

Multi Location Field Evaluation of BC₁F₂ Sorghum Populations for Striga Resistance in Niger

Ousseini Ardaly Abdou^{1,2}, Aissata Mamadou Ibrahim², Yaw Eleblu John Saviour¹, Ofori Kwadwo¹, Ousmane Zakari Moussa³

¹School of Basic and Applied Sciences, College of Agriculture, University of Ghana, West African Centre of Crop Improvement (WACCI), Accra, Ghana

²Département Cultures pluviales, Institut National de la Recherche Agronomique du Niger (INRAN), Niamey, Niger

³Département des Productions Végétales, Université Abdou Moumouni (UAM) de Niamey, Niamey, Niger

Email: o.zakari@gmail.com

How to cite this paper: Ardaly Abdou, O., Ibrahim, A.M., Saviour, Y.E.J., Kwadwo, O. and Moussa, O.Z. (2024) Multi Location Field Evaluation of BC₁F₂ Sorghum Populations for Striga Resistance in Niger. *American Journal of Plant Sciences*, 15, 1010-1021. <https://doi.org/10.4236/ajps.2024.1510064>

Received: May 23, 2024

Accepted: October 26, 2024

Published: October 29, 2024

Copyright © 2024 by author(s) and Scientific Research Publishing Inc. This work is licensed under the Creative Commons Attribution International License (CC BY 4.0).

<http://creativecommons.org/licenses/by/4.0/>



Open Access

Abstract

In Niger, a landlocked country, sorghum is the second staple food cultivated over the country by smallholder farmer. The crop is important for human and animal consumption. Despite its importance, the crop is affected by biotic and abiotic constraints. Among those constraints, striga has a high impact on yield. In fact, to survive, farmers are growing their local preferred sorghum varieties which is highly sensible to the weed. Striga management is a challenge that requires a permanent solution. In addition, the development of high-yielding Striga resistant genotypes will be appreciated by farmers. The development of striga resistance will be based on the breeding population performances under farmer's diverse environmental conditions adaptation. The main objective of this study is to evaluate two breeding populations for striga resistance in two different environments at Boulke and Dibissou in Tahoua region, to identify the early and high-yielding striga tolerant genotypes under natural infestation.

Keywords

Striga Resistance, Sorghum, Breeding Population, Multi Environment

1. Introduction

Striga hermonthica (Del.) Benth is one of the most ubiquitous parasitic witchweed of cereal crops [1]-[3]. This parasitic flowering weed is an outcrossing species widely distributed in the savannah ecologies of West and Central Africa [4], where it causes serious damage to crop production. To germinate from the soil the

Striga seed should be in good agronomic condition. These conditions require humidity (20%), specific temperature (between 25°C and 42.5°C) and specific hormones, strigolactones, essential for the germination [5]. When all the required conditions are present, the seed will not germinate without that hormone. Strigolactone is produced by the sorghum crop by symbiotic arbuscular mycorrhizal fungi for nutrient supplied [6]. It is also well noted that infested areas by striga are generally characterized by poor soil fertility and the insufficient use of fertilizer [7].

In Niger, striga largely affects sorghum production areas, including Maradi, Tahoua, Zinder and a small part of Dosso region [8]. Striga control is a big challenge and requires an efficient and effective strategy that is cost-effective, accessible and profitable to smallholder, medium and large-scale farmers. Several control methods have been proposed to reduce striga incidence. These includes the utilization of ethylene, nitrogen fertilizer application, trap crops, utilization of chemical stimulant, hand pulling, Gamma Irradiation [9], herbicides and sesame seed [10]. Some of these methods are effective but not accessible by poor farmers [11] [12]. Meanwhile, to survive, farmers deal with their preferred local landraces that are highly susceptible to striga. However, in their field's, striga management still a challenge and durable solution is required. In addition, selection of high-yielding striga resistant genotypes will be appreciated by them [13] [14]. So, selection of high yielding striga resistant sorghum genotypes is based on the breeding population performances under farmer's diverse environmental conditions adaptation [15].

The objective of this study is to evaluate two breeding populations for striga resistance in two different environments at Boulke and Dibissou in Tahoua region, to identify the early and high-yielding striga tolerant genotypes under natural infestation.

2. Materials and Methods

2.1. Experimental Site Location and Materials

The field trials were conducted in Tahoua region (L: 5° 15'00"; L: 13° 48'00") at Boulke (L: 005° 18', 135; l: 13° 48', 424) and Dibissou (L: 005° 14', 234; l: 13° 50', 522) historically highly infested by the weed. The trials villages are located in Tahoua region, especially in Konni. The first village Dibissou is located in the south part of Konni, whereas the second village Boulke is located in the Northwest part of Konni. Konni is located 417 km in the eastern part of Niger, where it rains 500 to 600 mm per year [16].

2.2. Development of Breeding Generations

To generate the F₁ hybrids four parental lines, including F2-20 (P1), Mota Maradi (P2), P9401 (P3), and El tsedaoua (P4), were crossed in a North Carolina design II where P1 and P3 are striga resistant lines and P2, P4 are farmers preferred varieties. To generate the F₁ hybrid, two sowing date were made. The fourth lines flowered at different dates. Mota Maradi and El tsedaoua flowers at 70 days after the

sowing, and P9401, F2-20 75 to 80 days after the sowing. The resistant's lines were used as male and the susceptible as female. For P9401 and El tsedaoua crossing, El tsedaoua was emasculated using plastic bags technics in the light to remove the others to prevent self-pollination. After the maturity, the panicles of each cross were cut and threshed separately. The obtained seeds were then conserved in labelled envelopes.

For P1 and P2 F1 hybrids, only one sowing row was obtained. For P3 and P4 two lines were obtained. The above parental lines were sowed and the F1 hybrids were used to develop the backcrosses population. Firstly, the F2-20 X Mota Maradi and P9401XElsedaoua F1 hybrids were emasculated using plastic bag technics, and pollens grains were collected from their respective recurrent covered parental lines Mota Maradi and Eltsedaoua to develop the BC₁F₁ populations respectively. The obtained BC₁F₁s were then selfed to produce the BC₁F₂ populations.

Thus, the main objectives of the experiment were to assess those two breeding populations in the light to identify early and high-yielding striga tolerant sorghum genotype under natural infestation in Niger (**Table 1**).

Table 1. Origin of the genotypes used in the crosses.

Crosses	Parent Name	Characteristics	Origin	Breeding Population
Cross1	F2-20	Striga resistant	Senegal	-BC₁F₂ (F2-20XMota Maradi)
	Mota maradi	Land race	Niger	
Cross 2	P9401	Striga resistant	USA	-BC₁F₂ (P9401XElsedaoua)
	El tsedaoua	Land race	Niger	

3. Data Collection and Statistical Analysis

The data's collections in the trials were focused on the assessed parameters, including the following items:

- Sorghum plant germination percentage (Plant vigor): The number of germinated plants after two weeks of sowing.
- The 50% flowering (Flo): The days from the sowing to when the plants start flowering.
- Number of striga plant at 45 days (NS45).
- Number of striga plant at 60 days (NS60).
- Number of striga plant at 90 days (NS90).
- The plant height (HTR): It is measured using graduate ruler (0 - 3 m).
- Number of panicles harvested (NPANI).
- Number of hole obtain (N).
- 1000 grains weight.
- Grain yield estimation.

After the harvest, the recorded data's were analyzed using SAS, XLSAT 2019, and GenStat 15th program to perform a normality test, ANOVA test, correlation studies and a principal component analysis (PCA).

4. Results

4.1. Variability among Striga and Sorghum Traits

Most of the traits were significantly ($p < 0.05$) different (**Table 2**). The genotype by environment interaction of the two sites, Dibissou and Boulke were not significant, and hence differences in performance of genotypes were consistent across the two environments.

Table 2. Mean squares for grain productivity, yield attributes and striga resistance traits under natural field infestation at Boulke and Dibissou, Niger.

Source of variation	Mean Square (MS)											
	DF	Vig	EMR	NS45	NS60	NS90	NPSORG	Flo	HTR	NPANI	POIGR	Yield
Genotypes	5	0.41ns	452.37ns	45.18ns	72.53*	85.92*	38.52 *	33.26ns	4482.73*	146.89*	19.12*	14067.90*
GXE interaction	5	0.16 *	26.42ns	Ns	ns	Ns	1.02ns	11.12*	53.86ns	42.65ns	3.69ns	4028.31ns
Error	14	0.23	341.85	27.04	30.92	35.60	8.29	13.50	572.47	56.93	6.88	5454.01

EMR = striga emergency; Flo = 50% flowering date; HTR = Plant height; NPANI = Panicles number; NPSorg = Hole number; NS45 = Number of striga plants at 45 days after planting date; NS60 = Number of striga plants at 60 days after planting date; NS90 = Number of striga plants at 90 days after planting date; PoiGR = 1000 grain weight; Vig = Plant vigor; Yield = grain yield Kg/ha; ns = non-significant; GXE = Genotype by environment.

4.2. Association between Striga and Sorghum Parameters

To perform, the correlation study between the sorghum and striga parameters, a log10 transformation was made using Excel. As a result, the transformed data's were used to determine the different correlation. Thus, among the variables used, several significant correlations were found. Concerning the plant vigor (Vg), a negative correlation followed by two positive correlations were respectively observed with the 50% flowering date (Flo), the number of panicles (NPANI) and the grain yield, at -67.2% , 67.3% , and 67.1% (**Table 3**). For the striga emergency (EMR), a correlation of 75.7% , 75.8% , 78.4% , -68% , -89.7% were respectively observed to be significantly linked to the number of striga plant at 45 days after planting (NS45), the number of striga plants at 60 days (NS60), the number of striga plant at 90 days after planting (NS90), the flowering date (FLO) and the plant weight (HTR). The number of striga plant at 45 days (NS45), was identified to be highly correlated positively and negatively at 99.2% , 99.3% and -73.7% to the number of striga plant at 60 days, the number of striga plants at 90 days and the number of panicles (NPANI) respectively. In addition, for the number of striga at 60 days (NS60), a high positive correlation was observed at 99.7% with the number of striga at 90 days after the sowing. The number of hole of sorghum plant (NPSorg) was highly correlated to the number of panicles (NPANI) and the grain yield (Yield), respectively at 71.50% , 72.8% in the experiment. For the flowering date (Flo), three negative highly significant correlations were observed with the plant height (HTR) (-82.7%), the number of panicles (NPANI) (-89.5%). Concerning the plant height (HTR) a positive correlation of 76.2% was observed with the grain yield. Thus, for the number of panicles (NPANI) and the grain weight (PoiGR) a highly positive correlation of 99.99% and 87.5% respectively

with the grain yield.

Table 3. Phenotypic correlations among the variables.

	Vig	EMR	NS45	NS60	NS90	NPSorg	Flo	HTR	NPANI	PoiGR	Yield
Vig											
EMR	0.24ns	1.00									
NS45	0.33ns	0.75*	1.00								
NS60	0.30ns	0.75*	0.99**	1.00							
NS90	0.32ns	0.78*	0.99**	0.99**	1.00						
NPSorg	0.53ns	0.47ns	-0.85**	0.20ns	0.40ns	1.00					
Flo	-0.67*	-0.68*	-0.501ns	-0.45ns	-0.50ns	-0.49ns	1.00				
HTR	0.40ns	-0.89*	0.28ns	0.47ns	0.30ns	0.55ns	-0.82**	1.00			
NPANI	0.67*	0.45ns	0.73*	0.37ns	0.41ns	0.71*	-0.89**	0.77*	1.00		
PoiGR	0.35ns	0.49ns	0.29ns	0.29ns	0.33ns	0.05ns	-0.65*	0.58ns	0.49ns	1.00	
Yield	0.67*	0.45ns	0.35ns	0.19ns	0.23ns	0.72*	-0.87**	0.76*	0.99**	0.87**	1.00

EMR = striga emergency; Flo = 50% flowering date; HTR = Plant height; NPANI = Panicles number; NPSorg = Hole number; NS45 = Number of striga plants at 45 days after planting date; NS60 = Number of striga plants at 60 days after planting date; NS90 = Number of striga plants at 90 days after planting date; PoiGR = 1000 grain weight; Vig = Plant vigor; Yield = grain yield Kg/ha; * Significant, ** Highly significant, ns = non-significant.

4.3. Relative Contribution of the Different Traits to the Genotypic Variation

Among the principal component used to assess the fourth sorghum population at Boulke and Dibissou, only three components had an Eigenvalue greater than one under striga natural infestation. These Component explained respectively 68.4%, 14.3 % and 9.5% of the genotypic variation between the four breeding populations (Table 4). The traits that contributed positively to the observed variability were flowering date, plant height, panicle number and grain yield. Plant vigor and grain weight negatively influenced the variability. The Striga traits contributed to the variability in the second principal component.

Several correlations were identified between the three components and the sorghum and striga variables involved in the study.

5. Contribution of Different Components to Variation among Genotypes

The component one and the component two plotting scores are divided into four different environments (Env1, Env2, Env3 and Env4) where the genotypes and the fourth breeding population where distributed according to their correlation. Thus, the population seven (BC₁F₂/P9401XElsedaoua) and the population eight (BC₁F₂/F2-20XMM) are positively correlated to Environment one (Env2) of Component one. Genotype three (Eltseadaoua) and Genotype four (Mota Maradi) are positively correlated to Environment one of Component one. Concerning Genotype one (P9401), it is negatively correlated to Component two and Component one. In addition, Genotype two (F2-20) are positively correlated to Component

two and negatively to Component one.

Table 4. Variables, eigen values and eigen vectors for the different sorghum and striga related traits.

Variables	Eigenvectors		
	PC1	PC2	PC3
Plant vigor	-0.593	-0.340	0.214
Striga emergency	0.311	0.406	0.019
Number of striga plant at 45 days	0.325	0.343	0.031
Number of striga plant at 60 days	0.315	0.365	0.086
Number of striga plant at 90 days	0.324	0.328	0.093
Number of sorghum plant hole	0.288	0.295	-0.406
50% flowering date	0.407	-0.301	0.034
Plant height	0.318	-0.125	0.280
Panicle number	0.341	-0.160	-0.153
1000 grains weight	-0.459	0.192	0.410
Grain yield	0.342	-0.135	-0.163
Eigen value	7.525	1.569	1.046
% Variance	68.41	14.2	9.51
Cumulative % variance	68.41	82.68	92.20

EMR = striga emergency; Flo = 50% flowering date; HTR = Plant height; NPANI = Panicles number; NPSorg = Hole number; NS45 = Number of striga plants at 45 days after planting date; NS60 = Number of striga plants at 60 days after planting date; NS90 = Number of striga plants at 90 days after planting date; PoiGR = 1000 grain weight; Vig = Plant vigor; Yield = grain yield Kg/ha.

In the two components, the genotypes and the breeding population newly developed are distributed across the cited component. Thus, the genotypes Eltsedaoua and the breeding population BC₁F₂ obtained by crossing P9401 and Eltsedaoua are distributed and correlated positively in environment one (Env1) of the Component one. Concerning the second BC₁F₂ breeding population, a cross from the F2-20 and Eltsedaoua are distributed and correlated positively to environment two (Env2) of the Component one. Component three contains the environment three (Env3) and the environment four (Env4). Environment three contains the genotype F2-20 positively correlated to the Component one and negatively correlated to the Component three. Environment four (Env4) comprise the genotype P9401 and Eltsedaoua are negatively correlated to both Component one and Component three.

Component two and Component three, as the previous components, have positive and negative correlations with the genotypes and the breeding populations. So, Component three, which contain Environment one and Environment two, are positively correlated. Thus, environment one possesses the BC₁F₂ (P9401XElsedaoua) breeding population. Environment two is positively correlated in Component three and contains the genotype F2-20 and the BC₁F₂ (F2-20XMota Maradi) population. In addition, Component three contains Environment three and

Environment four. Environment three is positively correlated to Component three and negatively to Component two and contains the genotype, Mota Maradi. Environment four is negatively correlated to Component three and Component two and contain the genotypes P9401 and Eltsedaoua (**Figures 1-4**).

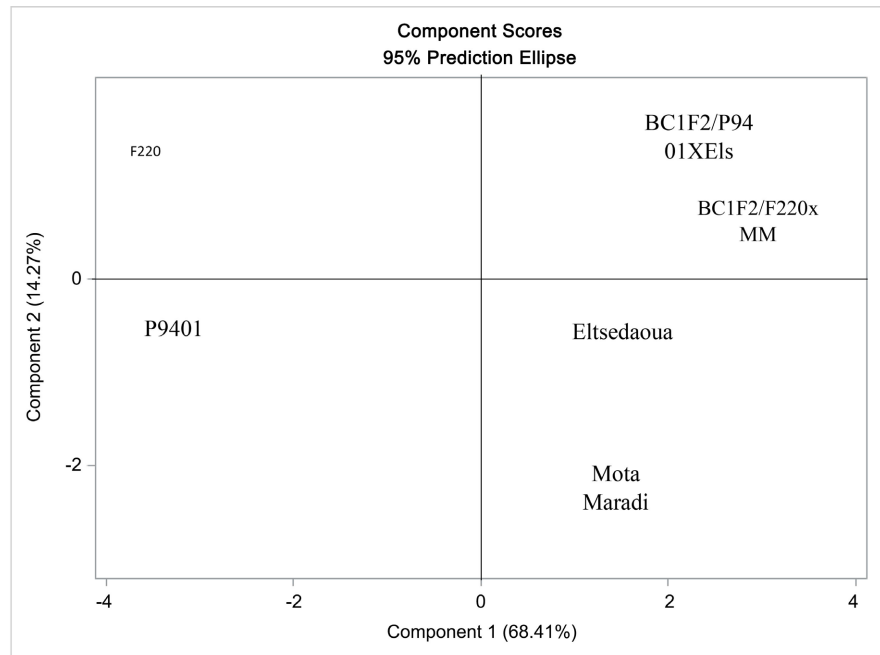


Figure 1. Biplot of Component 1 and Component 2 representing relationship among the striga and sorghum-related traits.

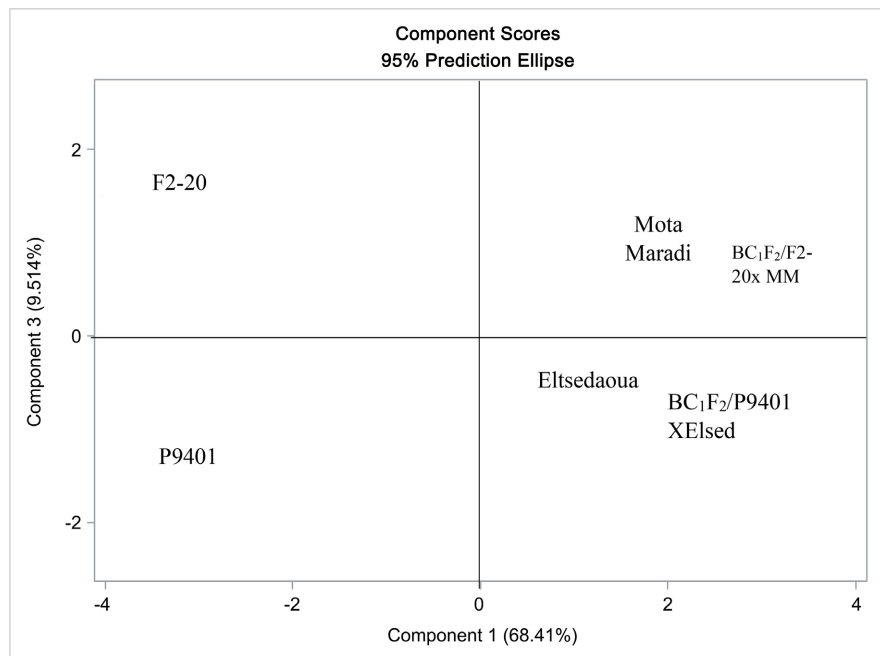


Figure 2. Biplot of Component 1 and Component 3 representing relationship among the striga and sorghum related traits.

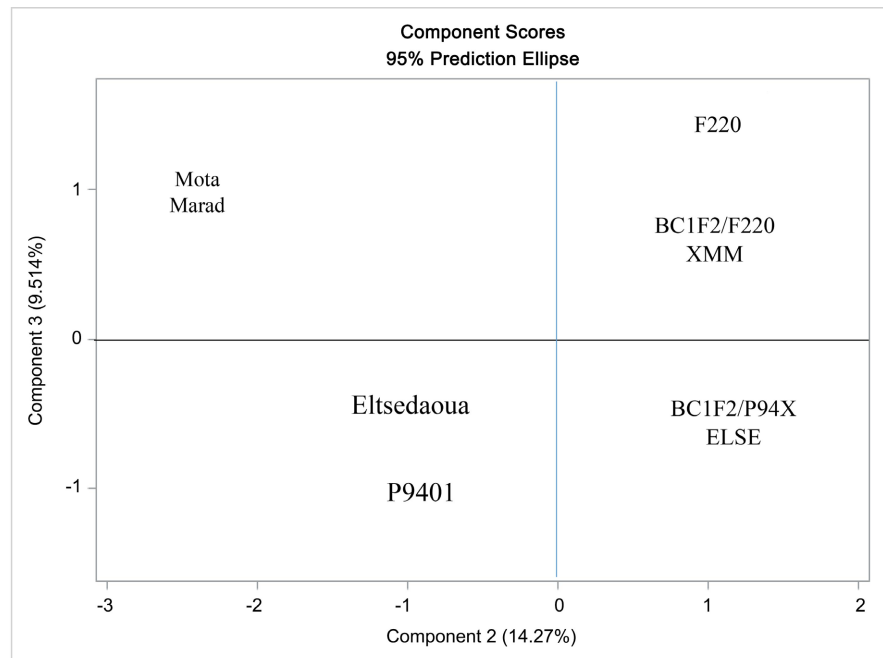


Figure 3. Biplot of Component 2 and Component 3 representing relationship among the striga and sorghum related traits.

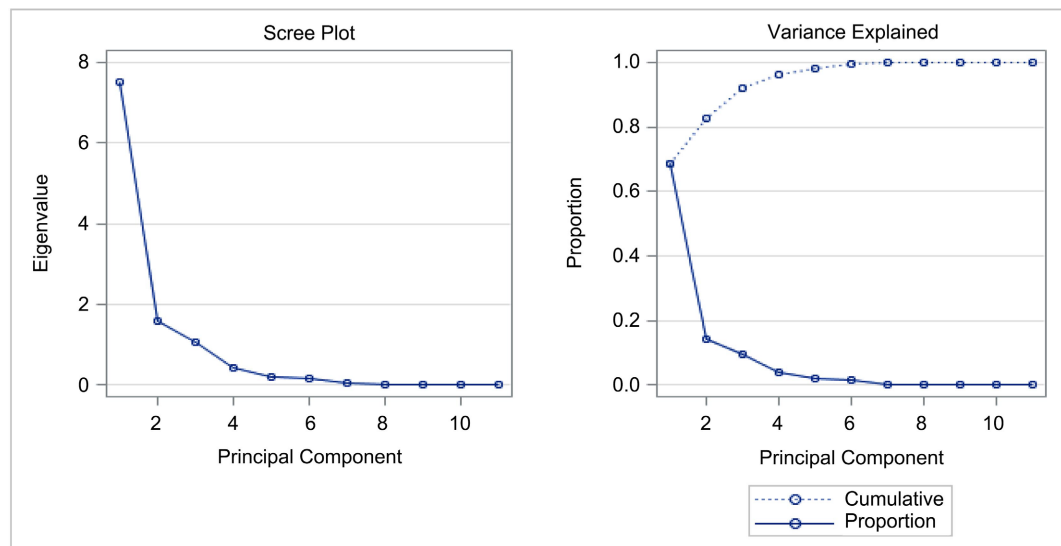


Figure 4. Scree plot and cumulative variance progression in the different components.

6. Discussions

This study was undertaken with the aim of grouping the developed breeding sorghum population and their parents based on grain yield productivity, grain yield attributes, and striga tolerance variables. Thus, an analysis of variance through a general linear model was made among the different variables for variability confirmation among the BC_1F_2 breeding populations. The obtained means square of the different genotypes and the breeding populations were highly significant for the majority of the 11 traits, which confirm the presence variability among those

populations. So, the significant negative correlation observed between the plant vigor and the flowering date is explained by the fact that, when the sorghum crop get a good vigor percentage combined with a late flowering date it will highly impact the yield. This is contrary to what was found by Trachsel [17], on which a good early plant vigor and an earlier flowering date combination can highly improve the grain yield. Thus, always concerning the plant vigor (Vig), the positive correlations found with the number of panicles and the grain yield is explained by the fact that when better is the plant vigor, much better will be the panicle number (NPANI) and obviously the grain yield will increase, confirmed by the work made by different research on diverse speculation [18] [19]. The striga-related traits, including the emergency date (EMR), the number of striga plant at 45 days, 60 days and 90 days, are positively correlated to each other. Which mean, where the striga plants emergency start earlier, the number of plants will exponentially increase from the 45 days to the 90 days after the planting date. This statement is confirmed by the studies made by Abdalroof *et al.* [20] in which they have mentioned that if at the earlier stage of the plant development the number of striga is less important, so at the late stage the number will not increase, and inversely. Concerning the flowering date (Flo), it was highly positively correlated to grain yield, and explain the fact that if earlier is the flowering higher will be the grain yield is confirmed by the studies made by Liang *et al.* [21] and Sowmy *et al.* [22]. In addition, the positive significant correlation observed among the number of hole (NPSorg), the panicles number (NPANI) and the grain yield is explained by the fact that when higher is the number of hole, higher will be the panicles number and the grain yield confirm by the study made by Naim [23]. As observed previously in **Table 5**, the sorghum plant vigor (Vg), the plant height (HTR), the number of panicles (NPANI), the grain weight (PoiGR) and the grain yield are those which are highly contributing at 68 % of the variation in Component one. After this process, a principal component analysis was performed to highlight the contribution of each agronomics and striga trait performance in the variability. Thus, based on the Eigen value and the correlation variances distribution, three components were identified to contribute at 92.20% on the phenotypic variation observed, it concerned Component one, Component two and Component three. Those cited component have an Eigen value greater than one, and was confirmed by the study made by Hair *et al.* [24], on which the Eigen values less than one should be removed, only component which have an Eigen value greater than 1 should be conserved. In addition, the graphics of the selected components with the best Eigen value, show the variables, the sorghum populations and the parent's distribution along the different environments. So according to the variables correlation with the components, they are positively or negatively distributing. Thus, Component one and the Component three are the grain yield and yield attributes component. Component two contain the striga variables. Moreover, a Ward's minimum cluster variance analysis where used to grouped the sorghum genotype and the news developed population, into fourth different cluster based on their correlation. This cluster analysis highlights the diversity among those populations according to the 11 variables

involved in the study based on their means.

Table 5. Mean square values of the 11 traits distributed along the Sorghum genotypes.

Genotypes	Vig	EMR	NS45	NS60	NS90	NPSorg	Flo	HTR (cm)	NPANI	PoiGR (g)	Yield (kg/ha)
P9401	1.5 ^{ab}	19.17 ^b	0.5 ^b	1.00 ^c	1.00 ^c	12.50 ^c	61.50 ^{ab}	168.33 ^d	19.00 ^{bc}	16.66 ^{bc}	186.97 ^{bc}
F2-20	1.00 ^b	36.83 ^{ab}	3.16 ^{ab}	3.50 ^c	3.50 ^c	11.33 ^c	65.00 ^a	201.67 ^{dc}	1416 ^c	15.16 ^{bc}	139.53 ^{bc}
Eltседаoua	1.66 ^{ab}	53.67 ^a	6.33 ^{ab}	7.33 ^{abc}	8.33 ^{abc}	14.83 ^{bc}	57.00 ^{bc}	248.33 ^{ab}	32.00 ^{ab}	16.33 ^{bc}	314.83 ^{ab}
BC1F2 (P9401XEL)	1.83 ^{ab}	51.33 ^{ab}	11.66 ^a	13.66 ^{ab}	15.00 ^{ab}	21.83 ^a	57.16 ^{bc}	261.67 ^{ab}	35.16 ^a	17.83 ^{abc}	345.33 ^{aa}
Mota Maradi	1.83 ^{ab}	52.33 ^a	5.16 ^{ab}	6.00 ^{abc}	6.83 ^{abc}	13.66 ^{bc}	54.33 ^c	288.33 ^a	29.50 ^{ab}	22.00 ^a	288.20 ^{ab}
BC1F2 (F220xMM)	2.00 ^a	55.50 ^a	11.83 ^a	15.66 ^a	16.66 ^a	18.66 ^{ab}	57.83 ^{bc}	270.00 ^{ab}	29.16 ^{ab}	18.16 ^{abc}	286.3 ^{ab}

Means with the same letter are not significantly different; EMR = striga emergency; Flo = 50% flowering date; HTR = Plant height; NPANI = Panicles number; NPSorg = Hole number; NS45 = Number of striga plants at 45 days after planting date; NS60 = Number of striga plants at 60 days after planting date; NS90 = Number of striga plants at 90 days after planting date; PoiGR = 1000 grain weight; Vig = Plant vigor; Yield = grain yield Kg/ha.

7. Conclusion

The two breeding populations (BC₁F₂: P9401xelsedaoua and BC₁F₂: F2-20x Mota Maradi) showed superior performances for plant height, panicles numbers, shorter flowering date, high tolerance to striga coupled with a good average grain yield.

Conflicts of Interest

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

References

- [1] Ayman, A., Maged, A., Dafalla, A.D., Rawda, Y.E. and Lubna, E.K. (2014) Effects of Some Formulations of Chlorsulfuron, on Striga Control and Sorghum Yield. *International Journal of Life Sciences Research*, **2**, 185-188.
- [2] Teka, H.B. (2014) Advanced Research on Striga Control: A Review. *African Journal of Plant Sciences*, **8**, 492-506.
- [3] Ifie, B.E., Badu-Apraku, B., Gracen, V. and Danquah, E.Y. (2015) Genetic Analysis of Grain Yield of IITA and CIMMYT Early-Maturing Maize Inbreds under *Striga*-Infested and Low-Soil-Nitrogen Environments. *Crop Science*, **55**, 610-623. <https://doi.org/10.2135/cropsci2014.07.0470>
- [4] Choudhury, M.K., Phillips, A.L. and Mustapha, A. (1998) Pharmacological Studies of *Striga senegalensis* Benth (Scrophulariaceae) as an Abortifacient. *Phytotherapy Research*, **12**, 141-143. [https://doi.org/10.1002/\(sici\)1099-1573\(199803\)12:2<141::aid-ptr201>3.0.co;2-t](https://doi.org/10.1002/(sici)1099-1573(199803)12:2<141::aid-ptr201>3.0.co;2-t)
- [5] Yohannes, T., Ngugi, K., Ariga, E., Abraha, T., Yao, N., Asami, P., et al. (2016) Genotypic Variation for Low Striga Germination Stimulation in Sorghum "*Sorghum bicolor* (L.) Moench" Landraces from Eritrea. *American Journal of Plant Sciences*, **7**, 2470-2482. <https://doi.org/10.4236/ajps.2016.717215>
- [6] Akiyama, K., Matsuzaki, K. and Hayashi, H. (2005) Plant Sesquiterpenes Induce Hyphal Branching in Arbuscular Mycorrhizal Fungi. *Nature*, **435**, 824-827.

- <https://doi.org/10.1038/nature03608>
- [7] Abayo, G.O., Oswald, A., Ransom, J.K. and Ariga, E.S. (1997) Stimulation of *Striga hermonthica* Germination by Plant Species Indigenous to Eastern Africa. *Proceedings of the 16th Biennial Weed Science conference for Eastern Africa*, Kampala, 15-18 September 1997, 231-239.
- [8] Ousseini, A.A., Ibrahim, M.A., Eleblu, J.S.Y., Ofori, K. and Hamani, I.B. (2022) Identifying Sorghum Yield Limiting Factors and Farmer's Criteria Traits in East and Northern West Niger. *Open Access Library Journal*, **9**, e9543. <https://doi.org/10.4236/oalib.1109543>
- [9] Nikiéma, M., Yonli, D., Rabefiraisana, H., Ali, A., Ouédraogo, N., Traoré, H., Yanogo, H., Dao, K., Sawadogo, M., Jankuloski, L., Ivan, I. and Abdelbagi, M. (2020) Induced Resistance to *Striga hermonthica* in Sorghum by Gamma Irradiation. *American Journal of Plant Sciences*, **11**, 1545-1561.
- [10] Ousseini, A.A., Ibrahim, M.A., Eleblu, J.S.Y. and Ofori, K. (2024) Sesame (*Sesamum indicum* L.) Seeds and Di Ammonium Phosphate (DAP) Potential for Controlling Striga Seed Germination, Sorghum Growth and Grain Yield. *Journal of Precision Agriculture*, **1**, 10-18. <https://doi.org/10.14302/issn.2998-1506.jpaa-22-4349>
- [11] Lagoke, S.T.O., Parkinson, V. and Agunbiade, R.M. (1991) Parasitic Weeds and Control Methods in Africa. *Proceedings of the International Workshop on Combating Striga in Africa*, Ibadan, 22-24 August 1988, 3-14.
- [12] Aliyu, L., Lagoke, S.T.O., Carsky, R.J., Kling, J., Omotayo, O. and Shebayan, J.Y. (2004) Technical and Economic Evaluation of Some Striga Control Packages in Maize in the Nigerian Guinea Savanna. *Crop Protection*, **23**, 65-69. [https://doi.org/10.1016/s0261-2194\(03\)00141-8](https://doi.org/10.1016/s0261-2194(03)00141-8)
- [13] Mandumbu, R., Mutengwa, C., Mabasa, S. and Mwenje, E. (2018) Challenges to the Exploitation of Host Plant Resistance for *Striga* Management in Cereals and Legumes by Farmers in Sub-Saharan Africa: A Review. *Acta Agriculturae Scandinavica, Section B—Soil & Plant Science*, **69**, 82-88. <https://doi.org/10.1080/09064710.2018.1494302>
- [14] Ousseini, A.A., Ibrahim, M.A., Maina, F., *et al.* (2023) Screening Sorghum Genotypes for Striga Resistance. *Journal of Agronomy Research*, **5**, 16-23. <https://doi.org/10.14302/issn.2639-3166.jar-22-4356>
- [15] Ejeta, G. (2007) Breeding for *Striga* Resistance in Sorghum: Exploitation of an Intricate Host-Parasite Biology. *Crop Science*, **47**, 216-227. <https://doi.org/10.2135/cropsci2007.04.0011ipbs>
- [16] Institut National de la Statistique du Niger (INS) (2017).
- [17] Trachsel, S., Sun, D., SanVicente, F.M., Zheng, H., Atlin, G.N., Suarez, E.A., *et al.* (2016) Identification of QTL for Early Vigor and Stay-Green Conferring Tolerance to Drought in Two Connected Advanced Backcross Populations in Tropical Maize (*Zea mays* L.). *PLOS ONE*, **11**, e0149636. <https://doi.org/10.1371/journal.pone.0149636>
- [18] Camargo, C.P. and Vaughan, C.E. (1973) Effect of Seed Vigor on Field Performance and Yield of Grain Sorghum (*Sorghum bicolor* (L.) Moench). *Proceedings of the Association of Official Seed Analysts*, **63**, 135-147.
- [19] Mondo, V.H.V., Nascente, A.S. and Cardoso Neto, M.O. (2016) Common Bean Seed Vigor Affecting Crop Grain Yield. *Journal of Seed Science*, **38**, 365-370. <https://doi.org/10.1590/2317-1545v38n4166814>
- [20] Abdalroof, M., Eltayeb, A. and Abusin, R. (2017) Effects of Inter-Cropping and a

Herbicide on Management of *Striga hermonthica* on Sorghum. *Asian Research Journal of Agriculture*, **5**, 1-10. <https://doi.org/10.9734/arja/2017/34562>

- [21] Liang, G.H.L., Overley, C.B. and Casady, A.J. (1969) Interrelations among Agromomic Characters in Grain Sorghum (*Sorghum bicolor* Moench). *Crop Science*, **9**, 299-302. <https://doi.org/10.2135/cropsci1969.0011183x000900030014x>
- [22] Sowmy, H.H., Brunda, S.M., Deepak Kumar, G.S., Vidya, G. and Kamatar, M.Y. (2015) Estimation of Correlation Coefficients and Path for Yield Traits in Grain Mold Tolerant F3 Progenies of Sorghum. *International Journal of Science Research (IJSR)*, **4**, 1420-1424.
- [23] El Naim, M.A., Ibrahim, M.I., Abdel Rahman, E.M. and Ibrahim, A.E. (2012) Evaluation of Some Local Sorghum (*Sorghum bicolor* L. Moench) Genotypes in Rain-Fed. *International Journal of Plant Research*, **2**, 15-20. <https://doi.org/10.5923/j.plant.20120201.03>
- [24] Hair, J.R., Anderson, J.F., Tatham, R.E. and Black, W.C. (1998) *Multivariate Data Analysis*. Prentice-Hall International.