Inheritance of chinch bug resistance in grain pearl millet

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Abstract

Pearl millet (*Pennisetum glaucum*) is a promising alternative feed grain for southeastern US crop productions systems because of its ability to reliably produce grain under drought conditions on sandy, acidic and low fertility soils. Chinch bug [*Blissus leucopterus leucopterus* (Say) (Heteroptera: Blissidae)] infestation was very high under the drought conditions in southern Georgia in 2006 and 2007 when 37 elite inbred breeding lines and 145 hybrids were screened for chinch bug resistance. The objective of this research was to determine if chinch bug resistance existed in current elite inbred parental materials, and if so, what level of inheritance was demonstrated for this trait. In September 2006, 37 inbred lines replicated six times were assessed for resistance under heavy natural chinch bug infestation. In 2007, 145 F_1 hybrid progenies, replicated three times were assessed twice (July 16 and 30) under heavy natural chinch bug infestation. Plots were scored 0 (no damage) to 4 (dead) for insect damage. The damage rating ranged from 1.0 to 2.86 in inbred lines and from 1.0 to 3.3 in hybrids. Seven of the 37 inbred lines and 8 of the 145 hybrids were identified as chinch bug resistant, while seven of the 37 inbred lines and four of the 145 hybrids were identified as the most susceptible to chinch bug infestation. Observed inheritance (h_n^2) for this population was 0.69 with $P < 0.001$.

Introduction

Pearl millet (*Pennisetum glaucum*) is a promising alternative feed grain for southeastern US crop production systems because of its ability to reliably produce grain under drought conditions on sandy, acidic, and low fertility soils (Menezes et al. 1997). Chinch bug [*Blissus leucopterus leucopterus* (Say) (Heteroptera: Blissidae)] infestation was very high under drought conditions in 2006 and 2007 confirming early predictions by Hudson (1995) that chinch bug would be the most important insect pest on pearl millet grown for grain. Chinch bug is a piercing-sucking insect with multiple generations occurring throughout the growing season (Hudson 1995). The US dwarf grain pearl millet hybrids average 85 days to maturity allowing for a large growing window in southern Georgia or an opportunity for double cropping, but the multiple generations of chinch bug severely limit this if the grower seeks to plant millet to avoid infestation. Additionally pearl millet is typically being grown under yield-limiting conditions such as drought or on low fertility soils making low input costs of critical importance. Zeta-cypermethrin [S-cyano (3-phenoxyphenyl) methyl (+) cis/trans 3-(2,2-dichloro-ethenyl)-2,2 dimethylcyclopropane carboxylate] is labeled for use on pearl millet, but it can account for as much as 15% of the variable costs of production (Lee et al. 2004). Additionally chinch bugs are difficult to control due to the lush growth of pearl millet and the insect's preference to inhabit the inside of the leaf sheath unless populations are exceptionally high (Hudson 1995). Because of these factors natural host plant resistance would provide the best form of insect control. The objective of this research was to determine if chinch bug resistance exists in 37 current elite parental inbred lines, and if so what level of inheritance was demonstrated for this trait in the related hybrids.

Materials and methods

Thirty-seven elite inbred breeding lines from a diverse background developed by the USDA-ARS pearl millet breeding program at Tifton, Georgia, USA, and 145 F_1

hybrid progenies were assessed over two seasons under heavy natural insect infestations of chinch bugs at Tifton. The 37 elite inbreds were planted in a randomized complete block design (RCBD) with six replications on 8 August 2006 and assessed for chinch bug damage on 7 September 2006. The 145 hybrids were also planted in a RCBD with three replications on 16 May 2007 and assessed for chinch bug damage on 16 July and 30 July 2007. Visual injury scoring of plots were utilized as Ni et al. (2007) found this rating to be stable across varied planting dates, whereas insect numbers, leaf chlorophyll content and plant height showed significant differences due to planting date. All plots were rated using a 0–4 rating system with score of zero representing no apparent necrotic damage and a score of 4 if the plants were dead. Stunting was rated independently as a simple rating with 0 and 1 to denote non-stunt, or stunted. Designation of resistance and susceptiblity was based on mean rating and level of stunting for inbred lines. Mean necrosis rating and yield for hybrids were utilized for selection of resistant and susceptible hybrids.

Data were analyzed using generalized least squares method in SAS software (SAS Institute 2002) for determination of mean difference between lines. The inbred and hybrid rating data were analyzed using PROC MIXED procedure with LS mean separations. The means of the rating and yield data were also further analyzed using PROC CLUSTER, and a dendrogram was generated using PROC TREE procedure of the SAS software, to objectively classify resistant and susceptible hybrid types. Restricted maximum likelihood methods in SAS were used for the determination of heritability (h_n^2) (Fry 2004).

Figure 1. Chinch bug infestation of pearl millet in 2007.

Results

Severe drought conditions in the fall of 2006 and summer 2007 provided excellent natural conditions to evaluate resistance to chinch bug in pearl millet (Fig. 1). Typically hybrid millet plants grow so vigorously that severe damage and yield loss are not observed (Dr Wayne Hanna, personal communication); however, severe chlorosis, stunting and death were observed in 2006 and 2007 (Fig. 2).

Inbreds were rated in 2006 to determine if actual resistance existed in elite breeding material. By assessing inbreds rather than hybrids it provided the ability to specifically identify sources of resistance without the confounding effect of the more vigorous growth of hybrid material. Necrosis ratings among the 37 inbred lines were significantly different (F = 4.62; df = 36, 277; P = 0.0001) and so were the stunt ratings (F = 3.92; df = 36, 277; P = 0.0001). Mean necrosis ratings were 1 to 2.86 with a standard error of 0.33 suggesting chinch bug resistance was present in the breeding population (Table 1). The seven genotypes in groups with letters i and j with no stunting were rated as resistant and the six genotypes in groups with letters a and e along with 05-5223a, which had the highest stunting rating were considered susceptible (Table 1). The seven resistant genotypes were 04-7049, 05-5212a, 05-5206a, 04-7041, 02-7978, 02-7747 and 04-7040, whereas the seven susceptible genotypes were 04-7030, 02-6900, 04-7008, 04-07, 02-6848, 04-15 and 05-5223a. The remaining 23 entries were identified as moderately resistant to chinch bug feeding.

In 2007, the 145 hybrids were assessed before and after flowering of the millet plants to provide temporal responses of the flowering plants to high chinch bug infestation to mitigate the effects of lower replication numbers per hybrid. The mean for the necrosis ratings

Figure 2. Chinch bug damage to pearl millet in 2006 and 2007.

were significantly different (F = 4.59; df =144, 343; P = 0.0001) (Table 2). At the same time, the hybrid yield was also significantly different among the 145 hybrid entries (F = 4.59, df = 144, 343; P = 0.0001). Mean necrosis rating scores ranged from 1.0 to 3.33 under considerably higher insect pressure with a standard error of 0.34 (Table 2). Because only few plants in all experimental plots were observed with stunting, the stunting data for the hybrids were not presented. The range and standard errors of the necrosis ratings were similar to those obtained for the inbreds in 2006 suggesting similar effectiveness of the assessment technique for chinch bug damage evaluation on grain millet plants. The analysis of means for yield and necrosis ratings (Table 3) showed that the eight experimental hybrids with chinch bug resistance and good yield were: 6017, 6059, 6064, 7017, 7018, 7021, 7028 and 7030. The eight hybrids with moderate chinch bug resistance and good yield were: TifGrain 102, 5163, 5185, 5186, 6070, 6085, 7041 and 7046. In addition, four susceptible hybrids identified

Table 1. Necrosis and stunt ratings of 37 pearl millet inbred lines in evaluation for clinch bug resistance.

Inbred entry[1]	*n*	Necrosis[2]	Stunting[2]
04-7049	7	1j	0c
05-5212a	15	1j	0c
05-5206a	15	1.07ij	0c
04-7041	7	1.14ij	0c
02-7978	7	1.14ij	0c
02-7747	7	1.14ij	0c
04-7040	7	1.14ij	0c
04-14	7	1.14ij	0.14b
05-5217a	15	1.2h-j	0.07c
454	7	1.29g-j	0c
04-13	7	1.29g-j	0c
04-18	7	1.29g-j	0.14b
04-7039	7	1.29g-j	0.29b
04-10	7	1.29g-j	0c
04-11	7	1.43f-j	0c
04-06	7	1.43f-j	0c
02-6917	7	1.57e-j	0c
04-16	7	1.57e-j	0c
04-7635	7	1.57e-j	0c
04-7032	7	1.57e-j	0c
05-5228a	15	1.67d-i	0c
05-5235a	15	1.8c-h	0.07c
04-17	7	1.86c-g	0c
04-08	7	1.86c-g	0c
04-7031	7	1.86c-g	0c
99a	15	1.87c-g	0c
05-5223a	15	1.93c-e	0.53a
04-12	7	2b-f	0c
04-7035	7	2b-f	0c
04-7038	7	2c-f	0c
8677	7	2c-f	0c
04-7030	7	2.14b-e	0c
02-6900	7	2.14b-e	0c
04-7008	7	2.29a-d	0c
04-07	7	2.43a-c	0c
02-6848	7	2.57ab	0c
04-15	7	2.86a	0c

1. Inbred numbers ending in 'a' are A_1 cytoplasmic male sterile females.
2. Means followed by different letters within a column are significantly different (P <0.05).

Table 2. Chinch bug damage ratings and yield of 145 experimental hybrids.

Entry	Experimental hybrid	Female[1]	Male	*n*	Damage rating[2]	Yield[3] (kg ha^{-1})
1	TifGrain 102	99a	454	50	1.56	1490.4
2	5032	05-5206a	04-7031	3	2.17	2238.9
3	5041	05-5212a	04-7008	3	1.83	1984.2
4	5091	05-5223a	04-7008	3	1.83	1896.1
5	5163	99a	04-6	3	2.5	1552.7
6	5167	99a	04-10	3	2.92	1125.7
7	5168	99a	04-11	3	1.33	1958.8
8	5169	99a	04-12	3	1.58	1990.9
9	5170	99a	04-13	3	1.92	1441.2
10	5171	99a	04-14	3	2.17	1453.1
11	5172	99a	04-15	3	3.08	1227.6
12	5177	99a	04-7	3	2.25	1075.3
13	5185	99a	02-6848	3	1.5	1536.8
14	5186	99a	02-6900	3	1.83	1572.7
15	5188	99a	02-7747	3	2	1416.4
16	5193	05-5212a	04-6	3	1.75	773.9
17	6002	99a	04-7008	3	1.58	1290.5
18	6003	99a	04-7030	3	2.58	837.1
19	6004	99a	04-7031	3	2.25	1096.2
20	6005	99a	04-7032	3	1.92	1111.8
21	6007	99a	04-7035	3	1.67	981.6
22	6008	99a	04-17	3	1.5	1079.9
23	6009	99a	04-7040	3	1.58	1266.3
24	6010	99a	04-7049	3	2.08	843.5
25	6011	99a	04-7635	3	2.75	755.5
26	6016	99a	04-7016	3	2.42	979.2
27	6017	99a	04-7039	3	2.17	1692.6
28	6019	05-5206a	02-7979	3	2.42	1387.5
29	6020	05-5206a	454	3	2.17	937.3
30	6022	05-5206a	04-12	3	1.92	1394.6
31	6023	05-5206a	04-10	3	1.67	1331.0
32	6024	05-5206a	04-11	3	1.92	1241.2
33	6027	05-5206a	04-14	3	2.5	1170.3
34	6029	05-5206a	04-7008	3	3.17	233.6
35	6030	05-5206a	04-7030	3	2.5	957.9
36	6031	05-5212a	04-07	3	2.33	986.8
37	6032	05-5206a	02-6900	3	3.5	389.8
38	6034	05-5206a	02-6917	3	3.17	566.6
39	6037	05-5212a	04-7031	3	2.67	1356.1
40	6039	05-5206a	04-7035	6	2.04	1025.5
41	6040	05-5206a	04-7035	3	2.25	667.0
42	6042	05-5212a	8677	3	2.25	866.8
43	6043	05-5217a	04-7039	3	2.42	539.5
44	6044	05-5217a	04-7040	2	3.13	457.9
45	6047	05-5206a	02-7747	3	2.75	374.0
46	6050	05-5212a	454	3	2.5	551.0
47	6051	05-5212a	04-10	2	1.88	860.3
48	6054	05-5212a	04-11	3	2.58	424.1
49	6055	05-5228a	04-10	3	1.75	1011.0
50	6056	05-5228a	04-18	3	1.75	1067.8
51	6059	05-5212a	04-16	3	1.83	1739.2
52	6062	05-5212a	02-6900	3	2.58	886.5

contd.

Table 2. (contd.)

Entry	Experimental hybrid	Female[1]	Male	*n*	Damage rating[2]	Yield[3] (kg ha^{-1})
53	6063	05-5212a	04-7030	3	2.83	426.4
54	6064	05-5212a	04-7032	3	2.17	2768.1
55	6065	05-5217a	04-7049	3	1.67	1425.3
56	6067	05-5212a	04-7035	3	2.42	820.1
57	6068	05-5223a	04-6	3	2.33	1195.4
58	6069	05-5212a	04-7049	3	2.25	1242.3
59	6070	05-5212a	04-7635	3	1.67	1561.7
60	6072	05-5212a	02-7747	3	2.5	828.6
61	6073	05-5223a	04-10	3	2	1288.2
62	6074	05-5217a	04-6	3	1.58	864.0
63	6075	05-5217a	04-8	3	1.5	1034.5
64	6076	05-5217a	04-10	3	1.25	629.4
65	6081	05-5223a	04-11	3	1.83	1043.0
66	6083	05-5217a	04-16	3	1.83	1178.2
67	6085	05-5217a	04-18	3	2	1589.0
68	6086	05-5217a	02-6848	3	1.92	859.3
69	6087	05-5217a	02-6917	3	2.17	888.1
70	6088	05-5217a	04-7008	3	2	961.8
71	6089	05-5217a	04-7030	3	1.75	885.8
72	6090	05-5223a	04-7030	3	1.58	1270.4
73	6092	05-5217a	04-7032	3	1.67	1235.0
74	6093	05-5223a	04-7032	3	2.33	642.3
75	6094	05-5217a	04-7038	3	1.92	1046.6
76	6095	05-5217a	04-7041	3	2.08	792.6
77	6096	05-5223a	04-7038	6	1.92	623.2
78	6097	05-5217a	04-7035	3	2.75	650.1
79	6100	05-5217a	04-7035	3	3.5	138.8
80	6101	05-5223a	04-7039	3	2.58	644.3
81	6105	05-5228a	454	3	1.67	870.2
82	6106	05-5217a	04-7	3	2.5	454.9
83	6107	05-5206a	8677	3	2.92	583.8
84	6110	05-5206a	04-8	3	3.33	286.7
85	6113	05-5206a	04-18	3	3.17	371.3
86	6114	05-5212a	02-6917	3	2.5	837.6
87	6116	05-5217a	454	3	3.42	766.6
88	6118	05-5206a	04-7041	3	3.08	654.1
89	6119	05-5206a	04-7040	3	2.58	1005.7
90	6123	05-5206a	04-7039	3	2.42	1235.6
91	6128	05-5206a	04-7038	3	2.42	792.6
92	6131	05-5206a	04-7032	3	3.08	791.9
93	6132	05-5212a	04-9	3	2.83	1168.3
94	6135	05-5212a	04-15	3	2.42	641.6
95	6166	05-5212a	04-15	3	1.5	1256.0
96	6167	05-5212a	04-18	3	1.58	649.5
97	7001	05-5217a	04-7031	3	2.25	884.0
98	7003	05-5223a	8677	3	2.17	911.6
99	7004	05-5217a	02-7979	3	2.33	1024.4
100	7005	05-5212a	04-7041	3	2.42	529.9
101	7006	05-5212a	04-7040	3	2.67	363.7
102	7007	05-5217a	02-6900	3	2.42	707.0
103	7008	05-5217a	02-7747	3	1.92	755.2

contd.

Table 2. (contd.)

Entry	Experimental hybrid	Female[1]	Male	*n*	Damage rating[2]	Yield[3] (kg ha^{-1})
104	7009	05-5223a	04-7035	3	1.25	822.9
105	7010	05-5223a	04-7040	3	1.33	1399.4
106	7011	05-5228a	04-7030	3	1.42	1391.8
107	7012	05-5228a	04-7008	3	1.67	1353.8
108	7013	05-5228a	04-17	3	2	818.3
109	7014	05-5228a	04-14	3	1.5	646.8
110	7015	05-5223a	04-8	3	1.33	993.1
111	7016	05-5223a	04-12	3	1.75	915.1
112	7017	05-5223a	04-14	3	1.17	1748.0
113	7018	05-5223a	04-18	6	1.42	1783.8
114	7020	05-5228a	04-7	3	1.58	1046.0
115	7021	05-5228a	04-7041	3	1.75	1796.3
116	7022	05-5228a	02-7747	3	1.42	1101.8
117	7023	05-5235a	454	3	1.58	1081.4
118	7024	05-5235a	04-7	3	1.25	661.1
119	7025	05-5235a	04-10	3	1.67	498.3
120	7027	05-5235a	04-11	3	1.75	501.1
121	7028	05-5235a	04-12	3	1.67	2649.0
122	7029	05-5235a	02-7979	3	1.25	1864.4
123	7030	05-5235a	04-7049	3	1.33	1695.1
124	7031	05-5235a	04-7041	3	1.33	1312.0
125	7033	05-5235a	04-7040	3	1.75	2145.9
126	7035	05-5235a	04-7039	3	1.67	605.3
127	7036	05-5235a	04-7035	3	2	858.9
128	7037	05-5228a	04-7040	3	2.17	569.0
129	7038	05-5228a	8677	3	1.33	1135.1
130	7039	05-5223a	02-7979	3	1.5	1133.5
131	7040	05-5223a	02-7747	3	1.33	1224.4
132	7041	05-5223a	04-7635	3	1.17	1542.1
133	7042	05-5228a	04-7032	3	1.67	907.2
134	7043	05-5228a	04-7635	3	2.42	1037.4
135	7044	05-5228a	04-7038	3	2.58	567.3
136	7046	05-5228a	04-7039	3	2.08	1518.5
137	7047	05-5235a	04-7032	3	1.92	958.1
138	7048	99a	04-16	3	2.42	734.8
139	7049	99a	04-18	3	2.42	718.2
140	7050	99a	04-7041	3	1.5	1062.2
141	7051	99a	04-7039	3	1.42	807.1
142	7052	05-5235a	04-7008	3	1.67	1249.2
143	7053	05-5235a	02-6917	3	1.5	903.3
144	7054	05-5235a	04-14	3	1.75	1188.7
145	7055	99a	04-8	3	1.83	1252.4

1. Inbred numbers ending in 'a' are A_1 cytoplasmic male sterile females.
2. $LSD_{0.05}$ for necrosis rating is 0.74.
3. $LSD_{0.05}$ for yield is 677.66.

were entries 6097, 6100, 6101 and 6106 with less than one-sixth of the yield of the resistant hybrids (Table 3). The current study supported a previous report by Ni et al. (2007) that TifGrain 102 had moderate chinch bug resistance and good yield potential.

To further decipher the genetic information involved in observed chinch bug resistance in both inbred lines and hybrids, the inbred and hybrid data were further analyzed for narrow sense heritability. Observed inheritance for this population was 0.69 with a $P < 0.001$, which suggests a solid opportunity for improvement through selection.

Conclusion

Chinch bug resistance is present in current elite US grain pearl millet lines, and inheritance is very high providing an opportunity for effective selection for this trait in a pearl millet breeding program.

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Table 3. Categorization of elite hybrids from the 145 experimental hybrids evaluated for chinch bug resistance.

		Female		Male		Hybrid	
Entry	Experimental hybrid	Name	Resistance ranking	Name	Resistance ranking	Damage rating	Yield (kg ha^{-1})
Most resistant with good yield							
27	6017	99a	m	04-7039	m	2.17	1692.6
51	6059	05-5212a	r	04-16	m	1.83	1739.3
54	6064	05-5212a	r	04-7032	m	2.17	2768.1
112	7017	05-5223a	s	04-14	m	1.17	1748.0
113	7018	05-5223a	s	04-18	m	1.42	1783.8
115	7021	05-5228a	m	04-7041	r	1.75	1796.3
121	7028	05-5235a	m	04-12	m	1.67	2649.0
123	7030	05-5235a	m	04-7049	r	1.33	1695.1
Mean						1.69	1984.0
Moderate resistance with good yield							
1	TifGrain 102	99a	m	454	m	1.56	1490.4
5	5163	99a	m	04-6	m	2.5	1552.7
13	5185	99a	m	02-6848	s	1.5	1536.8
14	5186	99a	m	02-6900	s	1.83	1572.8
59	6070	05-5212a	r	04-7635	m	1.67	1561.7
67	6085	05-5217a	m	04-18	m	2	1588.9
132	7041	05-5223a	s	04-7635	m	1.17	1542.1
136	7046	05-5228a	m	04-7039	m	2.08	1518.5
Mean						1.79	1545.5
Most susceptible hybrids							
78	6097	05-5217a	m	04-7035	m	2.75	650.1
79	6100	05-5217a	m	04-7035	m	3.5	138.8
80	6101	05-5223a	s	04-7039	m	2.58	644.3
82	6106	05-5217a	m	04-17	m	2.5	454.9
Mean						2.83	310.5

1. The rankings of the parental genotypes were based on data from Table 1; r = resistant; m = moderately resistant; and s = susceptible.

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