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Striga Resistance/Tolerance in Sorghum: an Outcome of Interactive Intrinsic and Extrinsic Factors

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Abstract

An experiment was conducted in two consecutive seasons (2016/17 and 2017/18) at two sites, irrigated and rain-fed environments with the objective of transfer *Striga* resistance genes from the donor parents, IS9830, 555, SAR33, Framida, N13, ICSV006, ICSV007, PQ-34, Brhan and SRN39, and its derivatives P401, P402 and P405, to the improved elite Sudanese sorghum cultivars, Wad Ahmed, Tabat, Butana and Arfagadamek-8 as recurrent parents. The experiment, set in a randomized complete block design with four replicates, was laid in *Striga hermonthica* sick plots. The F_1 plants were backcrossed (BC_1F_1) to the recurrent cultivars to obtain BC_2F_1 families, which were subsequently salved for two successive generations to generate BC_2F_3 progenies. Data analyses indicated highly significant differences ($P \leq 0.01$) for all traits among crosses and the respective checks. Spatiotemporal variations in *Striga* emergence, biomass, productivity and sorghum grain yield were observed. Several crosses (35.7% of the total) showed some degree of resistance to the parasite across the environments others (54.8%) showed resistance only under irrigation. The level of resistance varied from very low (12%) to high (89%) as raveled by reductions in *S. hermonthica* emergence. Correlation analysis revealed, consistently, highly significant negative relation between sorghum grain yield, *Striga* counts at 75 days after sowing and *Striga* biomass at harvest ($r = -0.711$ and -0.685, respectively $P \leq 0.001$) in the irrigated environments, but not in their rain-fed equivalents. The study indicates coexistence of two complementary mechanisms of defense, resistance and tolerance, against *S, hermonthica*, in the generated crosses and suggests a crucial role for both intrinsic and extrinsic factors in determining resistance and/or tolerance to the parasite.

Keywords: Environment**,** parasitic weeds, sorghum, *Striga hermonthica*, resistance, tolerance.

Introduction

Sorghum [*Sorghum bicolor* (L.) Moench], a diploid grass (2n=20), is the fifth most important cereal crop world-wide (FAOSTAT, 2012). It serves as a good source of food and nutrition to millions of people in the semi-arid regions of the world (Reddy *et al.*, 2010) and is increasingly gaining importance as a source of livestock feed and biofuel (Zhang *et al*., 2010). It is grown in at least 86 countries, on an area of 47 million hectares, with annual grain production of 69 million tones reflecting an average productivity of 1.3-1.5 t ha^{-1} (Elzein *et al*., 2008 and FAOSTAT, 2014). Sorghum was first domesticated in North East Africa in particular, the region of Eastern Sudan and Ethiopia (Doggett and Prasada Rao, 1995).

The role of sorghum in the life of the Sudanese people is not to be dwelled upon unduly. Suffice it to know that the name sorghum in Sudan, "Esh", means life. In Sudan, sorghum is grown in an area ranging between 4.3 and 7.1 million ha with an average of 5.2 million ha, which accounts for 73% of the cropped area (Elzein and Elamin, 2006).The national average grain yield reported is about 600 kg ha^{-1} which is very low compared to the world average of 1.3-1.5 t ha^{-1} (Elzein *et al*., 2008 and FAOSTAT, 2014). The low productivity could be attributed, mainly, to farming systems which are pre-dominated by low-yielding traditional varieties, low-inputs in soils of poor fertility, drought poor management practices and prevalence of the root parasitic weed *Striga hermonthica* (Del.) Benth. (Ibrahim *et al*., 1995).

The *Striga spp*., as an endemic parasitic weeds in sub-Saharan Africa, was progressively increasing their geographic domain and level of infestation, and greatly reduce crop yield (Parker, 2009). *Striga* spp. was a major biotic constraint and a serious threat to subsistence cereal crops including pearl millet (*Pennisetum glaucum* (L.).R. Br), finger millet (*Eleusine coracana* L. Gaertn), sorghum, maize (*Zea mays* L.) and upland rice (*Oryza sativa* L.) grown in sub-Saharan Africa (Teka, 2014). The area infested by *Striga* in the African savannah is nearly 100 million hectares with annual losses of $US 7 billion, and about 300 million people were being affected (Ejeta, 2005). The *Striga* problem in Africa is aggravated by its exquisite adaptation to the environmental conditions of the semi-arid tropics, copious seeds production and prolonged longevity of the seeds. It has been reported that more than 20% of the area under sorghum in Sudan was infested by the parasite (Babiker, 2008).

To date, several control measures have been researched, but were mostly not successful, displayed spatiotemporal variability in performance and/or were mismatch to the prevalent low inputs production systems in vogue. Research has shown clearly that *Striga* manageement can only be achieved through integrated strategies with host plant resistance and/or tolerance as the back bone (Ejeta, 2007). Host-plant defense against *Striga* spp. constitutes two complementary mechanisms: resistance, the opposite of susceptibility, and tolerance, the opposite of sensitivity. Following the general definitions, resistance refers to the ability to reduce or prevent infection and reproduction, while tolerance refers to the ability to withstand infection with lower or minimum yield loss (Rodenburg and Bastiaans, 2011).

To-date five specific *Striga* resistance mechanisms, which include resistance associated with low germination stimulant (LGS) production, low production of the haustorial initiation factor (LHF), germination inhibitors (GI), hypersensitive response (HR), and the incompatible response (IR) to parasitic invasion of host genotypes, had been described (Ejeta and Butler 2000). Few *Striga* resistant varieties were identified; including SRN39, Framida, 555, ICSV006, ICSV007, SRN39 derivatives (P401- P409) and N13 (Ejeta, 2007). SRN39, Framida, 555, ICSVs and SRN39 derivatives (P401- P409) have low production of germination stimulants as the main mechanisim of resistance. Resistance in N13 is based on mechanical barriers, while that in SRA33 is based on low stimulant production, antibiosis and hypersensitivty (Belay, 2018). However, the identified resistant varieties are generally low yeilders and may lack adaptation to *Striga* infested areas (Ejeta, 2007). The present study was undertaken to transfer *Striga* resistance genes from several *Striga*-resistant lines into four elite Sudanese sorghum cultivars with the objective of obtaining high yield, good quality grains and reducing *S. hermonthica* infection and concomitantly reproduction.

Materials and Methods

Gene introgression was based on a series of backcrosses, performed to add *Striga* resistance from a donor parent to adapted Sudanese sorghum cultivars. The high yielding improved cultivars released by the Agricultural Research Corporation (ARC) were Wad Ahmed, Tabat, Butana and Arfagadamek-8 (AG-8), they selected as the recurrent parents for backcrossing. The cultivars have valuable agronomic characteristics, but lack resistance to *Striga*. The cultivars were use as maternal parents, while pollens were obtained from the resistant parents. The resistant parents, obtained from Professor Ejeta, G. Purdue University USA, were IS9830, 555, SAR33, Framida, N13, ICVS006, ICVS007, PQ-34, Brhan and SRN39 and its derivatives P401, P402 and P405. Crosses were made between each of the resistant male parents and each of their maternal congeners. The F_1 plants were backcrossed (BC_1F_1) to the recurrent cultivars to obtain BC_2F_1 families. The latter were subsequently salved for two successive generations to generate BC_2F_3 progenies to be used for the phenotyping procedure.

The trial was conducted in *Striga* sick plots, in which the infestation was augmented annually, during two consecutive seasons (2016/17 and 2017/18) at two sites constituting two irrigated environments and two rain-fed ones. The irrigated environments were at the Gezira Research Station Farm of the ARC, Wad Medani, Sudan, (Latitude 13 ^{0}30′ - 15 ^{0}15′ N and Longitude 30 ^{0}33′ E) where the soil is a vertisol with pH ranging from 7.8 to 8.5, organic matter, total nitrogen and available phosphorus are very low being 0.22%, 0.034% and 3-4 mg/kg, respectively (SSAS, 1983). The second site was Gedarif Research Station Farm of the ARC, at Tawareet (a village) located 75 km south of the Gedarif town (Latitude 13^{o} 44’ N, Longitude 35^{o} 77’ E) in the relatively wet Doka district, with a cumulative rainfall, measured in the field during the trials, of 957 mm. The soil is vertisolic, pH 7.4, low nitrogen content (0.027%), low organic carbon (0.58%) and low available phosphorus (4 mg kg^{-1}). A randomized Complete Block Design (RCBD) with four replicates was used to layout the trial. The crop was sown in the third week of July in each season. In the rain-fed experiments each genotype was sown in four rows of five-meter length each, with spacing of 80 cm between rows and 30 cm between hills. Under irrigation, sowing was done on ridges 80 cm apart and 30 cm between hills. Sorghum seedlings were thinned to three per hill three weeks after sowing. Nitrogen, in the form of urea, at a rate of 47.62 kg ha^{-1} was applied, one week after thinning. Weeds, other than *S. hermonthica*, were removed by hand when needed. Plots were irrigated at 14 days’ intervals in Wad Medani site. The data recorded for sorghum were days to 50% flowering, plant height, panicle exertion, panicle length, 100 grain biomass and grain yield. Data collected for *S. hermonthica* included counts made at 45-60 and 75 days after sowing (DAS), henceforth referred to as early and late season, respectively and biomass at harvest. In the whole experiment, assessments were made in the two central rows of each sub-plot with half a meter discarded from each side. All data were based on 4 m of row length except for days to 50% flowering, which was estimated in the entire sub-plot. Harvesting and threshing were performed by hand.

Crosses were identified as resistant, tolerant or susceptible on an arbitrary scale based on *Striga* emergence and grain yield relative to the respective check cultivar (maternal parent). Crosses were identified as resistant (*Striga* emergence less than that on the corresponding check), tolerant (*Striga* infection more than on the respective check and grain yield significantly higher than the check and the grand mean) or susceptible, where plant growth and yield were comparable to or less than those of the corresponding check.

Statistical Analysis

Data on sorghum grain yield, *S. hermonthica* counts and biomass were analyzed to estimate analysis of variance using Gene Stat 17.1.13780 software. Data on *Striga* emergence were transformed to $\sqrt{x} + 0.5$ prior to statistical analysis.

Results

Performance of sorghum genotypes under *Striga* infestation

Analysis of variance indicated highly significant differences ($P< 0.01$) for all agronomic characters including days to 50% flowering, plant height, panicle exertion, panicle length, 100-grain biomass, grain yield, *Striga* emergence, and biomass and number of capsules per plant among crosses, checks and environments. In this study only data on grain yield, *Striga* emergence and biomass are presented.

At Wad Medani the cultivar AG-8 obtained grain yield of 220.5 and 325 kg ha^{-1}, in the first and second seasons, respectively. The cross P405 x AG-8 scored lesser grain yield than the check in both seasons, albeit not significantly. The crosses N13 x AG-8, P401 x AG-8 and ICSV007 x AG-8 outyielded the check significantly and the attained yield increments were 98.3-106% and 82.3-84.2% in the first and second seasons, respectively. The crosses IS9830 x AG-8, 555 x AG-8, Framida x AG-8, SRN39 x AG-8, SAR33 x AG-8, P402 x AG-8 and Brhan x AG-8 showed grain yield increments of 366.4-529.2% and 214.6-385.4% in the first and second seasons, respectively (Table 1). The cultivar Butana exhibited grain yield of 181.0 and 263.5 kg ha^{-1}. All crosses with Butana obtained higher yields than the check. The cross P401 x BU attained a higher yield than the check in the first season, albeit not significantly, however, a significant yield increment (51.9%) was attained in the second season. The cross P402 x BU scored significantly higher grain yield than the respective check and the attained increment were 66.7 and 62.7%, in the first and second seasons, respectively. The crosses IS9830 x BU, PQ-34 x BU, Framida x BU, N13 x BU, ICSV006 x BU, ICSV007 x BU, SAR33 x BU and Brhan x BU showed grain yield increments of 473.6-698.0% and 293.7-414.8% in the first and second seasons, respectively (Table 1). The cultivar Tabat displayed grain yield of 53 and 80 kg ha^{-1} in the first and second season, respectively. All crosses obtained higher grain yield than the check (Table 1). In the first season the cross Framida x TA outyielded the check, albeit not significantly, however, a significant increase in yield (152.7%) was observed in the second season. The rest of the crosses however, scored significantly higher yield in both seasons. The crosses Brhan x TA, N13 x TA and ICSV007 x TA displayed grain yield increase of 369.7-418.3% and 347.3-473.1% above the check in the first and second seasons, respectively. The cross IS9830 x TA outyielded the check by 1375.5 and 1277.3% in the first and second seasons, respectively, while the crosses P405 x TA, ICSV006 x TA, SAR33 x TA and P402 x TA, showed yield increments of 1994.4-2515% and 1439.4-1897.8% in the first and second season respectively. Among the crosses Framida x TA and SAR33 x TA gave the lowest and highest yields, respectively (Table 1). The cultivar Wad Ahmed displayed grain yield of 303.5 and 435.0 kg ha^{-1} in the first and second seasons, respectively (Table 1). The crosses IS9830 x WA and P402 x WA affected yield significantly less than the check in both seasons. The cross ICSV007 x WA affected a significantly higher yield (594.2 kg ha^{-1}) than the check in the first season, but a significantly lesser yield (460.5 kg ha^{-1}) was attained in the second season. Conversely the crosses 555 x WA and ICSV007 x WA displayed significantly lesser grain yields (410 and 401 kg ha^{-1}, respectively) in the first season, but significantly higher yields (585 and 664.2 kg ha^{-1}) in the second season. The crosses PQ-34 x WA, P405 x WA, Framida x WA, N13 x WA, P401 x WA, SAR33 x WA and Brhan x WA exhibited significantly higher yields and the attained yield increments were 324.4-201.6% and 165.6-286.8% above the respective check in the first and second seasons, respectively. Differences in grain yield among crosses were highly significant (P<0.01%) (Table 1).

At Gedarif the cultivar AG-8 obtained grain yield of 484.4 and 539.1 kg ha^{-1} in the first and second season, respectively. The crosses, P405 x AG-8, N13 x AG-8, P401 x AG-8, affected significantly lesser yields than the check. ICSV007 x AG-8 affected grain yield comparable to the check. The crosses IS9830 x AG-8, 555 x AG-8, Framida x AG-8, SRN39 x AG-8, SAR33 x AG-8, P402 x AG-8 and Brhan x AG-8 showed grain yield increase of 94.1-151.1% above the respective check (Table 1). The cultivar Butana displayed grain yield of 197.9 and 307.3 kg ha^{-1} in the first and second season, respectively (Table 1). The crosses P401 x BU and P402 x BU affected, yields comparable to the check in both season. The crosses Framida x BU, ICSV007 x BU and Brhan x BU showed grain yield increments of 381.8-393.5% and 219.5-234.7% in the first and second seasons, respectively. The crosses IS9830 x BU, PQ-34 x BU, N13 x BU, ICSV006 x BU and SAR33 x BU showed grain yield increments of 416.8-527.6% and 230.9-318.6% in the first and second seasons, respectively (Table 1).

The cultivar Tabat displayed grain yield of 78.1 and 119.8 kg ha^{-1} in the first and second seasons, respectively (Table 1). Crosses with N13, Framida and Brhan affected comparable grain yield to the check in the first season, but a significant increase (117.4-310.9%) was achieved in the second seasons (Table 1). The cross ICSV007 x TA displayed a slight, albeit significant increase in grain yield in both seasons. Crosses with IS9830, P405, ICSV006, SAR33 and P402 obtained significantly higher grain yields and the attained increments were 1137.2-1237.1% and 730.4-782.6% in the first and second seasons, exceeding the respective check (Table 1).

The cultivar Wad Ahmed displayed grain yield of 421.9 and 751.8 in the first and second season, respectively. The crosses IS9830 x WA, 555 x WA, ICSV006 x WA, ICSV007 x WA and P402 x WA attained grain yield significantly lesser than the check in both seasons. The crosses PQ-34 x WA, P405 x WA, Framida x WA, N13 x WA, P401 x WA, SAR33 x WA and Brhan x WA displayed significantly higher grain yield and the attained yield increments were 138.9-233.3% and 34-113.0% above the respective check in the first and second seasons, respectively. Differences in grain yield among crosses were highly significant (P<0.01%) (Table 1).

Table.1. Influence of genotype and environment on sorghum grain yield (kg ha^{-1}) under *S. hermonthica* infestation at Wad Medani and Gedarif (seasons 2016/17 &2017/18)

Crosses	Wad Medani		Gedarif	
	2016/17	2017/18	2016/17	2017/18
IS9830 x AG-8	1028.5	1217.5	1085.9	1205.7
555 x AG-8	1048.2	1112.5	994.8	974.0
P405 x AG-8	196.8	260.0	184.9	302.1
Framida x AG-8	1280.2	1412.5	1099.0	1151.0
N13 x AG8	437.3	595.0	72.9	651.0
ICSV007x AG-8	453.8	592.5	423.4	565.1
SRN39 x AG-8	1092.2	1290.0	968.8	953.1
P401 x AG-8	443.8	565.0	166.7	656.2
SAR33 x AG-8	1355.2	1022.5	940.1	945.3
P402 x AG-8	1387.5	1577.5	1216.1	1205.7
Brhan x AG-8	1212.8	1455.0	1054.7	1007.8
IS9830 x BU	1310.5	1037.5	1020.8	1016.9
PQ-34 x BU	1444.5	1620.0	1070.3	1250.0
Framida x BU	1278.8	1070.0	953.1	1028.6
N13 x BU	1364.0	1562.5	1239.6	1221.4
ICSV006 x BU	1038.2	1237.5	1242.2	1286.5
ICSV007x BU	1244.2	1392.5	976.6	1020.8
P401 x BU	245.8	400.2	177.1	445.3
SAR33 x BU	1384.5	1566.8	1174.5	1145.8
P402 x BU	301.8	428.8	96.4	528.6
Brhan x BU	1340.8	1499.5	968.8	981.8
IS9830 x TA	789.8	1101.8	1031.3	1046.9
P405 x TA	1319.0	1441.5	981.8	1028.6
Framida x TA	127.8	202.2	153.6	260.4
N13 x TA	251.3	420.8	192.7	492.2
ICSV006 x TA	1185.0	1383.8	1044.3	1033.9
ICSV007 x TA	277.3	458.5	259.6	557.3
SAR33 x TA	1452.5	1598.2	966.1	994.8
P402 x TA	1120.5	1231.5	1023.4	1057.3
Brhan x TA	260.8	357.8	148.4	447.9
IS9830 x WA	191.5	272.2	338.5	437.5
555 x WA	410.0	585.0	91.1	427.1
PQ-34 x WA	1417.8	1603.2	987.0	1044.3
P405 x WA	1344.2	1501.5	1432.3	1601.6
Framida x WA	1288.0	1433.8	1005.2	1044.3
N13 x WA	1421.8	1155.5	1062.5	1013.0
ICSV006 x WA	401.0	664.2	247.4	841.1
ICSV007 x WA	594.2	460.5	277.9	583.3

Table.1. Continued

P401 x WA	1463.0	1598.8	1036.5	1158.9
SAR33 x WA	1514.5	1682.5	1289.1	1320.3
P402 x WA	198.8	322.8	216.1	440.1
Brhan x WA	1522.5	1641.8	1406.2	1208.3
AG-8	220.5	325.0	484.4	539.1
Wad Ahmed	303.5	435.0	421.9	751.8
Tabat	53.5	80.0	78.1	119.8
Buttana	181.0	263.5	197.9	307.3
Range	53.5-1522.5	80-1682.5	72.9-1432.3	119.8-1601.6
Mean	873.9	981.2	728.3	854.3
SE±	39.4	32.6	59.3	51.4
Sig. level	**	**	**	**
(C.V. %)	9.1	6.7	16.3	12.0

AG-8 = Arfa Gadamak-8, BU = Butana, TA = Tabat, WA = Wad Ahmed, ** = significant at the 0.01 probability level.

Striga attributes as influenced by genotype and environment

Emergence

At Wad Medani *Striga* emergence in both seasons, on the check cultivars, progressively increased with time and was maximal on Tabat (6-19 plants m^{-2}). For the crosses *Striga*, emergence ranged between 1-13 plants m^{-2} (Table 2). Early in the first season most of the crosses, except P401 x AG-8 and Framida x BU, sustained lower *Striga* emergence (1-3 plants m^{-2}) than the respective checks. The crosses P401 x AG-8 and Framida x BU supported the highest *Striga* emergence (12 and 11 plant m^{-2}, respectively) (Table 2). Late in the season the crosses P402 x AG-8, Framida x AG-8, P402 x BU, PQ-34 x BU, Brhan x BU, P402 x TA, SAR33 x TA, Framida x TA, Brhan x WA, Framida x WA, SAR33 x WA and PQ-34 x WA supported and maintained the lowest *Striga* emergence (2-5 plants m^{-2}), while Framida x BU, P401 x BU and N13 x WA supported the highest *Striga* emergence (8-15 plants m^{-2}). Early in the second season *Striga* emergence on the crosses was 0-13 plants m^{-2}. The crosses IS9830 x AG-8, 555 x AG-8, PQ-34 x BU, P402 x BU, ICSV006 x TA, SAR33 x TA, P402 x TA, P401 x WA and SAR33 x WA supported the least *Striga* emergence (0-4 plants m^{-2}), while P401 x AG-8, Brhan x BU, N13 x BU, IS9830 x TA, P405 x TA, ICSV007 x TA, P405 x TA and 555 x WA sustained the highest (8-13 plants m^{-2}). Late in the season *Striga*, emergence on the crosses ranged between 3 and 18 plants m^{-2}. The crosses Brhan x BU, PQ-34 x BU, SAR33 x TA, 555 x AG-8, P401 x WA and SAR33 x WA sustained the least (3-4 plants m^{-2}) *Striga* emergence, while N13 x AG-8, Framida x BU, ICSV006 x BU, SAR33 x TA and PQ-34 x WA sustained the highest *Striga* emergence (10-18 plants m^{-2}). Differences in *Striga*, emergence among crosses were highly significant ($P<0.1\%$) (Table 2).

At Gedarif, in the first season *Striga* emergence was lowest on AG-8 (1-4 plants m^{-2}), moderate on Wad Ahmed (2-7 plants m^{-2}), and highest on Tabat and Butana, (5-10 plants m^{-2}) (Table 3). For the crosses *Striga*, emergence early in the season ranged between 1-12 plants m^{-2} (Table 3). The crosses with AG-8 displayed *Striga*, emergence significantly higher than the check. All crosses with Butana, Tabat and Wad Ahmed displayed *Striga*, emergence comparable to the respective checks. Among all crosses the highest *Striga* emergence was observed on Framida x AG-8 (12 plants m^{-2}), while the lowest emergence (4 plants m^{-2}) was observed on PQ-34 x BU, P405 x TA, IS9830 x WA, 555 x WA, PQ-34 x WA and SAR33 x WA (Table 3). Late in the season *Striga*, emergence on the crosses ranged between 5 and 17 plants m^{-2}. Crosses with AG-8 displayed *Striga*, emergence significantly higher than the check. Crosses with Butana, Tabat and Wad Ahmed displayed *Striga*, emergence comparable to the respective checks. Among all crosses the highest *Striga* emergence was observed on P405 x AG-8 and Framida x AG-8 (17 plants m^{-2}), while the lowest emergence was observed on PQ-34 x BU and 555 x WA (5 plants m^{-2}) (Table 3). In the second season *Striga* emergence on the check cultivars was 2-5 plants m^{-2} on AG-8 and 2-4 plants m^{-2} on Wad Ahmed, 6-9 plants m^{-2} on Tabat and 3-9 plants m^{-2} on Butana (Table 3). Early in the season *Striga*, emergence on the crosses ranged between 1 and 17 plants m^{-2} (Table 4). The cross IS9830 x AG-8, ICSV006 x BU, SAR33 x TA, P402 x TA, Brhan x TA, ICSV006 x WA, ICSV007 x WA, P401 x WA and SAR33 x WA supported the least *Striga*, emergence (2-4 plants m^{-2}), while P405 x AG-8, SAR33 x BU, N13 x TA, 555 x WA and N13 x WA sustained the highest (6-17 plants m^{-2}) (Table 3). Late in the season *Striga* emergence on the crosses, ranged between 2 and 22 plants m^{-2}. Crosses with Butana, Wad Ahmed and most of those with AG-8 (90.9%) and Tabat (88.9%) upheld *Striga*, emergence comparable to the checks (Table 3). The crosses IS9830 x AG-8, ICSV006 x BU, Brhan x BU, IS9830 x TA, P405 x TA, Framida x TA, ICSV006 x TA, SAR33 x TA, P402 x TA, ICSV007 x WA and P401 x WA supported the least *Striga*, emergence (2-5 plants m^{-2}), while P405 x AG-8, IS9830 x BU, N13 x TA, ICSV007 x TA, Brhan x TA and Framida x WA sustained the highest (6-22 plants m^{-2}). Analysis of variance showed highly significant differences in *Striga* mergence among the crosses (Table 3).

Striga biomass

At Wad Medani *Striga* on the check cultivars, displayed a biomass of 36.7-64.3 and 42.0-85.8 g m^{-2} in the first season and second season, respectively (Table 2). For the crosses the *Striga* biomass was 12.1-64.5 g m^{-2}. All crosses with Wad Ahmed, Butana and most of those with Tabat (66.7%) and AG-8 (63.6%) supported *Striga* biomass comparable to the respective checks (Table 2) The crosses P405 x AG-8, 555 x AG-8, P402 x AG-8 Framida x AG-8, P402 x TA, SAR33 x TA and Framida x TA affected significant reductions (55.2-81.2%) in *Striga* biomass. In the second season *Striga*, on the crosses displayed a biomass of 12.3-73.8 g m^{-2} (Table 2). All crosses with Butana and those with AG-8 (9.1%), Tabat (55.6%) and Wad Ahmed (66.7%) sustained *Striga* biomass comparable to the check (Table 2). The crosses IS9830 x AG-8, 555 x AG-8, Framida x AG-8, SRN39 x AG-8, SAR33 x AG-8, P402 x AG-8, IS9830 x TA, ICSV006 x TA, SAR33 x TA, P402 x TA, 555 x WA, Framida x WA, P401 x WA and SAR33 x WA supported significantly lower biomass (42.0-85.7% of the respective check), while the crosses P401 x AG-8, ICSV006 x BU, ICSV007 x TA and P402 x WA sustained higher biomass (74.8-133.5% of the respective check). Differences in *Striga* biomass among crosses were highly significant ($P<0.1\%$) (Table 2).

At Gedarif *Striga* biomass was 5.1-22.2 g m^{-2} in the first season and 30.5-68.5 g m^{-2} in the second season (Table 3). For the crosses the *Striga* biomass ranged between 6.6 and 37.0 g m^{-2} (Table 3). In the first season crosses with AG-8, and those with Butana (70%), Tabat (44.4%) and Wad Ahmed (83.3%) supported higher *Striga* biomass than the checks, albeit differences were often not significant. The crosses P402 x AG-8, PQ-34 x BU, SAR33 x TA, SAR33 x WA and Brhan x WA supported the lowest biomass (6.2-15.3 g m^{-2}). Conversely the crosses ICSV007 x AG-8, N13 x BU, Brhan x TA and Framida x WA supported the highest biomass (18.6-37 g m-^{2}) (Table 3). In the second season *Striga*, on the crosses, displayed a biomass of 18.0-89.2 g m^{-2} (Table 3). Crosses with AG-8, Butana, Wad Ahmed and those with Tabat (77.8%) supported *Striga* biomass comparable to the respective check (Table 3). The crosses ICSV006 x BU, P401 x BU, SAR33 x BU, N13 x TA, SAR33 x TA and P402 x TA supported the lowest biomass (26.2-58.7% of the respective checks), while their congeners 555 x AG-8, 555 x WA, ICSV007 x WA and P401 x WA supported the highest (92.4-200.7% of the respective check). Differences in *Striga* biomass among crosses were highly significant (P<0.1%) (Table 3).

Table.2. *Striga hermonthica* emergence and biomass at Wad Medani (seasons 2016/17 & 2017/18)

Crosses	Days after owing (DAS)						***S.* biomass (g m^2)**	
	45		**60**		**75**			
	2016	2017	2016	2017	2016	2017	2016	2017
IS9830 x AG-8	1.9(4)	1.0(1)	2(5)	1.8(4)	2.6(7)	2.3(5)	28.0	17.3
555 x AG-8	1.1(2)	1.1(1)	2.0(4)	1.6(3)	2.2(5)	2.0(4)	14.4	15.8
P405 x AG-8	1.8(3)	1.1(1)	2.2(5)	1.7(4)	2.7(7)	2.6(7)	13.2	33.5
Framida xAG-8	1.3(2)	0.8(1)	1.6(3)	1.8(4)	2.0(4)	2.3(5)	19.0	22.3
N13 x AG8	1.8(5)	2. (5)	2.0(6)	2.5(8)	2.6(8)	3.7(18)	22.6	32.5
ICSV007xAG-8	1.2(2)	1.4(2)	1.8(3)	2.3(6)	2.4(6)	2.9(8)	27.5	33.3
SRN39 x AG-8	1.2(2)	1.2 (2)	1.9(4)	1.8(4)	2.3(6)	2.5(7)	26.3	20.5
P401 x AG-8	3.3(11)	2.8(8)	3.3(12)	3.5(13)	3.8(15)	4.0(17)	64.5	73.8
SAR33 x AG-8	1.2(2)	1.0(1)	1.6(3)	1.8(4)	2.3(7)	2.4(6)	23.7	18.8
P402 x AG-8	1.0(2)	1.0(1)	1.4(2)	1.6(4)	2.0(4)	2.4(6)	18.2	18.0
Brhan x AG-8	1.9(4)	1.6(3)	2.4(6)	2.4(7)	2.8(8)	2.8(8)	24.1	32.5
IS9830 x BU	2.1(6)	1.7(3)	2.4(8)	2.2(7)	2.6(8)	3.0(9)	39.7	38.5
PQ-34 x BU	1.5(2)	0.8(1)	1.8(3)	1.6 (3)	2.3(5)	2.0(4)	21.5	14.5
Framida x BU	3.4(12)	1.0(1)	3.4(13)	2.2(6)	3.9(15)	3.0(10)	24.5	35.3
N13 x BU	2.0(5)	1.6(3)	2.2(6)	2.2(8)	2.6(7)	3.0(9)	28.5	44.8
ICSV006 x BU	2.4(7)	2.0(4)	2.7(8)	2.6(5)	3.0(10)	3.0(10)	43.0	46.3
ICSV007x BU	1.8(4)	1.5(2)	1.9(5)	2.0(7)	2.2(6)	2.5(7)	33.0	24.3
P401 x BU	1.9(4)	1.6(3)	2.3(6)	2.3(5)	2.6(7)	2.9(8)	42.5	37.3
SAR33 x BU	2.0(4)	1.6(3)	2.2(5)	2.0(5)	2.6(7)	2.7(7)	33.8	37.3
P402 x BU	0.8(1)	1.3(2)	1.5(2)	1.8(3)	2.0(4)	2.5(7)	31.6	30.8
Brhan x BU	1.6(3)	1.0(1)	1.7(4)	1.7(8)	2.0(5)	2.0(4)	27.2	15.3

IS9830 x TA	2.0(6)	1.7(5)	2.1(6)	2.5(9)	2.6(8)	3.2(11)	39.2	49.8
P405 x TA	1.9(5)	2.0(5)	2.4(6)	2.5(9)	2.6(8)	3.0(10)	35.9	51.5
Framida x TA	1.4(2)	2.0(4)	1.8(3)	2.8(8)	2.2(5)	3.4(12)	28.7	59.3
N13 x TA	1.6(3)	1.6(3)	2.1(5)	2.6(4)	2.7(8)	3.3(11)	43.5	54.8
ICSV006 x TA	1.7(4)	1.1(2)	2.1(6)	1.3(2)	2.8(9)	2.3(6)	33.7	18.3
ICSV007 x TA	1.5(3)	2.2(5)	1.8(4)	2.9(9)	2.3(7)	3.4(12)	38.2	64.2
SAR33 x TA	1.0(2)	1.0(1)	1.0(2)	1.3(3)	1.3(2)	1.7(4)	12.1	14.3
P402 x TA	1.5(3)	1.0(1)	1.6(3)	1.4(3)	1.8(4)	2.0(5)	19.0	12.3
Brhan x TA	1.7(4)	2.2(5)	2.2(6)	2.8(7)	2.9(9)	3.4(12)	39.9	54.5
IS9830 x WA	2.2(5)	1.9(4)	2.4(6)	2.5(6)	2.7(7)	2.9(9)	39.2	45.8
555 x WA	2.2(6)	1.7(3)	2.4(7)	2.4(8)	2.7(8)	2.9(9)	20.6	27.5
PQ-34 x WA	0.9(1)	1.7(3)	1.4(2)	2.2(5)	1.7(3)	2.9(10)	15.5	37.8
P405 x WA	2.4 (7)	1.4(3)	2.5 (8)	2.0(5)	2.7(9)	2.7(8)	40.2	40.3
Framida x WA	1.3(2)	1.0(1)	1.9(4)	2.0(6)	2.2(5)	2.6(7)	24.6	24.5
N13 x WA	2.4(8)	1.6(3)	3.2(12)	2.3(6)	3.5(14)	2.7(8)	45.6	38.8
ICSV006 x WA	1.8(3)	2.0(4)	2.3(5)	2.4(7)	2.6(7)	3.0(9)	31.8	42.5
ICSV007 x WA	1.8(4)	1.6(3)	2.3(6)	2.5(2)	2.7(8)	3.0(9)	42.5	43.8
P401 x WA	1.5(3)	0.7(0)	2.0(5)	1.2(3)	2.3(6)	1.8(3)	29.7	19.0
SAR33 x WA	1.1(2)	0.7(0)	1.6(2)	1.6(3)	1.9(4)	2.1(4)	18.0	20.5
P402 x WA	1.8(4)	1.5(2)	2.3(5)	2.5(7)	2.5(7)	2.9(8)	39.7	52.3
Brhan x WA	1.2(2)	1.6(3)	1.7(3)	2.0(4)	2.1(5)	2.9(8)	21.0	40.5
AG-8	2.5(8)	2.2(5)	3.0(10)	2.9(9)	3.5(13)	3.4(12)	55.0	55.3
Wad Ahmed	1.8(3)	2.3(5)	2.3(5)	3.0(10)	2.6(7)	3.7(13)	36.7	62.8
Tabat	2.5(6)	2.3(8)	3.2(10)	3.7(15)	3.9(15)	4.4(19)	64.3	85.8
Buttana	1.8(3)	2.4(6)	2.4(6)	3.4(12)	3.0(9)	3.9(15)	39.7	42.0
Range	1-12	0 - 8	2-13	2-15	2-15	3-19	12.1-64.5	12.3-85.8
Mean	1.7	1.5	2.1	2.2	2.5	2.8	31.8	36.9
SE±	0.46	0.33	0.45	0.4	0.42	0.4	11.53	10.9
Sig. level	N.S	**	N.S	**	*	**	N.S	**
(C.V. %)	53.7	42.8	43.0	33.9	33.5	28.4	72.6	59.1

Data in parenthesis is the actual. AG-8 = Arfa Gadamak-8, BU = Butana, TA = Tabat, WA = Wad Ahmed, * and ** = significant at the 0.05 and 0.01 probability level, respectively.

Table.3. *Striga hermonthica* emergence and biomass at Gedarif (seasons 2016/17& 2017/18)

Crosses	**Days after owing (DAS)**						***S.* biomass (g m^2)**	
	45		**60**		**75**			
	2016	2017	2016	2017	2016	2017	2016	2017
IS9830 x AG-8	2.4(6)	1.8(3)	3.1(10)	2.0 (4)	3.7(15)	2.1(5)	32.3	50.0
555 x AG-8	2.6(7)	2.3 (6)	3.2(11)	3.0(12)	3.8(15)	3.5(16)	34.9	89.2
P405 x AG-8	2.3(6)	2.8(10)	3.2(11)	3.8(17)	3.9(17)	4.2(22)	32.9	86.5
Framida xAG-8	2.6(7)	2.0 (5)	3.4(12)	2.4 (6)	3.9(17)	2.9(10)	34.6	73.2
N13 x AG8	1.8(4)	1.9 (4)	2.8(9)	2.4 (6)	3.4(14)	2.8(9)	16.8	71.7
ICSV007xAG-8	2.3(5)	2.5 (7)	2.9(9)	3.0(10)	3.6(14)	3.2(11)	35.4	71.0
SRN39 x AG-8	2.1(4)	2.0 (4)	2.9(9)	2.5 (7)	3.2(11)	2.9(9)	20.7	86.2
P401 x AG-8	1.7(3)	2.6 (8)	2.4(6)	3.0(10)	2.8(9)	3.4(13)	19.6	73.2
SAR33 x AG-8	2.2(5)	2.1(5)	2.9(9)	2.8 (8)	3.3(11)	3.2(10)	23.1	62.0
P402 x AG-8	1.9(4)	2.4 (7)	2.7(8)	2.8 (9)	3.2(11)	3.0(10)	10.2	88.5
Brhan x AG-8	2.3(5)	2.2 (5)	2.6(7)	2.7 (8)	3.1(10)	3.0(10)	28.4	58.7
IS9830 x BU	1.8(4)	1.6 (3)	2.6(7)	2.2 (6)	3.0(10)	2.6(9)	17.5	60.5
PQ-34 x BU	1.4(2)	1.7 (3)	1.9(4)	2.0 (4)	2.2(5)	2.3(8)	9.7	48.0
Framida x BU	2.1(5)	1.9 (4)	2.6(7)	2.4 (6)	3.1(10)	2.7(5)	28.1	48.0
N13 x BU	2.1(5)	1.8 (3)	2.7(7)	2.0 (4)	3.2(11)	2.3(8)	37.0	38.0
ICSV006 x BU	2.1(6)	1.3 (2)	2.7(8)	1.7 (3)	3.1(11)	1.7(5)	24.9	35.5
ICSV007x BU	1.9(4)	1.6 (3)	2.6(7)	2.0 (4)	3.0(10)	2.0(3)	22.1	40.5
P401 x BU	2.7(8)	1.5 (2)	3.1(10)	1.8 (4)	3.5(13)	1.8(4)	34.1	33.0
SAR33 x BU	2.5(7)	2.1 (6)	3.0(10)	2.4 (7)	3.5(15)	2.5(4)	28.5	37.7
P402 x BU	1.7(4)	2.0 (5)	2.7(8)	2.3 (6)	3.0(10)	2.5(7)	26.9	51.2
Brhan x BU	1.9(4)	1.5 (2)	2.3(6)	2.0 (4)	2.9(9)	2.0(3)	34.5	37.5
IS9830 x TA	2.6(7)	1.2 (1)	2.7(7)	1.8(3)	3.0(9)	2.0(3)	31.7	38.0
P405 x TA	1.7(3)	1.3 (2)	2.0(4)	1.8 (3)	2.4(6)	1.9(3)	18.9	57.7
Framida x TA	1.7(2)	1.9 (6)	2.4(5)	2.2 (3)	2.9(9)	2.3(3)	26.0	51.0
N13 x TA	1.5(2)	1.5 (3)	2.1(5)	1.6 (7)	2.5(7)	1.8(6)	10.1	24.7
ICSV006 x TA	1.9(3)	1.6 (3)	2.3(5)	2.2 (3)	2.6(7)	2.4(3)	14.3	37.2
ICSV007 x TA	2.0(4)	1.2 (1)	2.4(5)	1.5 (6)	2.7(7)	1.8(6)	13.9	42.2
SAR33 x TA	1.6(3)	1.0 (1)	2.0(6)	1.2 (2)	2.2(6)	1.2(3)	9.6	18.0
Brhan x TA	2.1(3)	1.3(2)	2.8(8)	1.7(2)	3.2(11)	1.7(6)	33.9	46.5
IS9830 x WA	1.7(2)	1.9(4)	2.1(4)	2.4(3)	2.4(6)	2.5(6)	9.2	58.0

555 x WA	1.3(1)	1.5(3)	2.0(4)	1.8(6)	2.3(5)	1.9(4)	8.8	61.2
PQ-34 x WA	1.1(3)	1.7(3)	2.0(4)	1.9(3)	2.4(6)	1.9(4)	8.7	34.5
P405 x WA	1.6(4)	1.4(2)	2.2(5)	1.6(3)	2.3(6)	1.7(3)	8.7	43.0
Framida x WA	1.9(4)	2.0(5)	2.5(6)	2.5(5)	2.7(7)	2.8(9)	18.6	53.7
N13 x WA	1.8(4)	1.9(3)	2.4(6)	2.2(6)	2.7(8)	2.5(6)	14.3	53.2
ICSV006 x WA	1.7(3)	1.8(4)	2.2(5)	2.1(2)	2.6(7)	2.2(6)	8.7	46.2
ICSV007 x WA	1.7(3)	1.1(1)	2.2(5)	1.6(2)	2.5(6)	1.6(2)	8.5	29.5
P401 x WA	1.7(3)	1.0(1)	2.3(5)	1.3(2)	2.7(7)	1.3(2)	15.3	28.2
SAR33 x WA	1.3(2)	1.4(2)	2.0(4)	1.6(2)	2.5(6)	1.8(3)	6.2	43.0
P402 x WA	2.2(5)	1.4(2)	2.2(6)	2.0(5)	2.5(7)	2.3(6)	17.9	30.7
Brhan x WA	1.7(4)	1.6(3)	2.0(5)	1.8(3)	2.3(6)	1.9(3)	6.6	43.0
AG-8	0.8(1)	1.2(2)	1.6(3)	2.0(4)	1.9(4)	2.2(5)	5.1	59.2
Wad Ahmed	1.3(2)	1.5(2)	2.3(5)	1.8(3)	2.7(7)	2.0(4)	6.7	30.5
Tabat	2.1(5)	2.5(6)	2.7(8)	2.7(7)	3.1(10)	3.0(9)	17.6	68.5
Buttana	2.2(5)	1.9(3)	2.7(7)	2.5(6)	3.1(10)	3.0(9)	22.2	64.2
Range	1-8	1-10	3-12	1-17	4-17	2-22	5.1-37.0	18.0-89.2
Mean	1.9	1.7	2.5	2.1	2.9	2.3	19.7	50.8
SE±	0.37	0.38	0.35	0.43	0.40	0.52	7.61	14.48
Sig. level	N.S	N.S	N.S	*	*	*	**	*
(C.V. %)	40.1	43.6	28.8	40.4	27.9	44.8	77.4	57.1

Data in parenthesis is the actual. AG-8 = Arfa Gadamak-8, BU = Butana, TA = Tabat, WA = Wad Ahmed, * and ** = significant at the 0.05 and 0.01 probability level, respectively.

Discussion

The results in this study revealed that the check cultivars displayed very low grain yield in *Striga*-infested areas in comparison to their yields in *Striga*-free areas. Among the cultivars Wad Ahmed was the highest yielder (303.5-751 kg ha^{-1}), followed in descending order by AG-8 (201.5-539.1 kg ha^{-1}), Butana (181-307.3 kg ha^{-1}) and Tabat (53-119.8 kg ha^{-1}). The relatively high yield of Wad Ahmed and the very low yield of Tabat were consistent with the reported tolerance of the former and high susceptibility of the latter to the parasite (Yoneyama *et al.*, 2012 and Mohamed *et al.*, 2018).

The results further showed large variations between crosses in *Striga* infection and biomass as well as the impact of the infection on grain yield. Based on *Striga* emergence and sorghum grain yield several crosses (35.7% of the total) displayed some degree of resistance to the parasite across the four environments, while others (54.8%) showed resistance only under irrigation. The level of resistance as indicated by reductions in *S. hermonthica* emergence varied from very low (12%) to high (89%). Average grain yield varied from non-significant to very high (>25-fold) in case of Tabat the most susceptible cultivar. It is noteworthy that grain yield of the crosses in the irrigated environment, was highly and negatively correlated with *S. hermonthica* emergence at 75 DAS (r = -0.711) and biomass (r = -0.685). However, in the rain-fed environments grain yield showed low, inconsistent and often non-significant correlations with *Striga* emergence (r = -0.018ns and -0.222ns) and biomass (r = 0.003ns and -0.179ns). *Striga* biomass, showed positive correlation with *Striga* emergence. The notable differential relations of sorghum grain yield and *Striga* emergence and biomass between the irrigated and rain-fed environments indicate that the infection *per se* is more important than degree of infection in the rain-fed environment. The importance of infection rather than the degree of infection this may be attributed to involvement of different factors, possibly differential nutrients availability and/or drought stress associated with rain-fall amount and frequency, in determining the relationship between the parasite and its host. *Striga* is known to thrive best and be more debilitating under fitful rains than under irrigation (Ogborn 1972). Differential availability of nutrients is conducive to differential exudation of *Striga* germination stimulants (Yoneyama *et al.*, 2012). Further, drought and *Striga* infection are reported to increase abscisic acid (ABA) levels in planta (Gallé *et al.,* 2019). Increased ABA level decreases stomatal conductance in the host, but not the parasite and thus promotes diversion of nutrients and carbon form the host to the parasite (Taylor *et al.*, 1996). Further decreased stomatal conductance and the attended reduction of CO_2 uptake promote over production of reactive oxygen species (ROS) (Gallé *et al.*, 2019). The nutrients stress coupled with oxidative stress, engendered by over production of ROS, may account for the notable loss in yield of the *Striga*-susceptible check cultivars and crosses. However, the plausibility of involvement of *Striga* injected toxins in the parasite syndrome as proposed by several authors (Musselman, 1980, Runo and Kuria, 2018), without experimental evidence (Taylor *et al.*, 1996; Runo and Kuria, 2018), cannot be ruled out.

Crosses made between the resistant genotypes PQ-34, N13, ICSV007, SAR33, P402 and Brhan with Butana, SAR33, P402, IS9830, ICSV006, P405 with Tabat and SAR33, Framida, PQ-34 and P401 with Wad Ahmed each sustained low *Striga* emergence than the respective check across the 4 environments. Low sustenance of *Striga* emergence coupled with high yield indicates resistance and/or tolerance. However, with the exception of crosses made with SAR33, irrespective of the maternal parent, none of the crosses showed resistant across the four environments. Further, it is notable that none of the crosses with AG-8 showed low *Striga* emergence across the 4 environments. The crosses 1S9830 x AG-8, Framida x AG-8, SRN39 x AG-8, SAR33 x AG-8, P402 x AG-8 and Brhan x AG-8, each, sustained low *S. hermonthica* emergence under irrigation, but invariably supported high emergence of the parasite, but maintained high yield in the rain-fed environments. Conversely the check cultivars supported lower *Striga* emergence in the rain-fed environments and displayed low yields. High *Striga* emergence coupled with high yield indicate(s) tolerance, while low *Striga* emergence coupled with low yield indicate(s) sensitivity to the parasite (Rodenburg and Bastiaans 2011). However, involvement of differential seed bank size in the differential response cannot be ruled out. A large seed bank size may increase infection to a level that curtails emergence on a susceptible host, but not on its resistance congener.

All crosses showing resistance across the four environments displayed high grain yield (940.1-1641.8 kg ha^{-1}) across the four environments in comparison to the maternal parents which exhibited low yields across the environments (53.5-751.6 kg ha^{-1}). Based on variable sustenance of *Striga* emergence among the crosses, identified as high yielders, indicate that resistance alone may not account for the attained high yields and suggest participation of tolerance as a complementary defense mechanism.

The study revealed the successful generation of high yielding crosses endowed with resistance/tolerance to *S. hermonthica* across environments within both the irrigated and the rain-fed sectors in the Sudan. The generated crosses have the potential to be deployed as part of a strategy for *Striga* management. However, several studies including determination of grain quality, farmers and consumer's preference(s), the mechanisms of resistance and tolerance to the parasite and the genes involved together with yield adaptability and stability in *Striga*-free and infested areas need to be undertaken prior to release of the crosses for commercial production.

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مقاومة و تحمل الذرة لطفيل البودا: نتاج تداخل عوامل داخلية و خارجية

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المستخلص

أجريت الدراسة في موقعين موبوأين بطفيل البودا لموسمين 17/2016 و 18/2017 ، باجمالى اربع بيئات شملت القطاع المروى (محطة بحوث الجزيرة ود مدنى) و المطرى (محطة بحوث القضارف). بهدف نقل صفات المقاومة من سلالات مقاومة لطفيل البودا (IS9830, 555, SAR33, Framida, N13, ICSV006, ICSV007, PQ-34, Brhan and SRN39, and its derivatives P401, P402 and P405,) الى اصناف سودانية (مجازة هى) ود احمد، طابت، بطانة و ارفع قدمك كأباء رجعية وهى أصناف ذات انتاجية عالية و مفضلة لدى المزارعين فقط تنقصها مقاومة الطفيل. ثم التزاوج بين هذه الأصساف والاصناف المقاومة للحصول على نباتات الجيل الأول ثم تبع ذالك سلسلة من التهجين الرجعى و التلقيح الذاتى حتى الوصول الى نباتات الجيل الثالث التهجين الرجعى الثانى. التى قيمت باستخدام تصميم القطاعات الكاملة العشوائية باربعة مكررات. شملت الدراسة الانتاجية بالهكتار بالنسبة للذرة، عدد نباتات طفيل البودا و الوزن الجاف للطفيل. اظهرت نتائج التحليل الاحصائي ان هنالك فروقا معنويه عالية بين الهجن و الأباء لكل الصفات التي تمت دراستها. اظهرت نتائج التحليل الاحصائي ان هنالك فروقا معنويه عالية بين الهجن و الاباء لعدد نباتات الطفيل لوحظ اتساع مدى ظهور نباتات البودا من 2- 15 و 3- 19 فى ود مدنى و 4 - 17 و 2 - 22 فى جنوب القضارف فى الموسمين على التوالى مما يشير الى وجود مستويات متباينة من المقاومة للطفيل. أوضحت الدراسة ان العديد من الهجن(35.7%) اظهر درجات مختلفة من المقاومة للطفيل فى كل البيئات؛ و البعض الاخر (54.8%) اظهر مقاومة فقط فى البيئات المروية و تحمل فى البيئات المطرية. تفاوتت مستويات المقاومة بين منخفض (12%) و عال (89%) حسب معدل ظهور الطفيل. كما لوحظ ان هناك ارتباط معنوياً وسلبياً بين الإنتاجية و عدد نباتات الطفيل والوزن الجاف للطفيل فى ود مدنى- (r = -0.711 and 0.685, P≤0.001)، بينما كان سلبياً و غير معنوياً فى جنوب القضارف. اوضحت الدراسة وجود مشترك لمقاومة و تحمل الطفيل تتاثر بتداخل عوامل داخلية و خارجية مرتبطة بتفاعلات الهجين، الطفيل و البيئة.