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Correlation of Sorghum [*Sorghum bicolor* (L.) Moench] Seedling Morphological Characters with Shoot Fly (*Atherigona soccata* Rondani) Resistance

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A B S T R A C T

Sorghum [*Sorghum bicolor* (L.) Moench], one of the most suitable crops for rainfed agriculture facing production problem due to shoot fly (*Atherigina soccata* Rondani) infestation. So, to increase the production and reduction in the cost of cultivation, development of shoot fly resistant cultivars for rainy season is necessary. With this aim, a wide array of 112 genotypes were screened by Infester Row Technique in randomized block design for shoot fly resistance and observations on various seedling morphological characters viz., leaf sheath and plumule pigmentation (LSPP), leaf colour (LC), leaf erectness (LE), seedling height (SH), percent egg laying (%EL) and percent deadhearts (%DH) at 14 days after emergence (DAE) were recorded over consecutive two rainy seasons to study the correlation among them. Pearson correlation coefficient of pooled data over year exhibited, strong, positive, highly significant correlation of leaf sheath and plumule pigmentation (r = 0.504*), leaf erectness (r = 0.780**) and percent egg laying (r = 0.924**) with percent dead hearts at 14 DAE. The correlation of percent dead hearts was highly significant, strong, and negative with leaf colour (r = - 0.736**). Leaf sheath and plumule pigmentation had large, negative, highly significant association (r = -556**) with leaf colour. Leaf colour also had the highly significant large negative association (r = -0.630**) with leaf erectness. The association of seedling height was non-significant; negative with leaf sheath and plumule pigmentation, leaf colour, and positive with leaf erectness. This shows that seedlings with pink pigmented leaf sheath and plumule, pale yellow erect leaves and more height collectively or in combination of few of them, imparts the shoot fly resistance through non preference to egg laying. It is concluded that these closely associated traits can serve as marker and selection for more than one trait is possible at a time to speed up the shoot fly resistance breeding.

***Key words*:** *Sorghum bicolor, Atherigona soccata,* Correlation, Seedling morphological characters

Sorghum [*Sorghum bicolor* (L.) Moench] is an important nutri-cereal with health and industrial applications [9] and a leading cereal in arid and semi-arid region of global agriculture, ranking sixth by area and production [7] among the world's grain crops. Shoot fly is the most damaging pest in the seedling stage which affects the plant stand establishment and there by reduction in yield and huge economic losses to growers [15]. Recently yield losses up to 60% due to shoot fly (*Atherigona naqvii*) incidence in North India on spring maize was reported [16]. Twenty-two species of shoot fly causing economic losses to cultivated crops have been reported [8]. So, it's becoming a polyphagous pest and needs to be managed efficiently. Among the various preventive and control measures, host plant resistance is the most cost effective, eco-friendly method to reduce shoot fly damage [13]. Presently farmers don't have shoot fly resistant, agronomically acceptable sorghum hybrid cultivars to take up higher economic crop production. From this prospect an effort was made to understand the seedling morphological traits responsible for imparting shoot fly resistant and their correlation was studied to make effective use in genotype selection process of shoot fly resistance breeding program.

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MATERIALS AND METHODS

An experiment was conducted in rainy seasons of 2019 and 2020 in randomized block design at Hytech Seed India Pvt. Ltd. At /Post Pakhora, Gangapur, Aurangabad, Maharashtra. Total 112 diverse genotypes consisting of 8

CMS (cytoplasmic male sterile lines, PA1-PA8), their maintainers (PB1-PB8), 8 restorers (PR1-PR8), 64 crosses produced from 8 CMS lines and 8 restorers, 3 commercial hybrids and their 5 parents, 4 shoot fly resistant QTL introgressed lines and 4 wild relatives of sorghum were evaluated for shoot fly resistance as per the infester row screening technique [11]. Fresh seed of each genotype was produced in 2018 and 2019 post rainy seasons and used for evaluation in succeeding rainy 2019 and 2020 seasons respectively. The crop was raised as per recommended package of practices.

The data was recorded on following seedling morphological characters as per the standard scoring methods. Leaf sheath and plumule pigmentation (LSPP) was assessed on a 1 to 5 rating scale (1 = plumule or leaf sheath with a deep pink pigment, 2 = plumule or leaf sheath with a pink pigment, 3 = plumule or leaf sheath with light pink pigment, 4 = plumule or leaf sheath with very light pink pigment, 5 = plumule or leaf sheath of green colour) at 5 DAE (days after emergence), [4]. Leaf colour (LC) was scored on 1-5 rating scale at 14 DAE (1=Dark green, 2= Green, 3=Pale green, 4= pale yellow and 5= yellow). Leaf erectness (LE) was assessed on 1-5 rating scale at 14 DAE (1= Erect, 2= Semi erect, 3=Spreading, 4= semi drooping and 5= drooping). Seedling height (SH) from ground to tip of top leaf at 14th DAE was recorded in centimeter. Percent egg laying (%EL) / percent oviposition at 14 DAE was calculated based on number of plants having eggs out of total number of plants and percent dead hearts (%DH) at 14 DAE as shoot fly damage parameter were calculated by using formula:

Percent dead hearts = Numbers of plants with shoot fly dead hearts *100/Number of plants

On-line statistical tool OP STAT [14] and licensed Windostat version 9.2 (Indostat services, Hyderabad) were used for analysis of year wise RBD, Pearson correlation and pooled RBD respectively.

RESULTS AND DISCUSSION

There were significant differences among the genotypes for all the characters studied in individual year and homogeneous data from both the years was used for pooled analysis. Analysis of variance for pooled data over years shown highly significant, differences between years, genotypes and year x genotypes interaction effects for all the traits except leaf sheath and plumule pigmentation (Table 1). We observed the change in values of correlation coefficient between traits in two rainy seasons but the trend remains more or less same. Pooled mean performance of genotypes is presented in (Table 2) with mean, coefficient of variance and critical difference values, which indicates good quality data.

Table 1 Mean sum of squares for sorghum seedling morphological characters and shoot fly damage parameter from pooled data of 2019 and 2020 rainy seasons

Source of variations	DF	LSPP	LC	LE	SH	% EL	% DH 14
Replicates	2	1.451***	0.162	0.832	49.51**	959.991***	46.646
Year	1	0.595	19.001***	19.339***	5485.714***	2852.729***	35683.973***
Genotype	111	6.201***	1.327***	4.414***	130.64***	1964.178***	1984.391***
Year × Genotype	111	0.463***	1.431***	0.931***	18.531***	44.658***	135.341***
Error (B)	446	0.197	0.212	0.322	9.853	52.075	95.168
Total	671	1.238	0.626	1.13	39.548	374.037	467.232

**Significant at 1% level, ***Significant at 0.5% level

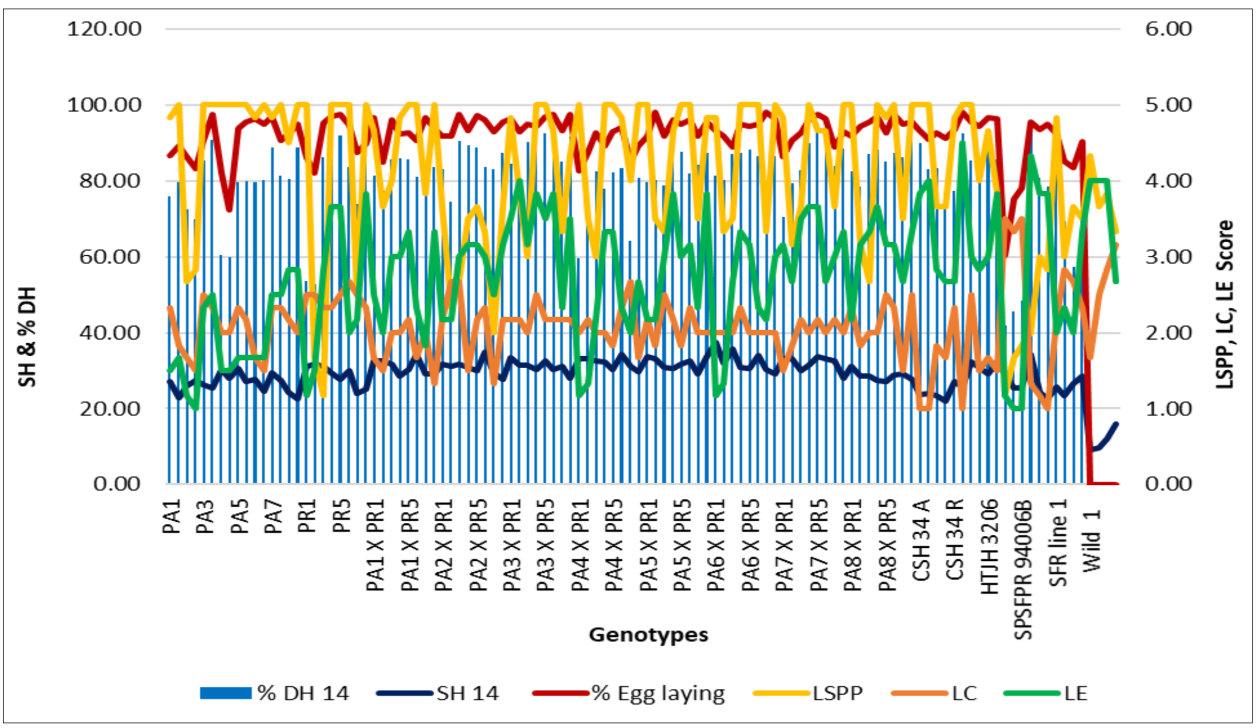

Fig 1 Association of morphological characters with shoot fly resistance

Table 2 Pooled mean performance of genotypes evaluated in 2019 and 2020 rainy seasons

Genotypes	LSPP	LC	LE	SH	Percent EL	Percent DH 14 DAE
CMS and maintainer lines						
PA1	4.83	2.33	1.50	27.17	86.78	75.98
PB1	5.00	1.83	1.67	22.83	89.25	79.73
PA2	2.67	1.67	1.17	26.00	86.42	72.65
PB2	2.83	1.50	1.00	27.50	83.26	70.06
PA3	5.00	2.50	2.33	26.17	90.55	85.50
PB3	5.00	2.33	2.50	25.33	97.48	90.70
PA4	5.00	2.00	1.50	30.17	82.10	60.49
PB4	5.00	2.00	1.50	28.00	72.22	59.88
PA5	5.00	2.33	1.67	30.67	93.81	79.61
PB5	5.00	2.17	1.67	27.17	95.63	80.01
PA6	4.83	1.67	1.67	27.67	96.30	79.63
PB6	5.00	1.50	1.67	24.67	95.06	80.25
PA7	4.83	2.33	2.50	29.33	96.87	88.69
PB7	5.00	2.33	2.50	27.33	90.62	81.27
PA8	4.50	2.17	2.83	24.17	92.45	80.39
PB8	5.00	2.00	2.83	22.67	95.04	88.77
Restorer lines						
PR1	5.00	2.50	1.17	31.17	86.17	53.63
PR2	1.67	2.50	1.50	31.67	82.03	52.73
PR3	1.17	2.33	2.83	31.00	95.36	86.29
PR4	5.00	2.33	3.67	29.50	96.87	90.60
PR5	5.00	2.50	3.67	27.67	97.53	91.86
PR6	5.00	2.67	2.00	30.00	94.75	83.57
PR7	2.50	2.50	2.17	24.00	87.58	73.93
PR8	5.00	2.33	3.83	25.00	89.78	86.08
Crosses						
PA1 × PR1	4.67	1.67	2.50	32.50	96.59	81.24
PA1 × PR2	3.67	1.50	2.00	32.67	84.99	77.43
PA1 × PR3	4.00	2.00	3.00	31.67	96.27	85.66
PA1 × PR4	4.83	2.00	3.00	28.67	92.40	86.08
PA1 × PR5	5.00	2.17	3.33	30.33	92.57	85.66
PA1 × PR6	5.00	1.67	2.33	34.17	90.55	81.20
PA1 × PR7	3.83	2.00	1.83	29.00	96.79	82.38
PA1 × PR8	5.00	1.33	3.33	29.00	93.76	83.67
PA2 × PR1	3.67	2.17	2.17	31.83	91.70	83.05
PA2 × PR2	2.33	2.67	2.17	31.17	91.73	74.52
PA2 × PR3	2.67	2.67	3.00	31.67	97.51	90.47
PA2 × PR4	3.50	1.50	3.17	30.83	93.17	89.39
PA2 × PR5	3.67	2.17	3.17	30.00	97.39	88.76
PA2 × PR6	3.33	2.33	3.00	34.83	96.25	83.63
PA2 × PR7	2.00	1.33	2.50	29.50	93.12	83.24
PA2 × PR8	3.67	2.17	3.17	27.83	95.63	87.44
PA3 × PR1	4.83	2.17	3.50	33.50	96.30	84.45
PA3 × PR2	3.83	2.17	4.00	31.50	93.09	80.77
PA3 × PR3	3.00	2.00	3.17	31.50	95.06	90.12
PA3 × PR4	5.00	2.50	3.83	30.33	94.37	91.88
PA3 × PR5	5.00	2.17	3.50	32.67	96.92	92.52
PA3 × PR6	4.67	2.17	3.83	30.17	97.53	86.28
PA3 × PR7	3.33	2.17	2.33	31.00	93.21	85.19
PA3 × PR8	4.33	2.17	3.50	28.00	97.49	91.81
PA4 × PR1	5.00	2.00	1.17	33.17	82.67	59.50
PA4 × PR2	3.50	2.17	1.33	33.00	87.65	71.61
PA4 × PR3	3.00	2.00	2.17	32.50	92.57	82.62
PA4 × PR4	5.00	2.00	3.33	32.17	89.26	77.85
PA4 × PR5	5.00	1.83	3.33	30.17	92.89	82.34
PA4 × PR6	4.83	2.33	2.33	34.33	94.25	83.51
PA4 × PR7	4.00	2.67	2.00	31.00	85.19	64.20
PA4 × PR8	5.00	1.67	2.67	29.83	89.13	80.72
PA5 × PR1	5.00	2.17	2.17	33.67	91.72	79.61
PA5 × PR2	3.50	1.83	2.17	33.00	98.25	80.10
PA5 × PR3	3.33	2.50	3.00	30.83	91.95	78.78
PA5 × PR4	4.67	2.17	3.83	30.50	96.23	88.06

PA5 × PR5	5.00	1.83	3.00	31.83	95.02	87.56
PA5 × PR6	5.00	2.33	3.17	32.50	96.25	81.82
PA5 × PR7	3.50	2.00	2.33	29.00	91.71	84.13
PA5 × PR8	4.83	2.00	3.83	33.83	95.68	87.40
PA6 × PR1	4.83	2.00	1.17	37.50	93.21	81.48
PA6 × PR2	3.33	2.00	1.33	32.00	91.98	80.25
PA6 × PR3	3.50	2.00	2.67	35.83	88.89	87.04
PA6 × PR4	5.00	2.33	3.33	30.83	94.99	87.54
PA6 × PR5	5.00	2.00	3.17	30.67	94.40	88.20
PA6 × PR6	5.00	2.00	2.33	34.00	95.06	86.42
PA6 × PR7	3.33	2.00	2.17	30.33	98.15	79.59
PA6 × PR8	5.00	2.00	3.00	29.17	96.30	86.42
PA7 × PR1	4.83	1.50	3.17	33.00	86.42	70.37
PA7 × PR2	3.17	1.83	2.67	33.00	90.65	79.49
PA7 × PR3	3.67	2.17	3.50	30.00	92.60	82.72
PA7 × PR4	5.00	2.00	3.67	31.33	96.25	90.03
PA7 × PR5	4.67	2.17	3.67	33.83	97.53	94.40
PA7 × PR6	4.67	2.00	2.67	33.17	96.27	88.75
PA7 × PR7	3.67	2.17	3.00	32.67	88.89	83.96
PA7 × PR8	5.00	2.00	3.33	28.00	92.99	88.48
PA8 × PR1	5.00	2.33	2.17	31.00	91.95	82.67
PA8 × PR2	3.17	1.83	3.17	28.67	94.45	78.40
PA8 × PR3	2.67	2.00	3.33	28.50	95.68	87.04
PA8 × PR4	5.00	2.00	3.67	27.33	96.91	88.13
PA8 × PR5	4.83	2.50	3.17	27.17	92.57	85.16
PA8 × PR6	5.00	2.33	3.17	28.83	97.51	87.42
PA8 × PR7	3.50	1.50	2.67	29.00	94.99	86.33
PA8 × PR8	5.00	2.50	3.33	27.83	95.58	90.51
Commercial hybrid parents						
CSH 34 A	5.00	1.00	3.83	23.67	93.16	90.01
CSH 34 B	5.00	1.00	4.00	24.00	90.94	83.13
CSH 37 A	3.67	1.83	2.83	23.33	92.60	83.33
CSH 37 B	3.67	1.67	2.67	22.00	91.16	76.89
CSH 34 R	4.83	2.33	2.67	27.00	93.69	77.41
HTJH 3206 R	5.00	1.00	4.50	25.83	98.12	92.47
CSH 37 R	5.00	2.50	3.00	32.17	95.63	85.51
Commercial hybrids						
CSH 34	4.00	1.50	2.83	30.83	94.40	85.49
HTJH 3206	4.67	1.67	3.00	29.00	96.82	92.97
CSH 37	3.83	1.50	3.83	32.17	96.30	85.80
Shoot fly resistant lines						
IS 18551	1.17	3.50	1.17	29.00	60.39	41.95
SPSFPR 94006A	1.67	3.33	1.00	25.33	75.11	45.51
SPSFPR 94006B	1.83	3.50	1.00	25.50	78.10	48.59
Shoot fly susceptible lines						
IS 3578	2.00	1.33	4.33	34.33	95.58	95.58
296A	3.00	1.17	3.83	24.33	93.68	80.72
296B	2.83	1.00	3.83	22.67	94.85	78.58
Shoot fly resistance QTL introgressed lines						
SFR line 1	4.83	2.17	2.00	25.83	92.48	84.60
SFR line 2	3.00	2.83	2.33	23.50	85.13	69.35
SFR line 3	3.67	2.67	2.00	26.67	83.54	57.34
SFR line 4	3.50	2.33	3.33	28.50	90.31	80.16
Wild relatives of sorghum						
IS 18944	4.33	1.67	4.00	9.17	0.00	0.00
IS 18945	3.67	2.50	4.00	9.67	0.00	0.00
IS 18947	3.83	2.83	4.00	11.83	0.00	0.00
IS 14275	3.33	3.17	2.67	15.83	0.00	0.00
Mean	4.12	2.09	2.74	28.91	88.87	78.26
C.V.%	10.78	22.03	20.73	10.86	8.12	12.47
C.D. (Bi-Bj) at 5%	0.50	0.52	0.64	3.56	8.19	11.07

Association of characters

Correlation is a bivariate analysis that measures the strength of association between two variables and the direction of the relationship. Pearson *r* correlation is the most widely used correlation statistics to measure the degree of the relationship between linearly related variables. (Table 3) indicates the correlation/association of different morphological characters with shoot fly damage parameter and is discussed below:

Percent dead hearts at 14 DAE

There was a significant, strong and positive correlation between % dead hearts and leaf sheath and plumule pigmentation (*r*= 0.504*). This means higher intensity of anthocyanin pigmentation was associated with less damage/ dead hearts by shoot fly. Similar findings were reported by [4, 2]. Whereas, negative association of pigmentation with oviposition, and dead hearts at 14 DAE was observed [1]. Positive correlation between oviposition and dead heart, was reported [1], which is in line with the present finding of highly significant, large, positive (*r* = 0.924**) correlation between percent oviposition and dead hearts. Similar observations were also reported [5], saying shoot fly susceptibility is significantly and positively associated with egg load per plant and per cent oviposition. Also, the highly significant, large, negative association of leaf colour (*r* = - 0.736**) and highly significant, large, positive association of leaf erectness (r = 0.780**) with percent dead hearts indicates pale green to pale yellow leaves with erect leaf type contributed to shoot fly resistance. This finding is in line with [5], who reported dead heart percentage was negatively correlated with light green colour of leaves, erect leaves, and seedling height. But this study shows non-significant positive association of dead heart percent with seedling height. The less shoot fly damage in deep pink pigmented leaf sheath and plumule, pale green to pale yellow leaf colour and erect leaves type genotypes indicates potential for shoot fly resistance. So, these traits can be used as maker traits for selection of shoot fly resistant genotypes.

Percent egg laying at 14 DAE

Large, positive and significant association of oviposition percentage with leaf sheath and plumule pigmentation (*r* = 0.515*) and leaf erectness (*r* = 0.692**) indicates pigmented, erect leaf type genotypes shows less oviposition. Whereas, large, negative, highly significant correlation with leaf colour (r = -0.649**) indicates less oviposition on pale green to pale yellow genotypes. Less oviposition on pigmented, erect and light green genotypes was reported [5]. Whereas, negative association of pigmentation with oviposition was reported [1]. Seedling height had non- significant positive correlation with oviposition. Significant correlation of percent oviposition with dead heart formation was reported [3]. Oviposition and leaf sheath pigmentation were associated with the expression of resistance/susceptibility to shoot fly, and these can be used as marker traits to select and develop shoot fly-resistant sorghums [10].

The result shows that genotypes with green leaf sheath and plumule pigmentation, spreading to drooping leaves and towards dark green leaf colour was preferred by shoot fly female for egg laying. This indicates that these traits contribute to shoot fly susceptibility as there was strong, significantly positive correlation between percent oviposition and percent dead hearts.

Seedling height at 14 DAE

Leaf sheath and plumule pigmentation and leaf colour had negative non-significant small association with seedling height. It also had non-significant, small but positive association with leaf erectness. Present study indicates not much association of seedling height with shoot fly resistance as seen from the small, non-significant positive association of seedling height with percent egg laying and percent dead hearts. Present findings are in close proximity to reports of [5]. Whereas, negative association of seedling height with dead heart percentage was reported [12].

Leaf erectness

Leaf erectness and leaf colour had highly significant, large, negative association (*r* = -630**). This shows, genotypes with erect leaves had pale green to yellowish leaves which were reported as shoot fly resistance contributing traits [5]. Higher oviposition in spreading type genotypes may be due to preference by shoot fly female for egg laying and less percent egg laying and less percent dead heart on erect leaved genotypes may be attributed to difficulty for egg laying and movement of larva to whorl of leaf. This finding is in line with [5]. Non-significant positive association was observed between pigmentation and leaf erectness in the present study.

Leaf colour

Highly significant, large and negative (*r* = -0.556**) correlation of leaf colour with leaf sheath and plumule pigmentation, and significant positive correlation (*r* = 0.924**) between percent egg laying and percent dead hearts indicates association of pale green to pale yellow leaf colour with deep pigmented genotypes. This may be because of reflection of light from leaf surface, which influence the oviposition behaviour of shoot fly females [12].

Table 3 Pearson correlation coefficient (r) between seedling morphological characters and shoot fly damage parameter in rainy season 2019 and 2020

Traits	LSPP	LC	LE	SH @14 DAE	Percent EL @ 14 DAE	Percent DH @ 14 DAE
LSPP	1					
LC	-0.556**	1				
LE	0.273NS	-0.630**	1			
SH @14 DAE	-0.150NS	-0.204NS	0.221NS	1		
Percent EL @ 14 DAE	0.515*	-0.649**	0.692**	0.228NS	1	
Percent DH @ 14 DAE	0.504*	-0.736**	0.780**	0.213NS	0.924**	1

**Significant at 1% level, ***Significant at 0.5% level

CONCLUSION

It can be inferred from present investigation that high intensity of pink leaf sheath and plumule pigmentation, pale green to pale yellow leaves and erect leaf plant type contribute to shoot fly resistance. All these traits deter shoot fly females from egg laying and results in less damage. The favourable association among these traits will help to select for two or more traits together, which will help in faster progress towards shoot fly resistance development.

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LITERATURE CITED

1. Apotikar DB, Venkateswarlu D, Ghorade RB, Wadaskar RM, Patil JV, Kulwal PL. 2011. Mapping of shoot fly tolerance loci in sorghum using SSR markers. *Journal of Genetics* 90: 59-66.
2. Chamarthi SK, Sharma HC, Sahrawat KL, Narasu LM, Dhillon MK. 2010. Physio-chemical mechanisms of resistance to shoot fly, *Atherigona soccata* in *Sorghum bicolor. Journal of Appl. Entomol*. doi:10.1111/j.1439-0418.2010.01564. x
3. Deshpande VP, Kamatar MY, Kathnalli DS, Malleshappa SM, Nayakar NY. 2003. Screening of sorghum genotypes against shoot fly. *Indian Jr. Plant Protection* 31(1): 91-93.
4. Dhillon MK, Sharma HC, Ram S, Naresh JS. 2005. Mechanisms of resistance to shoot fly *Atherigona soccata* in sorghum. *Euphytica* 144: 301-312.
5. Kamatar MY, Patil AM, Yadwad Arati, Salimath, PM, Swamy Rao T. 2010. Correlation and path analysis in parents and hybrids for resistance to sorghum shoot fly [*Atherigona soccata* (Rondani)]. *International Journal of Plant Sciences* 5(2): 399-403.
6. Khurana AD, Verma AN. 1985. Some physical plant characters in relation to stem borer and shoot fly resistance in sorghum. *Indian Journal of Entomology* 47: 14-19.
7. Lee TH, Amber, NH, Hannah R, Scott AJ, Soraya CM, Leal-Bertioli, Mark T, Caixia G, Ian DG, Ben JH, Brande BHW. 2019. Breeding crops to feed 10 billion. *Nature Biotechnology*. https://doi.org/10.1038/s41587-019-0152-9
8. Prabhu C, Ganiger. 2020. 50^{th} and 31^{st} virtual group meetings of All India Coordinated Research (AICRP) on Sorghum and Small Millets on 29.05.2020. *Small Millets Entomology, Progress and Achievements 2019-20*. www.millets.res.in/aicsip19_sm.php. accessed on 25 July, 2020.
9. Kumari P, Kumar V, Kumar R, Pahuja SK. 2021. Sorghum polyphenols: plant stress, human health benefits, and industrial applications. *Planta* 254: 47. https://dpi.org/10.1007/s00425-021-03697-y
10. Riyazaddin M, Polavarapu, B, Kavi Kishor, Are AK, Reddy BVS, Munghate RS, Sharma HC. 2015. Mechanisms and diversity of resistance to sorghum shoot fly, *Atherigona soccata*. *Plant Breeding* 134: 42—436. doi:10.1111/pbr.12276
11. Sharma HC, Taneja SL, Kameswara Rao N, Prasada Rao KE. 2003. Evaluation of sorghum germplasm for resistance to insect pests. Information Bulletin No. 63. Patancheru 502 324, Andhra Pradesh, India: *International Crops Research Institute for the Semi–Arid Tropics*. ISBN 92-9066-458-4. Order code IBE 063. pp 184.
12. Sharma HC, Nwanze KF. 1997**.** Mechanisms of resistance to insects in sorghum and their usefulness in crop improvement. Information Bulletin No. 45. *International Crops Research Institute for the Semi-Arid Tropics*, Patancheru- 502 324, Andhra Pradesh, India. pp 51.
13. Sharma HC, Reddy BVS, Dhillon MK, Venkateswaran K, Singh BU, Pampapathy G, Folkertsma RT, Hash CT, Sharma KK. 2005. Host plant resistance to insects in sorghum: Present status and need for future research. *SAT eJournal | ejournal.icrisat.org*. 1(1).
14. Sheoran OP, Tonk DS, Kaushik LS, Hasija RC, Pannu RS. 1998. Statistical software package for agricultural research workers. Recent Advances in information theory, Statistics and Computer Applications by D.S. Hooda and R.C. Hasija Department of Mathematics Statistics, CCS HAU, Hisar. pp 139-143.
15. Sonone CV, Thakare SV, Aware SA, Ghorade RB. 2015. Evaluation of shoot fly tolerance derived lines in sorghum. *Int. Jr. Curr. Microbiol. App. Sciences* 4(12): 166-177.
16. Vikal Y, Kaur A, Jindal J, Kaur K, Pathak D, Garg T, Singh A, Singh P, Yadav I. 2020. Identification of genomic regions associated with shoot fly resistance in maize and their syntenic relationships in the sorghum genome. https://doi.org/10.1371/journal.pone.0234335