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Farmer Participatory Evaluation of Sorghum Hybrid in Niger

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Abstract

Participatory varietal selection (PVS) with farmers and Seed Companies was conducted at Maradi research station (07˚05'E/13˚48'N) and in farmer field to evaluate and select sorghum hybrid varieties for high yield and other important agronomic traits. The experimental design was a randomized complete block with three replications where flowering (days), plant height (cm) and yield (kg) were collected. The analysis of variance showed highly significance among treatments of all traits measured Environment and Genotype by Environment interactions also contributed significantly to the performance of yield components. The highest average grain yield was recorded from hybrids P9511A x ST9007-5-2-1 (4289 kg/ha), NE223A x 90SN1 (3666 kg/ha), NE223A x Sepon 82 (3533 kg/ha) and NE223A x P9405 (3519 kg/ha) across locations. Farmers' preferences were the panicle size, good seed set, earliness, and seed color. Hence, in a variety selection farmer's preferences focus more on prioritized yield-related trait. The best varieties ranked by traits of interest were P9511A x ST9007-5-2-1, NE223A x 90SN1, NE223A x P9405 and P9511A x SEPON 82 that performed well under their circumstances. The results showed that farmers' preferred varieties match with researchers. Therefore, based on objectively measured traits, farmers' preferences and the agro ecologies of the site, varieties NE223A x 90SN1 and P9511A x ST9007-5-2-1 were found promising for production.

Keywords

Sorghum Breeding, Multi-Location Testing, Participatory Approaches, Yield, Niger

1. Introduction

Sorghum is one of the main staple food crops for the poorest and most food insecure people of the world [1] and is still largely a subsistence food crop in Sub-Saharan Africa. It is generally recognized to have wide agro-ecological adaptation, drought tolerance, diverse germplasm with varying degrees of photoperiod sensitivity associated with forage yield, excellent regenerative and tillering ability, and diverse sources of cytoplasmic-nuclear male sterility that enhance the possibility of exploiting heterosis for grain and forage production [2] [3]. It is one among the few resilient crops that can adapt well to future climate change conditions, particularly the increasing drought, soil salinity and high temperatures [4]. Sorghum is the second most important cereal crop in Niger after pearl millet. It is grown under rainfed conditions where annual precipitation never exceeds 400 - 800 mm. In Niger, only 12% of the land is available for rainfed agriculture cultivation and 85% of the crop is produced by subsistence farmers in marginal lands with declining fertility and the wide use of poor-yielding local cultivars which are largely responsible for the limited agricultural productivity [5].

Yield increase offers the best approach to solve increasing food demands in developing countries [6]. Hybrids are known to capitalize on the phenomenon of heterosis to produce higher yields than open-pollinated varieties even under stress conditions. Adoption of hybrids would also be beneficial to the environment since high and stable productivity may restrain the desperate use of marginal soils [7]. Hybrids produce 50% more than the landraces [8]. On research stations, hybrid yield was 5 t·ha^{-1} when local cultivars produce 2 t/ha or less. The margin of superiority was greater under rain-fed conditions than under irrigated conditions indicating that hybrid vigor or heterosis is not only limited to high input agriculture. But more research is needed to develop a wider range of sorghum hybrids that serve the diverse needs of the sorghum farmers and consumers in the country and the region.

Participatory plant breeding includes all approaches of close collaboration between farmer and scientist to bring about plant genetic improvement within a species [9]. A key attribute is the cooperation between scientists and farmers in evaluating plant material and in establishing plant-breeding goals. Farmer participation in the breeding of crop varieties for low-resource farmers is necessary to help ensure acceptance and eventual adoption [10]. In formal breeding programs yield is by far the most important. Sorghum farmers in most parts of Africa are known to select panicles with superior characters at maturity for seed [11]. Farmer-developed local varieties are an important resource and logical starting point for plant breeding programs that seek to strengthen plant-breeding systems. Evaluating the characteristics of pearl millets in western Niger, [12], noted that farmers showed more concern for panicle, grain and growth cycle characteristics than for high grain yield. According to [13] next to yield, yield stability, adaptation to production techniques and conditions, and various consumption purposes are selected for by farmers.

Farmers need adaptation to the local and variable water and soil conditions in combination with a variety of characteristics related to labor and food availability, intercropping and weed competition [14]. Researchers found out that farmer participation in variety evaluation provided a means of identifying a wide range of traits that were valued by farmers. This could provide guidance on farmers' demand for use in variety development.

Fifty-two (52) sorghum hybrids were generated by crossing the best varieties of the sorghum breeding program of Niger with male sterile lines (CMS). These hybrids were developed and evaluated at the research station of the national institute at the regional research center-CERRA of Maradi and in farmer's fields to select the best hybrids to propose for extension [15]. After evaluation, thirteen (13) hybrids were selected by seed companies and producers under the supervision of researchers. This evaluation was made on the basis of grain yield, flowering time and other desirable agronomic characteristics. The principal objective was to select high yielding hybrids with early maturity and drought tolerance.

2. Material and Method

Thirteen (13) hybrids were used for the experiment. Each hybrid was planted on two rows of three meters each with 50 cm between hills. The spacing between two rows was 0.8 m meter. Two fertilizers of 100 $kg \cdot ha^{-1}$ of NPK 15-15-15 and 100 $kg \cdot ha^{-1}$ of urea were applied twice during the growing season (tillering and flowering stages). The field was kept weed free by hand weeding during the cropping season.

The plots on dune soils received an input of well-decomposed park manure at the rate of 5 tons per hectare. The manure was buried by plowing followed by harrowing before sowing. NPK 15-15-15 fertilizer was applied one week after emergence, as a localized supply in holes made 10 cm from the pockets at the rate of 6 g per pocket. Urea was applied 30 and 45 days after sowing, as a localized supply at the rate of 2 g at the seed hole.

Based on farmers' criteria for the different regions and the Seed companies, thirteen (13) best performing hybrids were chosen derived from the Participatory Plant Breeding (PPB) approach conducted [15]. Hybrids were then subjected to participatory varietal selection (PVS) on-station at INRAN research station, farmers' field and Seed Companies for three years.

The experimental design used is a randomized complete block (RCBD) with three repetitions at each site. The elementary plot is represented by 4 lines of 3 m, the two central ones of which are useful. The spacing used is 40 cm between pockets and 80 cm between rows. After sowing, the seedlings were thinned to three seedlings during the first weeding carried out one week after emergence. At all sites, the trial was conducted under optimal water supply conditions. Apart from deep plowing, all cultivation operations were done manually. The plots were weeded 2 to 3 times depending on the degree of weed infestation. The agronomic data collected (flowering, height and grain yield) were subjected to analysis of variance (ANOVA) separately for each environment and combined across environments using the GENSTAT version 18.1 procedure. Varieties were considered as fixed factors and evaluation sites (environments) as random factors. Mean separation was performed using the Least Significant Difference (LSD) test to discriminate and select genotypes higher as a function of the trait of interest at the significance level of 1% and 5%. Mota Maradi was used as check because of its high adoption rate among farmers. According to farmers, Mota Maradi is early maturing with a good yield and taste with average plant height of 1.75m and white colored grain [13].

3. Results and Discussion

The analysis of variance (ANOVA) revealed significant differences for three major traits studied (**Table 1**). The interactions between genotypes, environments and the genotype-environment effect showed significant difference between the different genotypes for grain yield, plant height and earliness. Hence, the existence of genetic diversity between genotypes greatly contributed to the difference in the expression of these characters of the tested varieties.

The agronomic performance of the different varieties during the three years of experimentation is shown in **Table 2**. This table shows a significant variation for the different parameters studied during the three different years in the different environments. Very significant environmental variances were observed for all genotypes. This indicates that the conditions in the different environments were not similar and that the genotypes responded differently from one environment to another during each year.

The combined analysis of three years experimentation of the agronomic performance of the different varieties is shown in **Table 3**. The presence of highly significant differences ($P < 0.01$) between the genotypes tested for grain yields and other components indicates the presence of genetic variation between the

Table 1. Analysis of variance of three traits studied.

Source	DF	Flowering (days)	Height (cm)	Yield ($kg \cdot ha^{-1}$)
Year x Rep.	5	38.48***	5134.9***	1,233,565***
Year x Rep. x Var.	10	575.12***	53909.0***	51,147,110***
Error	50	200.51	13309.0	27,027,861
Total	65	814.12	72352.9	79,408,536
CV (%)		3.3	9.6	26.1
Mean		60.7	170.0	2821
l.s.d. (5%)		2.32	18.92	852.6

***Highly significant at 1%.

Table 2. Annual agronomic performance of the hybrids during the three years of experimentation.

Varieties	Year 1			Year 2			Year 3		
	Flowering (days)	Height. (cm)	Yield (kg/ha)	Flowering (days)	Height. (cm)	Yield (kg/ha)	Flowering (days)	Height. (cm)	Yield (kg/ha)
NE223A x MDKSU-49-1	63.5	162.5	2500	64	170	2773	64.00	170.0	1878
NE223A x IRAT 204	58	127.5	1146	59.5	122	2024	56.50	145.0	2187
NE223A x SEPON 82	62	140.0	3437	63	132.5	3293	64.00	155.0	2083
NE223A x 90SN1	59.5	137.5	4248	61.5	157.5	3208	63.00	155.0	3542
NE223A x P9405	60.5	122.5	4075	57	140	3781	59.00	160.0	2700
NE223A x MDKSU-10-1	64	175.0	2562	65	217.5	2578	65.00	160.0	1042
NE223A x ST9007-5-4-2	64	135.0	1354	61.5	142.5	1971	63.00	165.0	2917
P9511A x ST9007-5-2-1	63	167.5	4583	60.5	197.5	3598	62.00	210.0	4687
P9511A x SEPON 82	63	152.5	4292	58	205	2807	58.50	205.0	3500
P9511A x Macia	63	192.5	3250	58	209	2349	60.00	202.5	4479
MM	57	227.5	1456	52	217.5	1354	52.50	230.0	1445
Mean	61.5	158.2	2991	60	173.7	2703	60.68	178	2769
F-Probability	0.019(*)	<0.001(**)	<0.001(**)	0.008(**)	<0.001(**)	0.135(ns)	<0.001(**)	<0.001(**)	<0.001(**)
LSD (5%)	3.859	26.91	517.7	5.152	34.91	1634	1.876	16.33	609.2
CV (%)	2.8	7.6	7.8	3.9	9	27.1	1.4	4.1	9.9

(ns) = not significant; (**) = significant at the 1% level; (*) = significant at the 5% probability level.

genotypes (**Table 3**). A significant genetic effect of genotypes on grain yield and yield components of sorghum has also been reported by different authors [16] [17] [18]. Similarly, the significant effect of environment and genotype-by-environment interaction on yield performance and some yield components showed that genotypes respond differently to various environments [17] [19]. They found that sorghum cultivars are significantly affected by phonological growth as well as yield and yield-related parameters.

Of all the varieties tested, the average number of days to flowering ranged from 58.00 for 223A x IRAT 204 to 64.67 for 223A x MDKSU-10-1. Early yield is a desirable attribute for sorghum production in dry lands because early maturing varieties can escape drought conditions that set in during the later stages of growth and allow farmers to find food and the money. Regarding days to physiological maturity, the earlier maturing varieties were 223A x IRAT 204 and 223A x P9405 with 58.00 and 58.83 days, respectively. Amongst these varieties were 223A x MDKSU-49-1 and 223A x MDKSU-10-1 genotype with 63.83 and 64.67 days, respectively.

Table 3. Combined analysis of the characters observed and the comparison of the average for the grain yield during the three years of experimentation.

Hybrids	Flow (days)	Height (cm)	Yield (kg/ha)
223A x MDKSU-49-1	63.83ab	167.5cd	2383cd
223A x IRAT 204	58.00f	131.5e	1786de
223A x SEPON 82	63.00abc	142.5e	2938bc
223A x 90SN1	61.33cd	150.0de	3666ab
223A x P9405	58.83ef	140.8e	3519ab
223A x MDKSU-10-1	64.67a	184.2bc	2061de
223A x ST9007-5-4-2	62.83abc	147.5e	2081de
P9511A x ST9007-5-2-1	61.83bcd	191.7b	4289a
P9511A x SEPON 82	59.83def	187.5b	3533ab
P9511A x Macia	60.33de	201.3b	3359b
MM	53.83g	225.0a	1418e
Mean	60.76	170	2821
ANOVA (F-Probability)	<0.001(**)	<0.001(**)	<0.001(**)
LSD (5%)	2.322	18.92	852.6
CV (%)	3.3	9.6	26.1

The means followed by the same letters are not significantly different according to the Fisher test at the 5% level of probability. (ns) = not significant; (**) = significant at the 1% level; (*) = significant at the 5% probability level.

The average plant height recorded was 170 cm with a range of 140.8 to 201.3 cm. The shorter plant in height was recorded with variety 223A x P9405 while the taller plant in height was recorded by variety P9511A x Macia. There were significant differences between the sorghum genotypes tested for aboveground biomass ($p < 0.01$). It is important to note that the control variety Mota Maradi was not only the earliest variety (53.83 days) but also the taller (225 cm) with the lowest yield (1418 kg/ha).

The mean grain yield obtained for all the trials is 2821 kg/ha, which is different from the average yield of 450 kg/ha published by the National Institute of Statistics of Niger (INS/Niger) for the cultivation of sorghum from 2017 to 2021. This is due to the good cultivation practices used and especially to the performance of the genotypes tested during the evaluation. Also, the yields varied from 1418 kg/ha for the control Mota Maradi to 4289 kg/ha for the hybrid P9511A x ST9007-5-2-1 (Table 3). The highest grain yields were observed with the hybrid varieties P9511A x ST9007-5-2-1 (4289 kg/ha), NE223A x 90SN1 (3666 kg/ha) and with NE223A x Sepon 82 (3533 kg/ha) and NE223A x P9405 (3519 kg/ha) compared to the NAD-1 hybrid which has an average yield of 1700 to 3300 kg/ha. The yield of the hybrid NE223A x 90SN1 (3666 kg/ha) more than doubled that of the control Mota Maradi (1418 kg/ha) an improved variety widely used by producers. But more research is needed to develop a wider range of hybrid sorghum cultivar that better meet the diverse needs of sorghum growers nationwide.

The comparison of the means and the grouping of the varieties tested on the basis of grain yield with the test of the least significant difference (LSD) in Table 4 brings out four homogeneous groups A, B, C and D. Group A consists of by hybrids P9511A x ST9007-5-2-1, NE223A x 90SN1, NE223A x P9405 and P9511A x SEPON 82 with yields above 3.5 tons/ha. The second group is that of the P9511A x Macia and P9511A x SEPON 82 hybrids with a yield ranging from 3 to 3.3 tons/ha. The other acceptable group in a country where the average yield rarely exceeds 460 Kg/ha is that made up of NE223A x MDKSU-49-1, NE223A x MDKSU-10-1, NE223A x ST9007-5-4-2 with a yield ranging from 2 to 2.3 tons/ha. These results corroborate the clear superiority of hybrids compared to other types of varieties.

Lower yields were observed with NE223A x IRAT 204 (1786 kg/ha), NE223A x MDKSU-10-1 (2061 kg/ha) NE223A x ST9007-5-4-2 (2081 kg/ha), thus there is a need to continue the development of much more productive varieties.

Table 4. Means of level of tolerance to drought, smut and midge for tested varieties.

Hybrids	Long Smut tolerance	Midge tolerance	Drought tolerance
NE223A x 90SN1	3	3	2
NE223A x P9405	5	3	3
NE223A x MDKSU-10-1	5	-	-
NE223A x MDKSU-49-1	2	4	3
NE223A x IRAT 204	3	3	2
NE223A x SEPON 82	3	3	2
NE223A x ST9007-5-2-1	3	-	-
NE223A x MR 732	3	-	-
P9511A x ST9007-5-2-1	2	2	2
P9511A x SEPON 82	2	2	3
P9511A x MR 732	2	-	-
P9511A x Macia	3	3	4

1 = No damaged kernels, 2 = 1% to 10% of damaged kernels, 3 = 11% to 25% of damaged kernels, 4 = 26% to 40% of damaged kernels, 5 = More than 40% of damaged kernels.

Midge, striga and smuts affect sorghum cultivation in Niger inflicting huge losses on tested varieties. Farmers have acknowledged that midge damage can be severe with late planting, reaching up to 100% yield losses. Smuts are the most prevalent disease group in all sorghum growing regions of the country. According to [20], smuts affect both local and improved cultivars, especially where untreated seeds are sown. **Table 4** shows the evaluation of the genetic material studied for the tolerance to drought, long smut and midge on the genetic material used. Also, **Table 4** shows that hybrid NE223A x 90SN1 has a level of tolerance to drought but is sensitive to smut and midge. Hybrid P9511A x ST9007-5-2-1 is both tolerant to drought, midge, and long smut. It has been difficult to find cultivars with multiple resistances against all major diseases. The use of resistant cultivars as an alternative has been very slow in countries like Niger.

Parents A and R flowering synchronization test

The use of sterile male lines requires good synchronization during flowering period of the A and R parents for the production of hybrids on a large scale [5] [21]. Hence the importance of having restorer lines that synchronizes well with the sterile male line during flowering time. But according to the period of flowering of the A and R lines, it is important to note that the hybrids with the highest yield are not those that are selected for large-scale production.

Synchronization study between the flowering dates of the parents [22] showed that the differences in the flowering date between the parents (A and R lines) of the best hybrids is large enough to allow better synchronization (**Table 5**). Thus, the synchronization of flowering between the parents having exceeded more than three days, the production of hybrids for large-scale production is very difficult, especially because the female will no longer be receptive [5]. This explains why the most productive hybrids are not the best. This explained why the hybrid

Table 5. Result of the flowering synchronization test of parents A and R.

Hybrids	Flowering gap A-R (days)	Significance
NE223A x 90SN1	2	R flowers 2 days before A
NE223A x P9405	−3	R flowers 3 days later than A
NE223A x Sepon82	−2	R flowers 2 days later than A
NE223A x MR732	2	R flowers 2 days before A
NE223A x MDKSU49-1	−2	R flowers 2 days later than A
NE223A x MDKSU10-1	−7	R flowers 7 days later than A
P9511A x Sepon82	−6	R flowers 6 days later than A
P9511A x ST9007-5-2-1	−16	R flowers16 days later than A
NE223A x ST9007-5-4-2	−3	R flowers 3 days later than A
NE223A x ST9007-5-4-3	−7	A flowers 7 days before R

NE223A x 90SN1 has the best A and R synchronization and the best agronomic performance (flowering time, height and yield). Also, regarding the plant height and even the number of flowering days, this hybrid is very acceptable with height not exceeding 125 cm for a flowering cycle of 58 days.

4. Conclusions

The participation of producers in the varietal improvement process facilitates the selection of varieties in their own production situations while ensuring that the improved varieties are eventually adopted. This is how the hybrids NE223A x 90SN1 and NE223A x Sepon82 were selected by the producers and are already registered in the national catalog of plant species and varieties.

It is therefore hoped that farmers will highly use and adopt these hybrids for more dissemination.

Hybrid EL SALÉ

Hybrid NE223A x P9405

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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