Research Article

Exploitation of Hybrid Vigor for Identification of Promising Sorghum F1 Hybrid for High Grain Yield and Resistance to Sorghum Midge

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Sorghum is the second most grown cereal crop in Niger. However, sorghum production in the country is dominated by indigenous cultivars with low productivity. Productivity in grain sorghum has been achieved in developing countries around the world using hybrids. This study was conducted to evaluate heterosis in F_1 sorghum hybrids for grain yield and resistance to midge. Fifty F_1 sorghum hybrids were evaluated for grain yield and resistance to midge. Variation for grain yield, midge resistance, and flowering time was observed. The magnitude of better parent heterosis for grain yield and resistance to midge varied significantly among hybrids. Four hybrids combined high better parent heterosis for both grain yield and resistance to midge while eight hybrids were better than their better parent for resistance to midge. These hybrids performed well for grain yield and/or resistance to midge. Therefore, the parental lines involved in these hybrids can be advanced for commercial hybrids production or used in sorghum improvement programs.

1. Introduction

Sorghum (*Sorghum bicolor* (L.) Moench) is a tropical cereal crop grown in a wide range of environments where it plays an important role as a staple food for several millions of people all over the world. According to FAO [1], sorghum is the fifth most important cereal crop after wheat, maize, rice, and barley. In Niger, sorghum is the second most grown cereal after millet. However, sorghum production rarely meets the demand of the growing population in the country. Grain sorghum yields are very low, about 0.280 tons/ha, which is far below the genetic potential of the crop in countries such as USA (4.3 tons/ha), Argentina (4.9 tons/ha), and China (3.2 tons/ha) [1]. The low production is attributed, not only to abiotic and biotic stresses, but also to the use of low yielding local varieties susceptible to the above constraints [2].

Sorghum midge, *Stenodiplosis sorghicola* (Coquillett 1898), is one of the most damaging pests of grain sorghum [3]. Globally, losses due to sorghum midge are known to vary over seasons and locations, but are thought to approximate 10–15% of the world sorghum crop production [4]. In Niger, according to Amadou [5], sorghum midge appears in the field around mid-September to early October when sorghum is flowering, thereby causing serious damage to sorghum yield. The author documented a yield reduction of about 30% to 40% caused by the insect in Niger. On the other hand, yield reduction of about 55.8% to 67.3% was recorded in the country by Kadi Kadi et al. [6]. These data clearly indicate that local sorghum varieties grown in Niger

are highly susceptible to midge infestation. According to Hamidou et al. [7], sorghum midge is well known by farmers in Niger. However, early planting is the only midge control measure used by sorghum farmers. Since the timing of rainy seasons in the Sahel is unpredictable, it is difficult to determine a planting time at which sorghum midge incidence can be prevented.

Grain yield and resistance to midge in sorghum can be increased by exploiting heterosis or hybrid vigor. Heterosis breeding has been used to increase sorghum grain productivity by 47% in China and 50% in India from the 1960s to the 1990s [8]. In Australia, midge-resistant sorghum has been used in sorghum midge control. As a result, a worldwide recognized integrated pest management (IPM) program was implemented [9].

The cost of producing hybrids is only justified when the performance of the hybrids surpasses that of their parents [10]. According to Hochholdinger and Hoecker [11], the potential of sorghum hybrids is estimated from the percentage increase or decrease of their performance over the midparent (midparent heterosis), better parent (heterobeltiosis or better parent heterosis), and the standard check (standard heterosis). However, Lamkey and Edwards [12] indicate that heterobeltiosis or better parent heterosis is more realistic and practical because it compares the hybrid with the best parent unlike midparent heterosis that compares the hybrid with the mean of the two parents. Furthermore, Reif et al. [13] suggested that the selection of superior parents for outstanding hybrids should depend on superior heterobeltiosis. To date, only one sorghum hybrid has been developed and released to farmers in Niger. However, this hybrid does not satisfy farmers in the large sorghum producing agroecological areas of the country because of late maturity and susceptibility to midge. The development of early maturing sorghum hybrids with high grain yield and resistance to midge is needed to address low sorghum productivity in Niger. This study was undertaken to estimate better parent heterosis in experimental F_1 hybrids for grain yield, resistance to sorghum midge, and time to flowering.

2. Materials and Methods

2.1. Experimental Materials. The experimental materials consisted of fifty F_1 hybrids generated using line by tester mating design and two local checks. The hybrids were obtained by crossing 25 recombinant inbred lines (RILs) onto two male-sterile midge-resistant lines. The inbred lines used as male parents were F_{1-4} lines developed from a cross between a local sorghum variety (MDK) and an exotic sorghum midge-resistant cultivar from ICRISAT (ICSV88032) using the single-seed descent breeding method (SSD). The male-sterile lines were TX640 from Texas A&M University, USA, and QL33 from Queensland University, Australia.

2.2. Experimental Site. A field experiment was conducted during the 2015 rainy season at the research station of INRAN at Konni in Niger Republic. Konni has a latitude of

13° 47′23″ North and a longitude of 5° 14′ 57″ East, an average annual rainfall of 589.7 mm, and an average temperature of 29.3°C.

2.3. Experimental Design. The experimental design was an alpha (0.1) lattice with 3 replications. However, blocking was not significant and the data were reanalyzed using randomized complete block design. Each genotype was grown in a single 3 meters row in each replication. The intra- and interrow spacing was 0.20 m × 0.80 m. Five seeds were panted and thinned to three plants per stand three weeks after planting. Weeding was done when necessary, and standard cultural practices for optimum sorghum production were carried out. Harvesting was done at physiological maturity. In order to evaluate midge damage on the panicles, three panicles were covered at emergence using selfing bags. At harvesting, panicle and grain mass were recorded for the three covered and three noncovered panicles. The loss in grain yield in three noncovered panicles was expressed as a percentage of grain yields in covered panicles.

2.4. Data Collection and Analysis. Data collected were grain yield (GY), days to 50% flowering (FF), and midge damage (MD). Grain yield was measured in tons per hectare adjusted to grain moisture content at 12%. Days to 50% flowering was recorded by counting the number of days from planting to when 50% of the plants in a plot flowered. Midge damage was calculated as loss of grain yield in three noncovered panicles expressed as a percentage of grain yield in three covered panicles. Analysis of variance was computed for grain yield, days to 50% flowering, and midge damage using the model described by Kempthorne [14] in SAS 9.3 software.

Heterosis, expressed as percentage increase or decrease in hybrid F1 over its better parent (BP) value, was calculated as described by Turner [15] and Hayes et al., [16] using the following formula:

$$\text{better parent heterosis (\%)} = \frac{F_1 - \text{BP}}{\text{BP}} \times 100, \quad (1)$$

where F_1 = mean performance of F_1 and BP = mean performance of the better parent.

For computing better parent heterosis for grain yield, hybrids were compared with their higher yielding parent. Hybrids were compared to parents for low percentage of yield lost and fewer days to 50% flowering.

3. Results

3.1. Analysis of Variance. The analysis of variance showed significant differences among lines and the interaction of lines by testers for the traits under study. However, testers were significantly different for all the study traits except midge damage. The magnitude of mean squares indicates that crosses were different for grain yield, midge damage, and flowering time (Table 1).

Table 1: Mean squares for traits of 50 experimental hybrids evaluated in the 2015 rainy season.

Source of variation	d.f.	FF	GY	MD
Rep	2	3.795*	42540.29*	1.19*
Lines	24	8.371*	21725.33*	0.15*
Testers	1	36.358*	214220.59**	0.05^{ns}
Lines × testers	24	9.34*	10620.12*	0.11*
Residual	97	6.679	11339.524	0.07
CV		3.950	52.810	49.628

SV = seedling vigor; PH = plant height; FF = days to 50% flowering; TSW = 1000 seed weight; GY = grain yield; MD = midge damage; ns = nonsignificant; *significant at 5%; **significant at 1%.

3.2. Performance of the Experimental Hybrids. The range of mean performance was significant for grain yield and midge damage among genotypes. However, the range of mean performance of flowering time did not vary significantly. Grain yield of the crosses ranged from 1.17 t/ha for the hybrid QL33 × L11 to 12.70 t/ha for the hybrid TX640 × L18. The range of yield reduction caused by midge was from 15% for hybrid QL33 × L4 to 84% for hybrid TX640 × L19. The range of days to 50% flowering was from 61 DAP for hybrid TX640 × L21 to 69 DAP for hybrid TX640 × L12 (Table 2).

3.3. Better Parent Heterosis. The better parent heterosis for grain yield varied from 3.62% for QL33 × L5 to 61.40% for the hybrid TX640 × L24. The negative value of better parent heterosis for the resistance to midge ranges from −1.64% for the hybrid QL33 × L15 to −74.14% for the hybrid QL33 × L4. The negative value of better parent heterosis for days to 50% flowering ranges from −1.52% for the hybrid TX640 × L17 to −4.69% for the hybrid TX640 × L21. Fourteen (14) hybrids recorded positive and significant better parent heterosis for grain yield. Twenty-four (24) hybrids had desirable negative and significant better parent heterosis for resistance to midge. On the other hand, 5 hybrids showed desirable negative significant better parent heterosis for days to 50% flowering (Table 3)

4. Discussion

In this experiment, significant differences are present among genotypes. The magnitude of the mean squares observed in this study for traits among the genotypes indicates that selection of genotypes with different levels of grain yield potential, resistance to midge, and flowering time will be possible. Sorghum cultivars that combine grain yield potential and resistance to sorghum midge are important for insect management in sorghum [17]. In the present study, hybrids TX640 × L6, TX640 × L7, TX640 × L13, and TX640 × L24 had high and significant heterosis for both grain yield and resistance to midge. Hamidou et al. [7] reported significant specific combining ability in the hybrid TX640 × L24 for grain yield, yield-related traits, and resistance to midge. In addition to expressing significant heterosis, these genotypes had high grain yield and less yield reduction caused by midge. These results indicate that breeding for sorghum hybrids that combine both grain yield

Table 2: Mean performance of 50 experimental hybrids evaluated in the 2015 rainy season.

Crosses	Grain yield (t/ha)	Midge damage	Days to 50% flowering
TX640 × L1	6.18	0.72	65
QL33 × 1	3.84	0.35	65
TX640 × L2	5.56	0.34	68
QL33 × L2	3.99	0.79	64
TX640 × L3	4.34	0.45	66
QL33 × L3	5.42	0.46	63
TX640 × L4	8.37	0.59	67
QL33 × L4	10.39	0.15	67
TX640 × L5	4.03	0.61	66
QL33 × L5	5.09	0.65	64
TX640 × L6	9.71	0.2	66
QL33 × L6	4.63	0.77	66
TX640 × L7	10.65	0.25	67
QL33 × L7	3.35	0.84	65
TX640 × L8	4.95	0.66	67
QL33 × L8	5.83	0.57	64
TX640 × L9	3.65	0.54	67
QL33 × L9	3.77	0.6	66
TX640 × L10	4.71	0.58	62
QL33 × L10	2.52	0.59	64
TX640 × L11	8.41	0.47	69
QL33 × L11	1.17	0.3	64
TX640 × L12	4.56	0.6	69
QL33 × L12	4.87	0.61	64
TX640 × L13	9.89	0.25	64
QL33 × L13	6.49	0.33	68
TX640 × L14	8.69	0.46	65
QL33 × L14	3.60	0.64	63
TX640 × L15	7.13	0.61	65
QL33 × L15	6.03	0.6	63
TX640 × L16	7.24	0.62	66
QL33 × L16	2.78	0.59	63
TX640 × L17	5.05	0.43	65
QL33 × L17	2.71	0.81	66
TX640 × L18	12.78	0.74	66
QL33 × L18	9.16	0.25	66
TX640 × L19	4.69	0.84	68
QL33 × L19	6.70	0.49	62
TX640 × LL20	8.21	0.54	67
QL33 × L20	6.42	0.73	68
TX640 × L21	8.32	0.59	61
QL33 × L21	2.92	0.7	65
TX640 × L22	4.16	0.53	66
QL33 × L22	3.29	0.64	63
TX640 × L23	6.39	0.5	67
QL33 × L23	4.08	0.61	64
TX640 × L24	11.77	0.3	62
QL33 × L24	5.25	0.61	61
TX640 × L25	11.49	0.51	64
QL33 × L25	5.35	0.59	68
Grand mean	5.91	0.54	65
LSD		0.44	4.19

potential and resistance to sorghum midge can be achieved. Ashok Kumar [18] identified hybrids with grain yield potential and resistance to shoot fly in sorghum. Yerka et al. [19] reported the benefits of *bmr*-12 sorghum hybrids in both animal feeding and biofuel industries and

Table 3: Better parent heterosis of 50 experimental hybrids evaluated in the 2015 rainy season.

Crosses	Grain yield	Midge damage	Days to 50% flowering
TX640 × L1	−15.24**	33.33**	0.00[ns]
QL33 × L1	−23.38**	−39.66**	0.00[ns]
TX640 × L2	−23.77**	−44.26**	3.03*
QL33 × L2	−18.75**	29.51**	−1.54[ns]
TX640 × L3	−40.45**	−11.76**	3.13*
QL33 × L3	8.66**	−20.69**	−1.56[ns]
TX640 × L4	−10.78**	15.69**	1.52[ns]
QL33 × L4	10.78**	−74.14**	3.08*
TX640 × L5	−44.76**	−3.17**	1.54[ns]
QL33 × L5	3.62**	3.17**	−1.54[ns]
TX640 × L6	33.14**	−60.78**	0.00[ns]
QL33 × L6	−35.43**	32.76**	1.54[ns]
TX640 × L7	46.05**	−54.55**	1.52[ns]
QL33 × L7	−52.17**	44.83**	0.00[ns]
TX640 × L8	−32.10**	6.45**	1.52[ns]
QL33 × L8	8.16**	−8.06**	−1.54[ns]
TX640 × L9	−49.89**	−3.57**	1.52[ns]
QL33 × L9	−23.17**	3.45**	1.54[ns]
TX640 × L10	−35.44**	0.00[ns]	−1.59[ns]
QL33 × L10	−48.62**	1.72**	1.59[ns]
TX640 × L11	15.23**	−7.84**	4.55[ns]
QL33 × L11	−76.13**	−48.28**	−1.54[ns]
TX640 × L12	−37.55**	−1.64**	4.55[ns]
QL33 × L12	−0.85 ns	0.00 ns	−1.54[ns]
TX640 × L13	20.76**	−50.98**	−3.03*
QL33 × L13	−20.76**	−43.10**	4.62**
TX640 × L14	19.16**	−16.36**	1.56[ns]
QL33 × L14	−41.42**	10.34**	−1.56[ns]
TX640 × L15	−2.23**	0.00 ns	0.00[ns]
QL33 × L15	−8.38**	−1.64**	−3.08*
TX640 × L16	−0.69 ns	3.33**	3.13[ns]
QL33 × L16	−43.39**	−1.67**	−1.56[ns]
TX640 × L17	−30.79**	−30.65**	−1.52[ns]
QL33 × L17	−44.77**	30.65**	1.54[ns]
TX640 × L18	16.53**	45.10**	0.00[ns]
QL33 × L18	−16.53**	−56.90**	1.54[ns]
TX640 × L19	−35.68**	44.83**	4.62**
QL33 × L19	8.11**	−15.52**	−4.62**
TX640 × LL20	9.60**	−12.90**	1.52[ns]
QL33 × L20	−14.39**	17.74**	4.62**
TX640 × L21	14.02**	−7.81**	−4.69[ns]
QL33 × L21	−47.98**	9.37**	1.56[ns]
TX640 × L22	−43.02**	−8.62**	1.54[ns]
QL33 × L22	−32.93**	10.34**	−3.08*
TX640 × L23	−12.46**	−9.09**	1.52[ns]
QL33 × L23	−21.99**	5.17**	−1.54[ns]
TX640 × L24	61.40**	−43.40**	0.00[ns]
QL33 × L24	−23.67**	5.17**	−1.61[ns]
TX640 × L25	36.48**	−7.27**	−3.03*
QL33 × L25	−36.48**	1.72**	4.62**

Note: **significant at 1%, *significant at 5%, and ns: nonsignificant.

recommended its use in large-scale production. Ashok Kumar (2011) documented hybrids with both high grain yield and grain mold resistance in sorghum and suggested these hybrids as a potential source for grain mold resistance breeding.

The parental lines involved in the hybrids described here can be advanced and exploited in commercial sorghum hybrids with superior grain yield and resistance to sorghum midge. The heterosis for grain yield and resistance to sorghum midge identified in this study can also provide a source of midge resistance and grain yield increase in developing new sorghum cultivars for midge resistance and grain yield increase. On the other hand, the hybrids QL33 × L1, TX640 × L2, QL33 × L3, QL33 × L4, QL33 × L11, QL33 × L13, TX640 × L17, and QL33 × L18 recorded higher better parent heterosis for resistance to midge and low yield loss caused by midge. The parents of these hybrids can be used to develop midge-resistant hybrids. Patil et al. [20] documented high heterosis for midge resistance traits in twenty-eight sorghum hybrids. Specific combining ability effects for resistance to sorghum midge was reported in hybrids TX640 × L17 and TX640 × L2 by Hamidou et al. [7]. The hybrid TX640 × L25 with high significant heterosis for grain yield can be an important candidate for grain yield [21, 22].

5. Conclusion

From the results, high levels of better parent heterosis were evident for grain yield and resistance to sorghum midge among the hybrid evaluated here. The top promising crosses were TX640 × L6, TX640 × L7, TX640 × L13, and TX640 × L24 for both grain yield and resistance to midge and QL33 × L1, TX640 × L2, QL33 × L3, QL33 × L4, QL33 × L11, QL33 × L13, TX640 × L17, and QL33 × L18 for resistance to midge. These crosses need to be evaluated in a wide range of environments to identify the most stable for further exploitation [23, 24].

Data Availability

The underlying data supporting the results can be found at hmassaoud@yahoo.fr.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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