E-ISSN: 2618-0618
P-ISSN: 2618-060X

www.agronomyjournals.com
2024; 7(1): 358-363
Received: 27-11-2023
Accepted: 30-12-2023

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Correlation analysis for shoot fly resistance parameters in *Rabi* Sorghum [*Sorghum bicolor* (L.) Moench]

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DOI: https://doi.org/10.33545/2618060X.2024.v7.i1e.239

Abstract
The current study was conducted to examine the correlation coefficients among shoot fly resistance parameters in total 12 sorghum genotypes including 04 F_2 populations along with 06 parents and 02 checks in *Rabi* 2022-2023 at the Experimental Farm of Sorghum Research Station, Vasantrao Naik Marathwada Krishi Vidyapeeth, Parbhani (Maharashtra). Three replications of a randomized block design were used to conduct the current experiment. At the genotypic and phenotypic levels, the characters leaf glossiness (non-glossy), seedling vigour (non-vigorous), leaf angle and dead heart percent at 14 DAE were significant and positively correlated with shoot fly dead heart percent at 28 DAE. Whereas, trichome density (adaxial and abaxial) and plant height had recorded negative but significant association with dead heart percent at 28 DAE at both levels. While, 100 seed weight had recorded significant but positive correlation with dead heart percentage at phenotypic level only.

Keywords: Sorghum, correlation, shoot fly, significant, positive, relationship, negative

Introduction
Sorghum [*Sorghum bicolor* (L.) Moench] ranks as the fifth major cereal crop globally, following wheat, rice, maize and barley. Its significance is particularly pronounced in dry regions due to its notable drought tolerance. It is known as "Camel of the Desert" because it thrives on minimal rainfall. Insect pests pose significant challenges to sorghum production, with economic losses reaching up to 32.1 percent (Borad and Mittal, 1983) [2]. Among these pests, the sorghum shoot fly, *Atherigona soccata* (Rondani) (Diptera: Muscidae), stands out as the most destructive, causing substantial damage within four weeks of sowing and resulting in a staggering 75.6% yield loss (Pawar *et al*. 1984) [8]. The shoot fly, belonging to the genus Atherigona, is notorious for causing 'dead hearts' in various tropical grass species and wheat (Pont and Deeming, 2001) [16]. Despite the economic challenges faced by resource-poor farmers in the semi-arid tropics when adopting chemical methods for insect control in staple food crops, there is a need to address the issue. Systematic screening procedures at different locations have identified various sources of resistance (Singh and Narayana, 1978) [14]. While shoot fly infestations exhibit variation across locations and seasons, certain sorghum varieties consistently display lower susceptibility. So, this study aims to assess the genetic association of shoot fly resistance, both within its components and among the components themselves.

Materials and Methods
In the *Rabi* of 2022-2023, the experiment was carried out at Sorghum Research Station, Vasantrao Naik Marathwada Krishi Vidyapeeth, Parbhani, and Maharashtra. The experimental material for this study comprised of total 12 sorghum genotypes (04 F_2 populations along with 06 parents and 02 checks). Three replications of the experimental material were assessed using Randomized Block Design (RBD). Five random plants from parents and fifty random plants from F_2 populations in each plot and replications were chosen and labelled for recording observations. The average value of every characteristic was calculated using the measurements made on certain plants.

The observations were recorded for thirteen characters as seedling vigor, leaf glossiness, leaf angle, chlorophyll content, trichome density (adaxial and abaxial), plant height, days to 50 per cent flowering, fodder yield per plant, grain yield per plant, 100 seed weight, dead heart percent at 14 DAE and 28 DAE. The genotypic and phenotypic correlation coefficients were calculated from the corresponding variances and co-variances to determine the degree of link between various features. The correlation was computed using the formulas proposed by Johnson *et al*. (1955) [6].

Table 1: Experimental material

Sr. No.	F_2 Populations of following crosses	Sr. No.	Parents and Checks
1.	104B x IS-18551	5.	104B
2.	IS-153B x IS-2205	6.	IS-153B
3.	PR-108 x IS-18551	7.	PR-108
4.	CSV-29R x IS-2205	8.	CSV-29R
		9.	IS-2205
		10.	IS-18551
		11.	DJ-6514 (Susceptible check)
		12.	Parbhani Supermoti (Check)

Results and Discussion

The correlation coefficient was analyzed to explore the connection between morphological traits and the manifestation of shoot fly tolerance (*Atherigona soccata*) at both genotypic and phenotypic levels. The genotypic and phenotypic correlation coefficients for thirteen characters are presented in Table 1 and 2 and Fig. 1.

In the present investigation, the dead heart per cent at 28 DAE recorded significant and positive correlation with the characters leaf glossiness (non-glossy) (G=0.871, P=0.849), seedling vigour (non-vigorous) (G=0.914, P=0.889), leaf angle (G=0.605, P=0.598), dead heart% at 14 DAE (G=0.974, P=0.959). Whereas, trichome density (adaxial) (G=-0.917, P=-0.904), trichome density (abaxial) (G=-0.749, P=-0.735) and plant height (G=-0.789, P=-0.773) had recorded negative but significant association with dead hearts per cent 28 DAE. The results are in accordance with Gomashe *et al*. (2010) [5], Kamatar *et al*. (2010) [7], Raut *et al*. (2016) [11], Bornare *et al*. (2016) [3], Riyazzadin *et al*. (2015) [10], Syed *et al*. (2017) [15], Sekar *et al*. (2018) [13] and Salama *et al*. (2020) [12].

The characters leaf glossiness (G=0.738, P=0.739), dead heart at 14DAE (G=0.894, P=0.865) and dead heart at 28 DAE (G=0.914, P=0.889) were in significant positive association with seedling vigour at genotypic and phenotypic levels and showed positive and non-significant association with chlorophyll content and 100 seed weight at both levels. While trichome density (adaxial) (G=-0.762, P=-0.750), trichome density (abaxial) (G=-0.648, P=-0.632), plant height (G=-0.935, P=-0.906) and fodder yield (G=-0.644, P=-0.637) were observed significant and negatively correlated with seedling vigour at both genotypic and phenotypic levels. Also, it showed negative and non-significant correlation with days to 50% flowering. While, the trait grain yield (P=-0.409) was significant and negatively associated with seedling vigour at only phenotypic level. Positive and significant correlation of seedling vigor (poor) with leaf glossiness, dead heart at 14 & 28 DAE reveals that more vigorous genotypes (< 2 score) are less affected by shoot fly and negative significant correlation with trichome density (adaxial) and trichome density (abaxial). The results are in accordance with Gomashe *et al*. (2010) [5], Kamatar *et al*. (2010) [7], Raut *et al*. (2016) [11], Bornare *et al*. (2016) [3], Riyazzadin *et al*. (2015) [10], Syed *et al*. (2017) [15], Sekar *et al*. (2018) [13] and Salama *et al*. (2020) [12]. Seedling vigor (poor with > 3 score) showed significant and negative association with plant height, fodder yield and grain yield. Similar results were obtained by Kamatar *et al*. (2010) [7].

Leaf glossiness showed significant and positive association with leaf angle (G=0.789, P=0.772), dead heart at 14DAE (G=0.899, P=0.873) and dead heart at 28 DAE (G=0.871, P=0.849) at both genotypic and phenotypic levels and positive and non-significant correlation with chlorophyll content and 100 seed weight at genotypic level only. While trichome density (adaxial) (G=-0.861, P=-0.866), trichome density (abaxial) (G=-0.764, P=-0.749) and plant height (G=-0.662, P=-0.642) were observed significant negatively associated with leaf glossiness at both genotypic and phenotypic levels and negative and non-significant association with days to 50% flowering, fodder yield and grain yield at both the levels. Positive and significant association of dead heart% at 28 DAE shows that less glossy genotypes are susceptible to shoot fly. Positive and significant correlation of leaf glossiness with dead heart at 28 DAE and negative & significant with trichome density (adaxial & abaxial) were observed by Gomashe *et al*. (2010) [5], Kamatar *et al*. (2010) [7], Raut *et al*. (2016) [11], Bornare *et al*. (2016) [3], Riyazzadin *et al*. (2015) [10], Syed *et al*. (2017) [15], Sekar *et al*. (2018) [13] and Salama *et al*. (2020) [12]. Leaf glossiness showed significant and negative association with plant height. Similar results were obtained by Kamatar *et al*. (2010) [7].

Leaf angle showed significant and positive association with 100 seed weight (G=0.638, P=0.609), dead heart at 14 DAE (G=0.655, P=0.644) and dead heart at 28 DAE (G=0.605, P=0.598) at both genotypic and phenotypic levels and positive and non-significant association with chlorophyll content, days to 50% flowering and fodder yield. Leaf angle recorded negative and significant association with trichome density (adaxial) (G=-0.599, P=-0.595) at both genotypic as well as phenotypic level and negative non-significant relation with trichome density (abaxial) and plant height at both levels. While the trait grain yield (P=0.398) was significant and positively associated with seedling vigour at only phenotypic level and positive and non-significant correlation at genotypic level only. Significant and positive association of leaf angle with dead heart% at 28 DAE reported by Syed *et al*. (2017) [15].

Trichome density (adaxial) (P=-0.446), trichome density (abaxial) (P=-0.515) exhibited significant and negative association with chlorophyll content at only phenotypic level. It displayed positive and non-significant association with fodder yield, grain yield, 100 seed weight, dead heart at 14 DAE and dead heart at 28 DAE at both levels. It showed negative non-significant relation with plant height at both levels. Also, it showed negative non-significant association with trichome density (adaxial) and trichome density (abaxial) at genotypic level only. Positive and significant correlation between chlorophyll content and dead heart at 28 DAE reveals that genotypes with more chlorophyll might be susceptible reaction to shoot fly infestation. The similar results were obtained by Syed *et al*. (2017) [15].

Association of trichome density (adaxial) was highly significant and positive with trichome density (abaxial) (G=0.83, P=0.817) and plant height (G=0.724, P=0.713) at both genotypic and phenotypic levels. The trait dead heart at 14DAE (G=-0.886, P=-0.874) and dead heart at 28 DAE (G=-0.917, P=-0.904) showed significant and negative association with trichome density (adaxial) at both the levels. Fodder yield (P=0.426) has significant positive and negative association with trichome density at phenotypic level only. It displayed positive non-significant association with days to 50% flowering and grain yield at both levels. The results indicate that genotypes with more trichome density should be considered for genetic improvement of shoot fly tolerance. Positive and significant association of trichome density (adaxial) with trichome density (abaxial) and negative significant association with dead heart at 28 DAE was also observed by Gomashe *et al*. (2010) [5], Kamatar *et al*. (2010) [7], Folane *et al*. (2014) [4], Bhagat *et al*. (2015) [1], Raut *et al*. (2016) [11], Bornare *et al*. (2016) [3], Riyazzadin *et al*. (2015) [10], Syed *et al*. (2017) [15], Sekar *et al*. (2018) [13] and Salama *et al*. (2020) [12]. Trichome density (adaxial) showed positive and significant association with plant height and the similar results were obtained by Kamatar *et al*. (2010) [7].

Trichome density (abaxial) has recorded significant and positive correlation with plant height (G=0.708, P=0.688) at genotypic and phenotypic levels. The traits dead heart at 14DAE (G=-0.715, P=-0.687) and dead heart at 28 DAE (G=-0.749, P=-0.735) were found significant but negatively associated with trichome density (abaxial) at both genotypic and phenotypic level. It exhibited positive non-significant association with days to 50% flowering and grain yield and negative non-significant correlation with 100 seed weight at both levels. Negative and significant association of trichome density (abaxial) with dead heart% at 28 DAE was observed by Gomashe *et al*. (2010) [5], Folane *et al*. (2014) [4], Bhagat *et al*. (2015) [1], Raut *et al*. (2016) [11], Bornare *et al*. (2016) [3], Riyazzadin *et al*. (2015) [10], Syed *et al*. (2017) [15], Sekar *et al*. (2018) [13] and Salama *et al*. (2020) [12].

Highly significant and positive correlation of plant height was observed with days to 50% flowering (G=0.592, P=0.472), fodder yield (0=0.844, P=0.816) and grain yield (G=0.658, P=0.644) at both genotypic and phenotypic levels. Dead heart% at 14DAE (G=-0.790, P=-0.775) and dead heart% at 28 DAE (G=-0.789, P=-0.773) exhibited significant negative association with plant height at both genotypic and phenotypic level. It recorded negative non-significant correlation with 100 seed weight at both levels. The similar results were obtained by Kamatar *et al*. (2010) [7] and Syed *et al*. (2017) [15].

Association of days to 50% flowering was significant and positive with fodder yield (G=0.741, P=0.585) and grain yield (G=0.989, P=0.767) at both genotypic as well as phenotypic level. It showed negative non-significant correlation with dead heart at 14DAE and dead heart at 28 DAE at both levels indicating that early genotypes are more susceptible to shoot fly infestation. The similar results were obtained by Bhagat *et al*. (2015) [1] and Syed *et al*. (2017) [15].

Association of fodder yield was significant and positive with grain yield (G=0.741, P=0.585) at both genotypic as well as phenotypic levels. Dead heart at 14 DAE (P=-0.411) and dead heart at 28 DAE (P=-0.415) exhibited significant negative association with fodder yield at phenotypic level only. It recorded positive non-significant correlation with 100 seed weight at both levels. The similar results were obtained by Syed *et al*. (2017) [15].

Association of grain yield was significant and positive with 100 seed weight (P=0.5) at phenotypic level. It exhibited positive non-significant association with 100 seed weight (0.531) at genotypic level and negative non-significant correlation with dead heart% at 14DAE and dead heart% at 28 DAE at both levels. The similar results were obtained by Syed *et al*. (2017) [15]. 100 seed weight was recorded significant and positive correlation with dead heart at 14DAE (P=0.369) and dead heart at 28 DAE (P=0.436) at phenotypic level only. It exhibited positive non-significant association with dead heart% at 14DAE and dead heart% at 28 DAE at genotypic level only. The results were in accordance with Riyazzadin *et al*. (2015) [10] and Salama *et al*. (2020) [12].

Association of dead heart percentage at 14 DAE was highly significant and positive with seedling vigor (G=0.894, P=0.865), leaf glossiness (G=0.899, P=0.873), leaf angle (G=0.655, P=0.644) and dead heart percentage at 28 DAE (G=0.974, P=0.959) and also significant and negative association with trichome density (adaxial and abaxial) and plant height at both genotypic and phenotypic levels. The similar results were obtained by Gomashe *et al*. (2010) [5] and Syed *et al*. (2017) [15].

Table 1: Genotypic correlation coefficient matrix for shoot fly resistance parameters

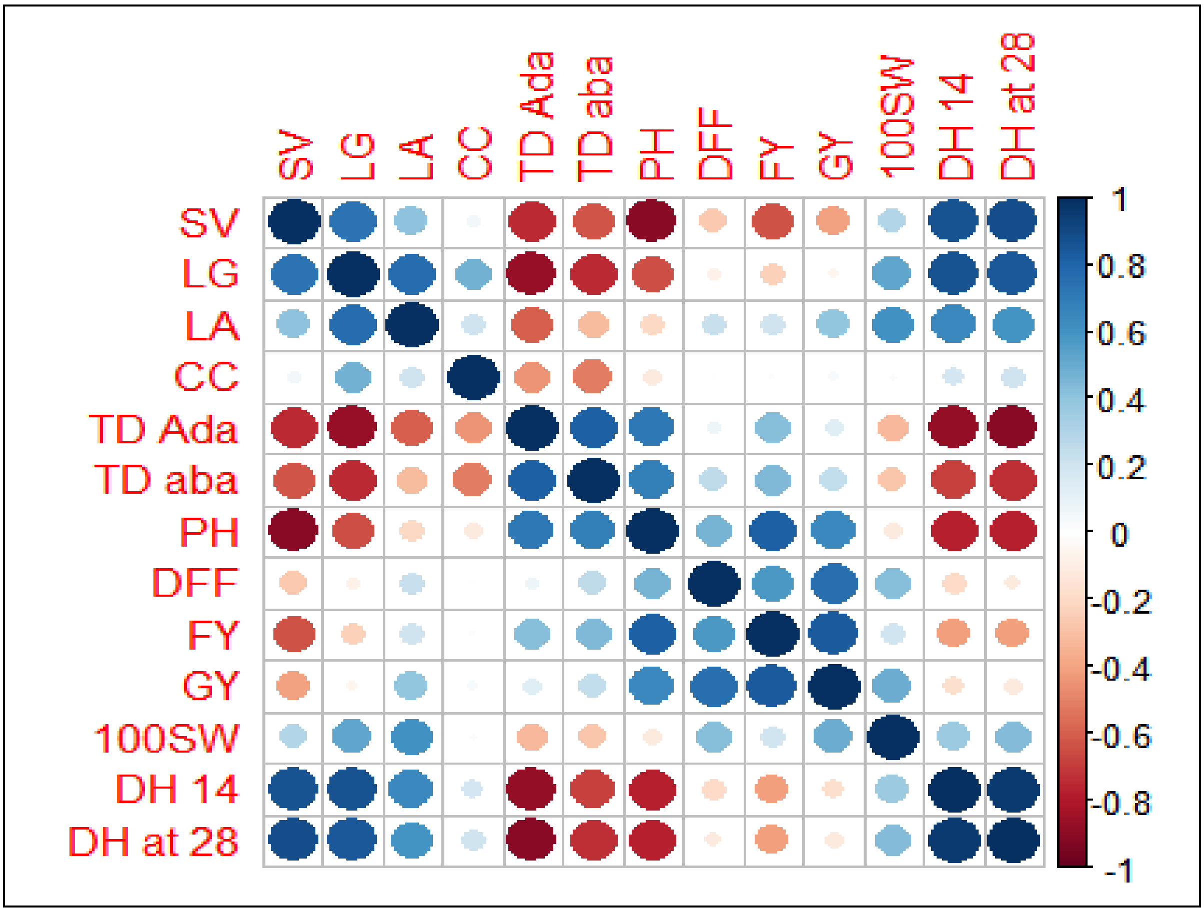
Sr. No.	Characters	Seedling vigor (1-5 scale)	Leaf glossiness (1-5 scale)	Leaf angle (Degrees)	Chlorophyll content (SPAD value)	Trichome Density (Adaxial)	Trichome Density (Abaxial)	Plant Height (cm)	Days to 50% Flowering	Fodder yield per plant (g)	Grain yield per plant (g)	100 Seed Weight (g)	Dead hearts at 14 DAE (%)	Dead hearts at 28 DAE (%)
1	Seedling vigor (1-5 scale)	1.000	0.738**	0.416	0.043	-0.762**	-0.648*	-0.935**	-0.375	-0.644*	-0.399	0.317	0.894**	0.914**
2	Leaf glossiness (1-5 scale)		1.000	0.789**	0.478	-0.866**	-0.764**	-0.662*	-0.138	-0.218	-0.026	0.542	0.899**	0.871**
3	Leaf angle (Degrees)			1.000	0.226	-0.599*	-0.311	-0.203	0.270	0.217	0.415	0.638*	0.655*	0.605*
4	Chlorophyll content				1.000	-0.450	-0.539	-0.123	0.029	0.029	0.053	0.008	0.196	0.222
5	Trichome Density (Adaxial)					1.000	0.83**	0.724**	0.121	0.424	0.122	-0.334	-0.886**	-0.917**
6	Trichome Density (Abaxial)						1.000	0.708**	0.274	0.451	0.237	-0.286	-0.715**	-0.749**
7	Plant Height (cm)							1.000	0.592*	0.844**	0.658*	-0.118	-0.790**	-0.789**

8	Days to 50% Flowering								1.000	0.741**	0.989**	0.544	-0.268	-0.141
9	Fodder yield per plant (g)									1.000	0.843**	0.216	-0.422	-0.424
10	Grain yield per plant (g)										1.000	0.531	-0.184	-0.118
11	100 seed weight (g)											1.000	0.377	0.449
12	Dead hearts at 14 DAE (%)												1.000	0.974**
13	Dead hearts at 28 DAE (%)													1.000

Table 2: Phenotypic correlation coefficient matrix for shoot fly resistance parameters

Sr. No.	Characters	Seedling vigor (1-5 scale)	Leaf glossiness (1-5 scale)	Leaf angle (Degrees)	Chlorophyll content (SPAD value)	Trichome Density (Adaxial)	Trichome Density (Abaxial)	Plant Height (cm)	Days to 50% Flowering	Fodder yield per plant (g)	Grain yield per plant (g)	100 Seed Weight (g)	Dead hearts at 14 DAE (%)	Dead hearts at 28 DAE (%)
1	Seedling vigor (1-5 scale)	1.000	0.739**	0.404*	0.056	-0.750**	-0.632**	-0.906**	-0.284	-0.637**	-0.409*	0.292	0.865**	0.889**
2	Leaf glossiness (1-5 scale)		1.000	0.772**	0.474**	-0.861**	-0.749**	-0.642**	-0.087	-0.234	-0.053	0.52**	0.873**	0.849**
3	Leaf angle (Degrees)			1.000	0.209	-0.595**	-0.311	-0.205	0.228	0.208	0.398*	0.609**	0.644**	0.598**
4	Chlorophyll content (SPAD)				1.000	-0.446**	-0.515**	-0.118	-0.007	0.015	0.040	0.023	0.187	0.207
5	Trichome Density (Adaxial)					1.000	0.817**	0.713**	0.083	0.426**	0.134	-0.329*	-0.874**	-0.904**
6	Trichome Density (Abaxial)						1.000	0.688**	0.249	0.448**	0.245	-0.274	-0.687**	-0.735**
7	Plant Height (cm)							1.000	0.478**	0.816**	0.644**	-0.116	-0.775**	-0.773**
8	Days to 50% Flowering								1.000	0.585**	0.767**	0.435**	-0.193	-0.111
9	Fodder Yield per plant (g)									1.000	0.837**	0.196	-0.411*	-0.415*
10	Grain yield per plant (g)										1.000	0.5**	-0.176	-0.116
11	100 seed weight (g)											1.000	0.369*	0.436**
12	Dead hearts at 14 DAE (%)												1.000	0.959**
13	Dead hearts at 28 DAE (%)													1.000

*Significant at 5 percent level, **Significant at 1 percent level



SV- Seedling vigour, LG- Leaf glossiness, LA- Leaf angle, CC- Chlorophyll content, TD Ada- Trichome density (Adaxial), TD Aba- Trichome density (Abaxial), PH- Plant height, DFF- Days to 50% Flowering, FY- Fodder Yield, GY- Grain Yield, 100SW- 100 Seed Weight, DH 14- Dead heart percent at 14 DAE, DH 28- Dead heart percent at 28 DAE

Fig 1: Correlation matrix for shoot fly resistance parameters

Conclusion

The traits high leaf glossiness, seedling vigour, trichome density on the upper surface of leaf (adaxial), leaf angle and chlorophyll content showing correlation in desirable directions are highly reliable parameters. These parameters can effectively serve as marker traits to screen and select genotypes for resistance to the sorghum shoot fly. In addition, it is notable that shoot fly resistance, morphological characteristics and agronomic traits display significant correlations in the same direction, whether positive or negative. Consequently, these traits can be employed as selection criteria when developing sorghum cultivars with resistance to the shoot fly.

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