend on rainfall distribution and/or the early onset of rains.

The aforementioned results show that lines that were developed through the multiple farmer selections at different trial sites and years express both quality traits (grain quality, plant type) and adaptation traits (maturity, perception of yield stability). The next step in the breeding program would therefore be to further explore yielding ability and stability across variable environmental conditions of the region via multi-location testing. This would be feasible, as by this stage the lines would be more homogenous and seed quantity no longer a constraint. By addressing preference and adaption related traits, the multi-location testing would be more efficient in terms of selection intensity related to grain yield. Furthermore, multi-location testing would facilitate the formal process for variety registration and release in Burkina Faso. Weltzien et al. (2008) discusses the necessity of such testing schemes within specific adaptation zones for sorghum breeding in Mali. In testing F6 lines, the authors show that sufficiently high repeatabilities for effective yield testing can be achieved in farmers' fields (42% of on-farm trials had repeatabilities based on entry means for grain yield exceeding 0.50). Such testing needs to continue to be on-farm in Burkina Faso in order to reach as many farmers from as many socio-economic backgrounds as possible and thereby address the strong variability of growing conditions in the region not covered by the research stations. To accelerate the diffusion and adoption of new varieties, Virk et al. (2005) and Ceccarelli and Grando (2007) all advocate participatory breeding and variety testing schemes that encourage and facilitate seed multiplications of the preferred varieties. After the production of bulk seed of the farmer-selected F6 lines from Pouni and Somé in 2004 at the Saria research station, a comparable testing scheme was started in 2005 at four sites in the Centre-West of Burkina Faso. Some of these lines have since been further tested in different agro-ecological regions of Burkina Faso and Mali. Results of this research are forthcoming.

5. Conclusions

The present study was focused on the early selection phase of a PPB breeding program. Although this early phase of a pedigree breeding program in sorghum precludes complex experimental designs and grain-processing evaluations due to the limited amount of seed available, the present study was nonetheless able to ascertain, via farmers' evaluations, traits such as appropriate cycle length, yield stability and culinary quality. The results of the study clearly show that farmers possess the necessary knowledge of their environment and their sorghum panicles to make predictions about adaptation and food quality that they can select effectively on the basis of a progeny and single plant, and that initial selections are consistent over the different selection years.

Farmers' assessment of traits is often more multivariate than the breeder's approach to assessing these same traits. This is especially true for the evaluation of cycle length, that is, when farmers are considering the adjustment of a variety to the variability of the local rainfall pattern. Meticulous assessment of grain quality, where a range of quantitative but mainly qualitative criteria is taken into account, is another example. Similarly, yield is not just grain yield but also flour yield, which is, again closely linked to grain hardness. In view of these facts, breeders need to validate selection criteria with farmers in the target environments when evaluating the progress of farmers' selection. If necessary, the breeders should redefine the targeted traits and their way of monitoring, e.g. productivity not simply in terms of grain yield but in connection with flour yield.

Some criteria are assessed differently by men and women, with stringent ranking practices being implemented for certain traits and opinions being divided on the value of a particular variety. This underlines the need to consult both female and male groups in the selection program and/or to listen closely to those groups who are specialised in certain areas, such as processing quality and flour yield.

Farmers define the performance of a plant in relation to the environmental conditions and in a more global way than breeders who have a rather additive vision of traits to enhance. Rather than assessing a variety on its genetic differences in yield performance among other varieties at a test site, as a breeder might do, farmers in Burkina Faso judge the productivity of a variety by integrating grain properties ensuring high flour yield and usefulness for tô in conjunction with its ability to complete its growing cycle and secure the production under the local environmental conditions. Farmers thus tend to assess the total value of the variety as they see it, which enables them to predict how it may perform under a specific condition. Farmers look at the "plant type" and not at the individual trait. For these particular farmers, plant traits, characteristics and climatic patterns are all inextricably linked; and all of these individual criteria must be met before they will accept a new variety.

The PPB approach used in the early selection stages of the present study has since led to the creation of farmer-selected F5/F6 lines, as mentioned above, that are adapted to the local conditions and which respond to farmers' complex quality demands in relation to the sorghum grain. The key lies in the early stages of the breeding program, where there are more opportunities for farmers to select with high selection intensities for desirable traits. By involving farmers in the selection cycle and decision-making processes from the very beginning, breeders can better cope with the diverse preferences of farmers and the variable and unpredictable growing conditions of the semi-arid tropics.

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