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Occurrence of the sorghum midge (*Stenodiplosis sorghicola*, Diptera: Cecidomyiidae), development cycle and resistance of different sorghum lines in Senegal

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Abstract
Sorghum grain is generally used as food, feed or in agri-food industries in Senegal. Despite this importance, the yield remains low with gaps of more than 1 $t.ha^{-1}$ compared to potentials of registered varieties. Several sorghum production limiting factors included sorghum midge. To manage this pest and reduce damage, various management methods are used. This study aimed at determining the occurrence of the midge and the duration of sorghum development of tested lines in relation to their resistance. The experiments were done during the cropping seasons of 2016 and 2017 where sorghum midge are abundant at Roff on the western side of the Senegalese Groundnut Basin. Sorghum midges began emerging in October and peaked in mid-November. Time to 50% flowering varied from 56 to 75 days. Severity of damage by midge scored between 3 and 7 for all lines. Three lines were moderately resistant to sorghum midge.

Keywords: Sorghum, midge, population dynamics, resistance, Senegal

Introduction
Originating in Eastern Africa and belonging to Poaceae, sorghum [*Sorghum bicolour* (L.) Moench] is one of the staple foods for subsistence people in the semi-arid and tropical areas of Asia and Africa. It is grown worldwide, but most production is in American and Asian countries [1, 2]. The grains are consumed in different forms [3, 4]. The average yield of 939 $kg.ha^{-1}$ recorded in Senegal is below the potential of improved varieties estimated at 2-6 $t.ha^{-1}$ *i.e.* a gap of 56 to 85% [5]. The gap is due mainly to abiotic and biotic stress such as poor agricultural practices, erratic rainfall, low soil fertility, unfavourable socio-economic conditions related to low income levels, weeds, diseases and insect pests [6]. The sorghum midge, *Stenodiplosis sorghicola* (Coquillet) (Diptera: Cecidomyiidae) is one of the most damaging insect pests of the crop in Senegal. The females of *S. sorghicola* emerge around 26-32 ^oC and start laying eggs on sorghum panicle spikelets two hours later after the peak populations. After hatching, larvae start eating the ovaries of the flowering sorghum leaving glumes empty (without grains) for the infested panicles [7]. When the second generation of midge coincided with the maximum plants flowering in a field, economic damage can be reached [8]. Many methods including good agricultural practices, insecticide application, biological control and use of resistant cultivars have been used for the management of sorghum midge. Some of these control methods have a very limited effectiveness in a short rain durations context or larvae, the damaging stage are protected inside the glumes for susceptible material. According to the day time flowering and a long duration of the flowering of sorghum lines lead to severe midge damaged if no action is taken [8]. The use of resistant varieties is the most environmentally friendly without any additional cost for farmers [9, 10].

This work is helping to develop a framework for a sorghum integrated pest management programme. It aimed at identifying sources of resistance to the sorghum midge and studying its population dynamics in relationship with flowering periods of the tested sorghum lines.

Material and Methods

Study area

The experiment was done at a farm in Roff located in the community of Malicounda, County of Mbour area (14°17'42' North, 16°52'3' West) in the Western part of the Groundnut Basin Centre within the Province of Thies (Senegal). It is one of the main sorghum production areas and very infested by sorghum midge (Figure 1)

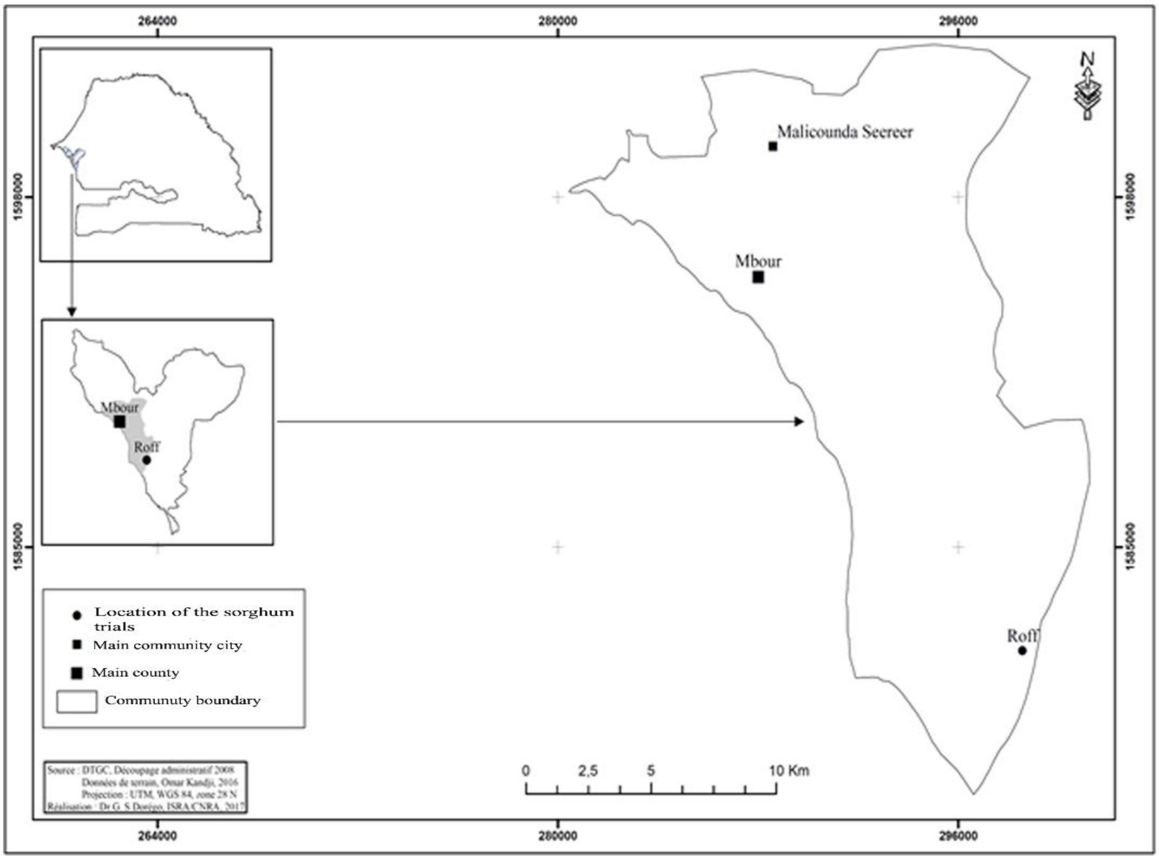

Fig 1: Map of the site and study area where sorghum was studied for resistance to sorghum midge.

Rainfall

The cropping season in both years was July to the end of September *i.e*. 2.5 months duration with an annual rainfall of 451 and 514 mm in 2016 and 2017, respectively. The rainfall period was shorter than normal, with a daily average of 20.5 and 23.4 mm in 2016 and 2017, respectively (Figure 2).

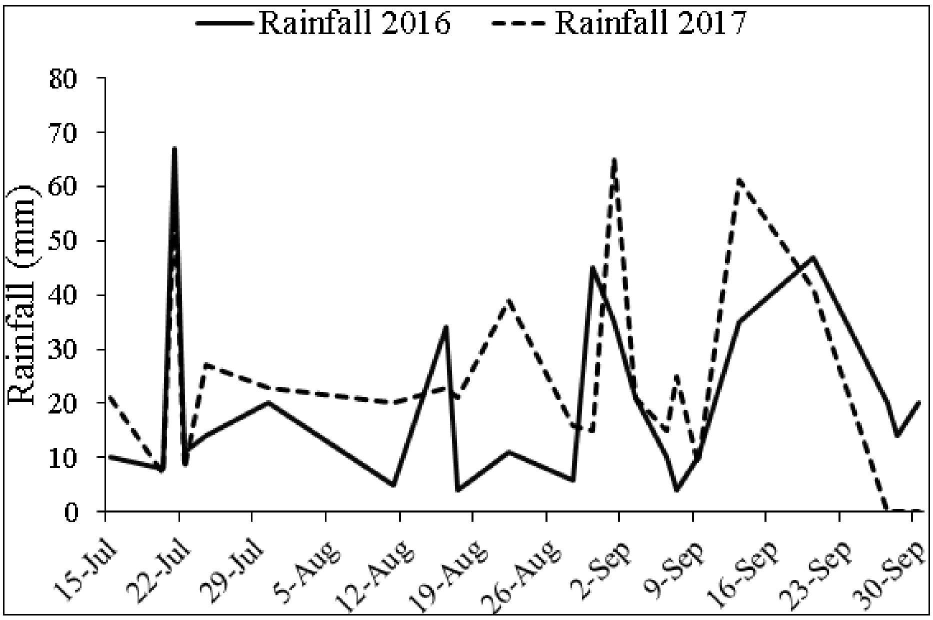

Fig 2: The rainfall pattern in Roff area in 2016 and 2017

Plant material

Nineteen (19) sorghum lines from Texas A & M AgriLife Research (USA) with different character traits were used during the study (Table 1).

Table 1: The characteristics of the different sorghum lines from Texas A & M AgriLife Research
SC: Susceptible Check, RC: Resistant Check, PC: Panicle Colour, GC: Grain Colour, P: Purple, R: Red, T: Tan, PR: Purple Red, W: White.

Code/Entry	Lines	Status	PC	GC
L1	BTx3042	SC	P	R
L2	BTx643	SC	P	W
L3	RTx430	SC	P	W
L4	Tx2782	RC	P	W
L5	BTx2755	RC	P	R
L6	Tx2767	RC	P	R
L7	Tx2880	RC	PR	W
L8	Tx2882	RC	P	W
L9	Tx2883	RC	PR	W
L10	MB108B/P.G.	R	PR	W
L11	TAM2566	RC	P	W
L12	B8PR1011	R	PR	W
L13	(Tx2880*(97M1/(PM12713*Tx2766)))-BE24-CM2-CM2	R	T	W
L14	(Tx2880*(97M1/(PM12713*Tx2766)))-BE31-CM2-CM2	R	T	W
L15	(9MLT176/(MR112B-92M2*Tx2880)*SV1)-CA3-CABK-CMBK	R	T	W
L16	(Tx2880*(97M1/(PM12713*Tx2766)))-BE31-CM2-CM2-CMBK-CMBK	R	T	W
L17	((R.9519/((SC120*Tx7000)*Tx2817))*MB108B/P.G.)-LG35-CA1-CM2-CM1	R	T	W
L18	(Tx2883*Tegemeo)-H2-CM1-CM1	R	PR	W
L19	((B.HF14/(B1*BTx635))*B8PR1011)-BE8-CA1-CG1-LM2	R	T	W

Experimental Design

A completely randomized block design with three replications was used. Sorghum was sown in a well-ploughed field previously fallow 30 days after the first sufficient rain of 20 mm or more with a spacing of 0.8 m between rows and 0.4 m within rows. Plants were thinned to three per row two weeks later *i.e.* a density of 930.750 plants ha^{-1}. Top dressing with a complex fertilizer (NPK 15.15.15) was applied at 150 kg ha^{-1} during soil preparation. Urea (50% nitrogen) at a rate of 50 kg ha^{-1} was applied in two parts, at two weeks after seedling germination and two weeks later. Weeding was done manually on demand.

Time to 50% flowering of sorghum lines

For each sorghum line, the date to 50% flowering was recorded when 50% of plants had flowered.

Occurrence and population dynamics of sorghum midge

To detect the flight and number of sorghum midges, yellow sticky traps of 20 cm x 20 cm size coated with odourless and transparent glue (TRAPCOLL) were placed at panicle height in the row of each sorghum line from flowering until the harvesting period. Numbers of sorghum midges were recorded at three-day intervals.

Evaluation and scoring of damage by sorghum midges

To assess damage by sorghum midge as well as resistance of the sorghum line, all the panicles were observed and given a score at maturity on a scale of 1 to 9 [11] where 1 is equal or less than 10% of the spikelets damaged; 2 is 11 to 20% of spikelets damaged; 3 is 21 to 30% of spikelets damaged; 4 is 31 to 40% of spikelets damaged; 5 is 41 to 50% of spikelets damaged; 6 is 51to 60% of spikelets damaged; 7 is 61 to 70% of spikelets damaged; 8 is 71 to 80% of spikelets damaged and 9 is more than 81% of spikelets damaged by sorghum midge.

To characterize the resistance status of the different sorghum lines a scale by [11] was adapted for scoring damage by sorghum midge (Table 2).

Table 2: Scoring for midge damage for resistance status.

Interval scores for panicle midge damage	Status
Score ≤ 1	High Resistance
1 < Score ≤ 3	Resistance
3 < Score < 5	Moderate Resistance
5 ≤ Score ≤ 7	Susceptible
Score > 7	Highly susceptible

Data Analysis

Analysis of variance (ANOVA) was done using SAS 9.1 software with the Least Significant Difference (LSD) test for mean separation at $\alpha = 0.05$. Before analysis of variance and for eliminating heteroscedasticity, all data (except those related to 50% flowering) were transformed using $\log_{10}(X+1)$ where X corresponded to count variables *i.e.* number of sorghum midge and damage scores.

Results

Sorghum midge abundance and population dynamics

Sorghum midges were in the experimental plots from the end of October before disappearing at the beginning of December during both cropping seasons of 2016 and 2017. The mean number of sorghum midges increased gradually for 12 days before increasing rapidly in abundance to a peak of 4726 individuals per day between the end of October and mid-November, then decreased rapidly to a minimum of 79 individuals per day at the end of November and beginning of December (Figure 3).

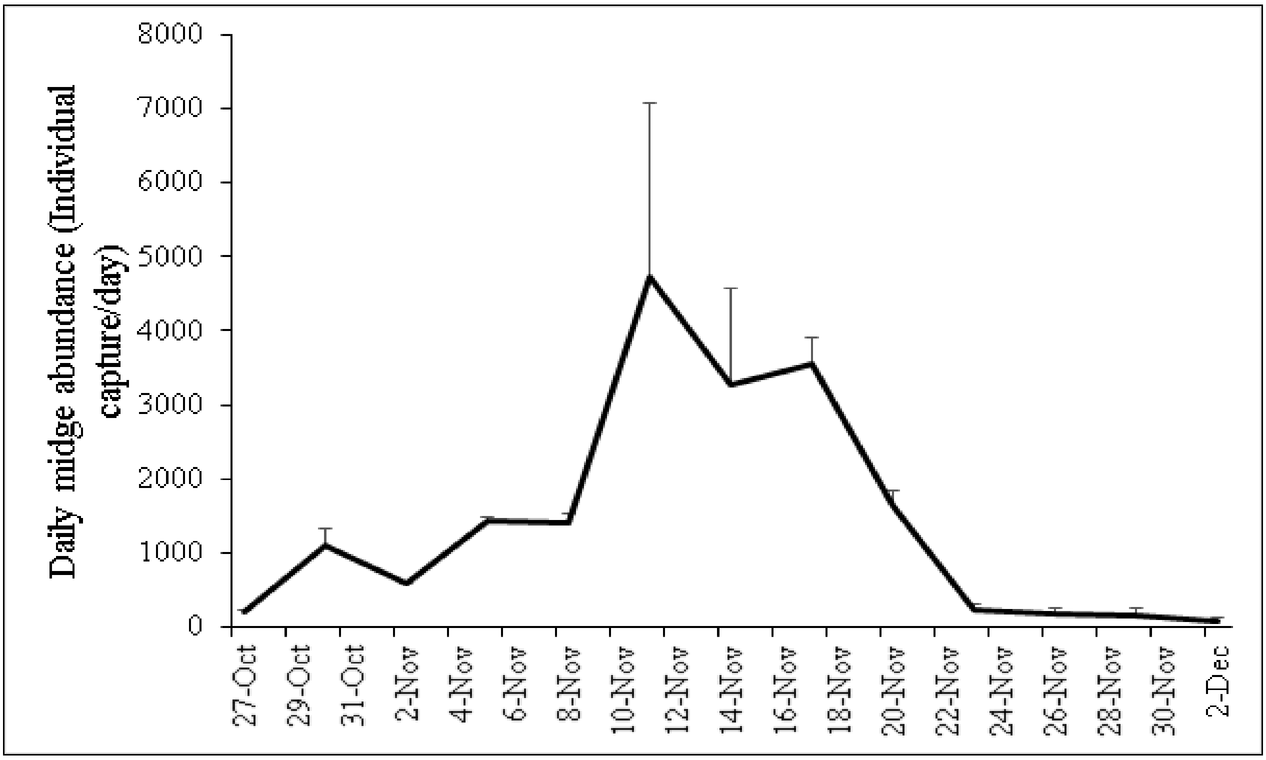

Fig 3: Average numbers of sorghum midges over time at Roff in 2016-2017.

Abundance of the sorghum midge

The abundance of sorghum midge varied between 9 ± 3 and 92 ± 42 individuals per panicle. Sorghum lines L5, L7 and L11 were infested with only 9 ± 2, 13 ± 2 and 9 ± 3 individuals per panicle, respectively. In contrast, sorghum midges were very abundant with 92 ± 42 individuals per panicle of L13 and abundant on L3, L6, L10 and L17 with 62 ± 44, 48 ± 21, 56 ± 4 and 65 ± 14 individuals per panicle, respectively (Figure 4).

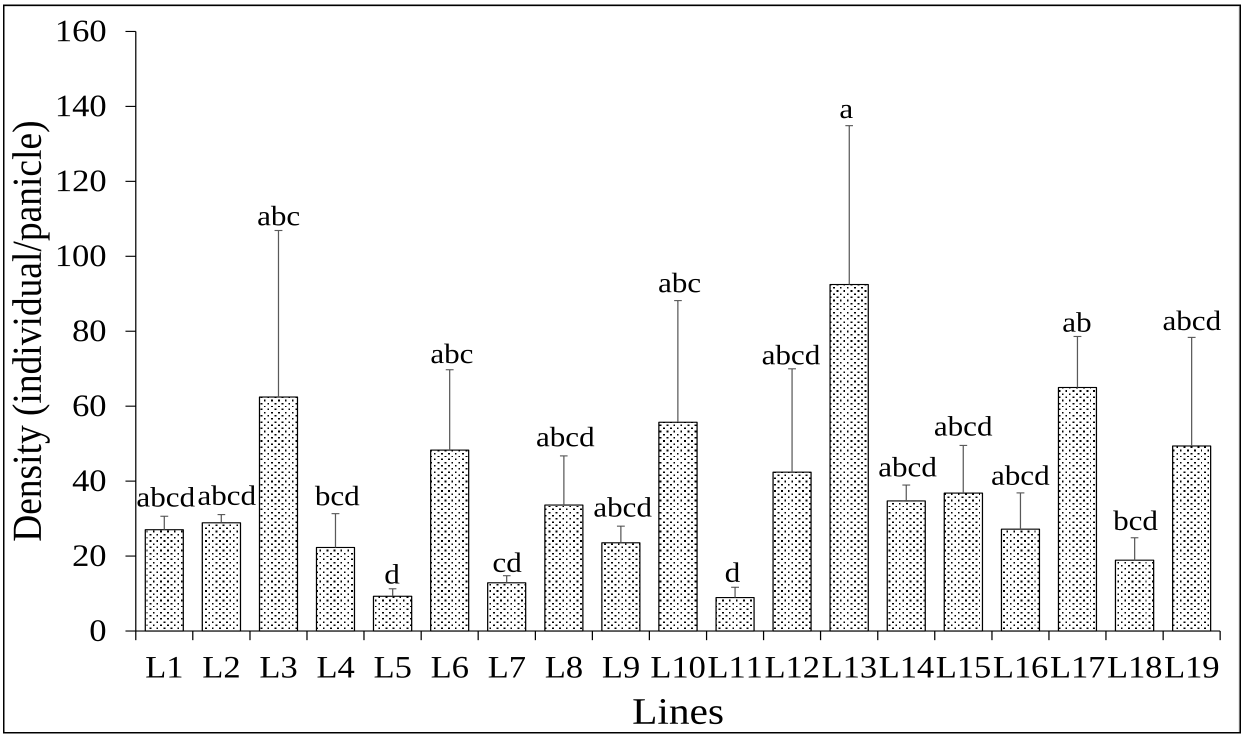

Fig 4: Abundance of sorghum midge on sorghum lines at Roff. Means followed by the same letter are not significantly different.

Time to 50% flowering for sorghum lines

Time from sowing to 50% flowering of sorghum lines varied between 56 ± 10 and 75 ± 1 days. Lines L1 and L5 were the earliest with 56 ± 10 and 57 ± 11 days, respectively. Lines that began flowering latest were L2, L9, L10, L13, L14, L15 and L18 with 70 ± 1, 74 ± 4, 71 ± 3, 75 ± 1, 71 ± 1, 73 ± 4 and 75 ± 2 days, respectively, to 50% flowering (Figure 5).

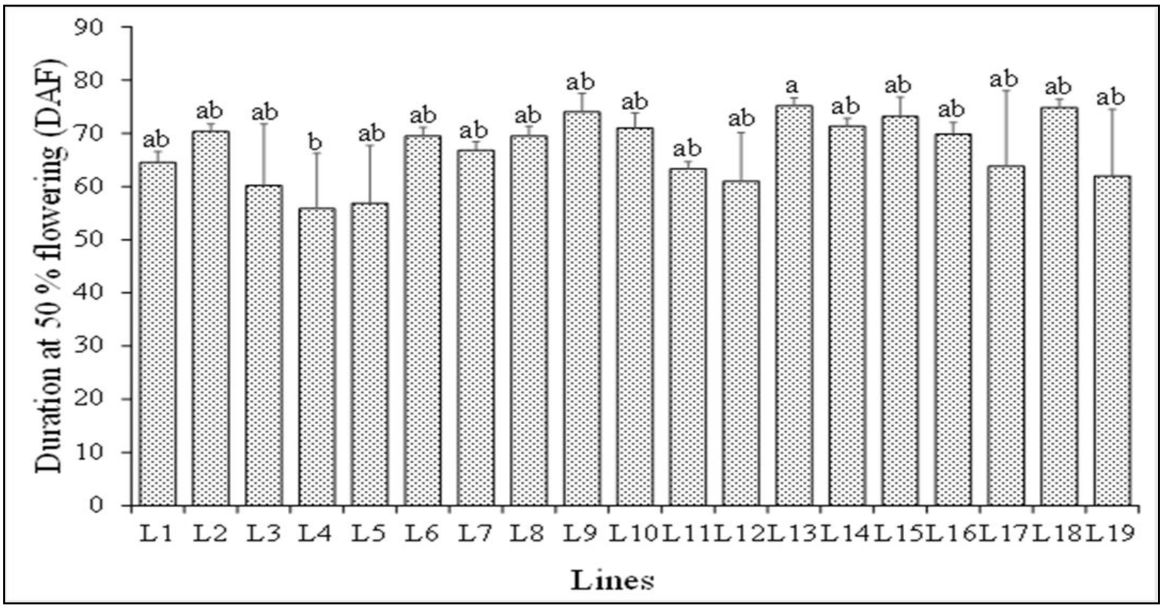

Fig 5: Time to 50% flowering of different sorghum lines at Roff. Means followed by the same letter are not significantly different.

Midge damage scores for sorghum line

Midge damage to sorghum panicle was significantly less on L4, L5 and L19 with scores of 3 ± 1, 3.9 ± 1 and 4 ± 1, respectively. The three lines were moderately resistant to sorghum midge. All other lines with scores greater than 5 were very susceptible to and damaged by midge including lines L1, L2, L3, L6, L7, L9, L10, L11, L12, L13, L15, L16, L17 and L18. However, the most significantly damaged and susceptible line was L8 with a score of 7 ± 1 (Table 3).

Table 3: Mean score (± standard error) of damage by sorghum midge and resistance status of different sorghum lines. S: Susceptible, MR: Moderate Resistance. Means followed by the same letter are not significantly different.

Code/Entry	Lines	Score (±SE)	Status
L1	BTx3042	7±1ab	S
L2	BTx643	6±1ab	S
L3	RTx430	6±1abc	S
L4	Tx2782	3±1c	MR
L5	BTx2755	4±1bc	MR
L6	Tx2767	7±1ab	S
L7	Tx2880	5±1abc	S
L8	Tx2882	7±1a	S
L9	Tx2883	7±1ab	S
L10	MB108B/P.G.	7±1ab	S
L11	TAM2566	6±0abc	S
L12	B8PR1011	6±1abc	S
L13	(Tx2880*(97M1/(PM12713*Tx2766)))-BE24-CM2-CM2	7±1ab	S
L14	(Tx2880*(97M1/(PM12713*Tx2766)))-BE31-CM2-CM2	5±1abc	S
L15	(9MLT176/(MR112B-92M2*Tx2880)*SV1)-CA3-CABK-CMBK	6±0abc	S
L16	(Tx2880*(97M1/(PM12713*Tx2766)))-BE31-CM2-CM2-CMBK-CMBK	6±1ab	S
L17	((R.9519/((SC120*Tx7000)*Tx2817))*MB108B/P.G.)-LG35-CA1-CM2-CM1	6±1abc	S
L18	(Tx2883*Tegemeo)-H2-CM1-CM1	6±1ab	S
L19	((B.HF14/(B1*BTx635))*B8PR1011)-BE8-CA1-CG1-LM2	4±1bc	MR

Discussion

Sorghum midge occurred in the Roff area of Senegal from the end of October for almost a month after the end of the rains in 2016 and 2017. Sorghum midges quickly increased in abundance during two weeks when daily temperatures were relatively warm in October until they disappeared three week later in November. According to [12] the greatest period of abundance of *S. sorghicola* coincided with the months of November and March even though sorghum panicle production was year around. The pest seems to prefer dry areas and relatively hot weather of about 30 ºC. Increase in abundance of sorghum midge might be triggered by rain and related to availability of flowering of susceptible sorghum panicles with favourable temperatures in the area, with no or very low pressure by natural enemies [13, 12]. At 30 ºC, the midge life cycle is about two week but doubles at 20 ºC when weather is cooler [13]. Because a sorghum midge can lay as many as 100 eggs during the life time, the population build-up can be very fast in one or two generations. Also, flowering panicles were scarce in the plots at the end of November and early December when temperature was cooler than 20 ºC most of the days. This led to decrease in abundance of sorghum midge with the last generation undergoing diapause for the next season. Delay in the sowing dates and production cycles of the sorghum lines caused the flowering periods to coincide with the emergence of sorghum midge [14]. This allowed longer exposure of the line to natural infestation by sorghum midge and evaluation for resistance.

Lines L4, L5 and L19 reached 50% flowering faster when sorghum midge were less abundant per panicle, and subsequent damage and score were lower. Surprisingly, resistant checks L6, L7, L8, L9, L10 and L11 were susceptible to sorghum midge in addition to all other tested lines. For lines L4, L5 and L19, this might have been due to moderate resistance in the line related to lack of synchronism between sorghum midges and the flowering period or the shorter period of time glumes of resistant sorghums opened daily during flowering [15] or because long glumes if not opened could be a physical barrier to oviposition by sorghum midges [16, 17, 18]. Characteristics of flowering structures or duration might partly explain vulnerability when sorghum midges were abundant. Authors [19] showed that early-maturing lines were less damaged than late-maturing ones by sorghum midge. According to [19], sorghum with compact panicles were infested by fewer midge adults, similar to the tested lines L4, L5 and L19. Authors [20, 17, 21] showed that egg-laying efficiency by sorghum midges on resistant varieties like RTx430 (L3) differed from that on susceptible sorghums with longer stigmas and anthers [20, 22].

Conclusion

At Roff, sorghum midges occurred in November after the rainy season, peaked in abundance in November, and went into diapause in December when temperatures cooled. Only sorghum lines L4, L5 and L19 were resistant to sorghum midge which might be because of lack of synchronism between flowering and abundant sorghum midge as well as long glumes and short stigmas of the lines. These sources of resistance to sorghum midge can be used in West African breeding programmes to improve interesting susceptible local sorghum material.

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