Original Research Article

Determination of twelve sorghum (*Sorghum bicolor* L. Moench) varieties status to midge damage in hotspot areas of Burkina Faso

ABSTRACT

Sorghum is a staple food for millions of people in rural areas of Burkina Faso and is the most important crop grown all over the three different climatic zones. However, in the eastern part of the country, its production is considerably reduced by sorghum midge, *Stenodiplosis sorghicola* (Coquillet, 1898). In this investigation, 12 sorghum varieties were assessed in midge hotspot areas (Fada) to determine their status to midge damage. The trial was set up in hotspot areas (Fada) during two years (2022 and 2023) and keys traits such as heading time, midge damage and grain yield were collected. Overall, tested varieties had different plant cycle, different midge damage score and different grain yield across years, but the result revealed that varieties performances in hotspot site were strongly linked to heading time and midge damage. Finally, the study revealed three groups status of tested varieties to midge attacks. The first group (Kouria, Kapelga and ICSV 1049) was constituted of materials that heading time or glume opening stage did not synchronized well with gall midge egg-laying period and are there tolerant to the insect by escapism mechanism. The second group (Sariaso 40 and Sariaso 41) was constituted of varieties that heading time synchronized with insect egg-laying period and important insect number in the field but with less damage on grain yield was recorded. Those varieties are tolerant and are probably using combination of mechanism (to be clarified) to avoid midge attacks. The third groups (PR3009B, 014-SB-EPDU-1004, 12B, Sariaso 39, Sariaso 42 and Sariaso 43) are constituted of varieties that headed lately with synchronization of glumes opening time to gall-midge egg-laying period. Unfortunately, midge attacks were important and damaged considerably their yield. Those varieties are susceptible to the insects.

Key words: *Stenodiplosis sorghicola*, Sorghum varieties, midge damage, tolerance, Burkina Faso

1. INTRODUCTION

Sorghum is one of the most important cereals grown in semi-arid tropic areas of the world and constituted a staple food for millions of people in Sahelian zones of Africa [1]. In Burkina Faso, sorghum constituted with millet the basis of food crop for rural population (Bal, 2005). It is the first cereal in Burkina Faso in terms of growing area and production [2, 3] and used as source of forage for cattle, small ruminants and poultry. It is cultivated in the three different agro-climatic areas of the country with an estimated production of 2 100 036 tons on about 2 007,650 ha in 2022 [3].

However, its production remains low in Sub-Saharan countries compared to yield in developed countries. In Burkina Faso, the National Center of Research and Scientific Technology (CNRST) [4] reported in 2002 a yield of 887 kg/ha and later on, in 2019, the Ministry of Agriculture and Hydraulic management (MAAH) [2] reported 982 kg/ha which are all less than 1 ton/ha. The low production is obvious and due to many reasons, such as low adoption of high yielding improved varieties in one hand and damage linked to biotic and abiotic constraints that considerably lessen its yield in other hand. In fact, many authors such as Zongo [5], Barro/Kodombo [6] Ouédraogo *et al* [7] and Compaore *et al* [8] reported that sorghum production in Burkina Faso is mainly ensured by local landraces (around 70%) that are low yielding potential materials [6,7] compared to improved which are recognized with better yield potential.

Biotics constraints such as diseases, weeds (striga), insects' pests and among them, sorghum midge [(*Stenodiplosis = Contarinia) sorghicola* (Coquillet, 1898)], is the most damaging pest on sorghum in the world [9]. It constitutes the main constraint of sorghum production in the southern, central western and eastern part of Burkina [10, 11]) where grain yield loss reached out 33% [11] and 88% by Ouédraogo *et al*. 2022) [12]. Sorghum is still cultivating in those areas; therefore, it is important to introduce varieties that meet farmers needs and moreover that can lessen midge effect on grain yield.

Recently, new sorghum varieties that meet two market segments have been developed and are being evaluated in different constraints hot spot areas for their adaptation and determination of their status to aforementioned constraints. In this study, particularly, eight sorghum varieties have been assessed in midge hot spot areas to come out with their level of tolerance or resistance to midge damage. In fact, in the definition of market segment some traits such as midge traits has been clearly mentioned as must have traits that new different varieties should incorporate in their background in order to facilitate agro-climatic adaptation and adoption by all stakeholders.

2. MATERIALS AND METHODS

2.1 Study locations

The field studies were conducted only at Kouaré, in Fada research station. Kouare is one of research station of the Institute of Environment and Agricultural research (INERA) which is located at the eastern part of Burkina Faso. Kouare is midge hot spot areas located in the transitional zone and has been chosen for midge screening assessment trial. The trials were set up during rainy season 2022 and 2023. Table below summarized details about planting date and geographical coordinates of the site.

Table 1: summarized details about planting date and geographical coordinates of the site

Site	Year	Rainfall	Planting date	Longitude	Latitude	Biotic constraint
Fada	2022	776.7mm	08/07/2022	0°17' E	11°56' N	Midge
	2023	797.1mm	15/07/2023	0°17' E	11°56' N	Midge

2.2 Methodology

Experimental design was a randomized complete bloc with genotypes as studied factors, four replications with the twenty lines. At each location, plot area was 12.8 m2, including four rows of 4 m length. Distance between rows was 0.8 m and 0.4 m between hills on each row with a total of 10 hills per row. Between 4 and 8 seeds were sown by hand in each hill, in 3-cm deep holes in all four locations. Seeds were sown only after receiving at least 20 mm rainfall. Two weeks after sowing, plants were thinned to two plants per hill.

2.3 Material

Twelve sorghum lines including checks (Kapelga, ICSV 1049) were evaluated in midge hot spot areas at Kouare. Tested genotypes were mainly of two races (guinea and caudatum including some interracial lines.

Table 2: summarize the lines status

No	Genotypes	Line race	Line status
1	014-SB-EPDU-1004	Caudatum-Guinea	Tested line
2	12B	Caudatum-Guinea	Tested line
3	ICSV1049	Caudatum	Tested line
4	Kapelga	Guinea	Check
5	Kouria	Guinea	Tested line
6	PR3009B	Caudatum	Tested line
7	Sariaso 38	Guinea	Tested line
8	Sariaso 39	Guinea	Tested line
9	Sariaso 40	Guinea	Tested line
10	Sariaso 41	Guinea	Tested line
11	Sariaso 42	Guinea	Tested line
12	Sariaso 43	Guinea	Tested line

2.4 Data collection and analysis

Data collected included days to 50% heading time (HT), plant height, thousand grain weight (Gr Weight), midge damage (MD) and grain yield (Gr Yield). Grain yield was measured in tons per hectare adjusted to grain moisture content at 12%. Days to 50% heading was recorded by counting the number of days from planting to when 50% of the plants in a plot headed. Plants height was measured in centimeter of main stalk from ground level to the flag leaf at maturity and grain weight were recorded by weighing in kilogram (kg). Midge damage was a visual assessment (scoring from 1-9) as loss of grain yield in five panicles expressed as a percentage (1: 1-10% of yield loss; 2:11-20% of yield loss; 3: 21-30% of yield loss; 4: 31-40% of yield loss; 5: 41-50% of yield loss; 6: 51-60% of yield loss; 7: 61- 70% of yield loss;

8: 71-80% of yield loss; 9: > 80% of yield loss). Midge population dynamic was also evaluated to come out with midge number evolution from flowering to maturity and also to determine its effect on tested genotypes. Analysis of the effect genotypes and their response to midge damage was computed with SAS 9.1 software. Means were calculated from collected data and yield losses percentage were deduced for each variety.

3. RESULTS AND DISCUSSION

3.1 Result

3.1.1 Analysis of variance of studied parameters

Analysis of variance (ANOVA) across year was highly significant ($P< 0.001$) for heading time, plant height and grain weight but did not indicate difference for midge damage and grain yield. For all studied traits, repetition was not significant in this experimentation. The analysis revealed high difference ($P< 0.001$) among tested genotypes for heading time, plant height, grain weight and was fairly significant for midge damage (P=0.0171) and grain yield (P=0.0222). For the interaction genotypes by year, heading time and plant height were highly significant ($P< 0.001$) while grain yield was fairly significant (P=0.0138) among genotypes (Table 3).

Table 3: Means square of genotypes, year and genotypes by year for studied traits

Source	Df	Heading time	Plant Height	Midge Damage (%)	Gr Weight	Gr Yield
Year	1	28.167***	36169.37***	18.37ns	43.83***	676520.52ns
Rep	3	2.37ns	1713.92ns	4.402ns	8.41ns	446440.12ns
Geno	11	242.96***	21095.26***	21.56*	63.57***	842673.75*
Year*Geno	11	96.03***	5035.61**	2.81ns	7.75ns	906790.73*
Error		15.483696	1671.7292	9.2795894	5.763488	377924.40
F value		15.69	12.62	2.32	11.03	2.23
Pr>F		<.0001	<.0001	0.0171	<.0001	0.0222

*Rep: repetition; Geno: genotypes; CV: Coefficient of variation; Gr Weight: Grain weight; Gr Yield: Grain yield; Df: degree of freedom; ns: non-significant; *: significant; **: fairly significant; ***: highly significant*

3.1.2 Descriptives analysis of studied parameters

In this study, varieties headed time average was around 74.85 days after sowing (das), however, earlier genotypes headed around 59 days after sowing (das) while later one headed 86 das. The coefficient of variation (CV=9.52) affected to this variable was low but the heritability (0.92) was high. For plant height, tallest varieties reached out 384.6 cm while shortest ones measured 133.3 cm with an average of 220.22 cm. The CV and heritability (0.57) were high and are respectively 68.37 and 0.84. Concerning midge trait, damage ranged from 1 to 9 with an average of 4.52. The CV (69.57) was high and the heritability affected to the variable was fairly high. Grain weight ranged from 0.99 gr to 25.41 gr with an average of 17.26 gr and a heritability of 0.86. For grain yield, genotypes performed ranged from 78.13 kg/ha to 4087.89 kg/ha with mean (970.99 kg/ha) below 1t/ha. The CV (72.69) was high while the heritability was low (0.47) (Table 4).

Table 4: Descriptive analyze of studied parameters

Trait	Min	Max	Mean	CV	Standard D	Heritability
Heading time	59	86	74.85	9.52	7.13	0.92
Plant Height	133.2	384.6	220.22	31.04	68.37	0.84
Midge Damage (%)	1	9	4.52	69.57	3.14	0.57
Gr Weight	0.99	25.41	17.26	21.02	3.62	0.86
Gr Yield	78.13	4087.89	970.99	72.69	705.89	0.47

Gr weight: Grain weight; Gr Yield: Grain yield; Min: Minimum; Max: Maximum: CV: Coefficient of Variation; Standard D: standard deviation

3.1.3 Varieties heading time and effect of midge damage on agronomic performances across year (2022 and 2023)

Heading time, midge damage and yield performances of varieties across two years are presented in Table 5. Comparison of heading time across years revealed that only five of tested varieties (014-SB-EPDU-1004, Sariaso 40, Sariaso 41, Sariaso 42, Sariaso 43) headed lately in 2022 than in 2023. The difference ranged from 6.5 days (Sariaso 43) to 12 days (Sariaso 41). In opposite, majority of genotypes

(12B, ICSV1049, Kapelga, Kouria, PR3009B, Sariaso 38, Sariaso 39) headed earlier in 2022 than 2023. Among them, the difference ranged from 1 days (Kapelga) to 9 days (Sariaso 39). Heading time was significant different between tested varieties except within 12B (3.75 days), ICSV1049 (1.75 days), Kapelga (0.5 days), Kouria (4 days) and PR3009B (3.75 day). Overall, across years, following varieties: 014-SB-EPDU-1004 (85 days), Sariaso 39 (81 days), Sariaso 40 (83.50 days), Sariaso 41 (83.25 days), Sariaso 42 (82.75 days), Sariaso 43 (85.75 days) have late maturity time.
Concerning midge damage, the analysis revealed that varieties with early heading time were observed with low midge dame score [Kouria (2.25), Sariaso 38 (2.50), Kapelga (2.75), ICSV1049 (3.25), PR3009B (3.50)]. Tested varieties recorded with midge damage score ranging from 2 to 3 were those with heading time ranging from 63 das to 71 das in 2022. In 2023, less midge damage (<4) was recorded again on the same varieties (Kouria, Sariaso 38, Kapelga, ICSV1049, PR3009B). In opposite, midge damage was high on varieties that headed lately [014-SB-EPDU-1004 (5.25), 12B (6.25), Sariaso 39 (5.50), Sariaso 40 (6.25), Sariaso 41 (7), Sariaso 43 (7) and Sariaso 42 (8)] in 2022. In 2023, midge damage was high on two varieties [014-SB-EPDU-1004 (5.50) and Sariaso 43 (7)] and slightly weak on four varieties [12B (4.25), Sariaso 39 (4.50), Sariaso 40 (4.50) and Sariaso 42 (4.75)].
For grain yield performances, genotypes average yield was higher in 2023 (Gr yield = 1054.94 Kg/ha) than in 2022 (Gr yield = 887.04 Kg/ha). Across years, varieties recorded with low midge damage score performed well (Gr yield >1000 Kg/ha) while majority of varieties observed with high midge damage score exhibited low grain yield (Gr yield <1000 Kg/ha). An exception was noted in 2022 with Sariaso 39 (1523.44 kg/ha) and in 2023 with Sariaso 41 (1925.88 kg/ha) which were respectively recorded with high midge damage score of 6.25 and 5 (Table 5).

Table 5: Means of studied key traits across years

Genotypes	**Heading Time**		**Midge Damage (%)**		**Gr Yield**		**Gr yield across year**	**Midge status**
	2022	**2023**	**2022**	**2023**	**2022**	**2023**		
014-SB-EPDU-1004	85.00	76.50	5.25	5.50	493.75	616.99	1431.36	Tolerant
12B	74.50	78.25	5.50	4.25	937.50	503.75	909.87	Susceptible
ICSV1049	71.00	72.75	3.25	2.25	1166.41	1589.45	1315.11	Tolerant
Kapelga	69.00	70.50	2.75	2.25	1523.44	1106.78	1377.93	Tolerant
Kouria	63.75	67.75	2.25	3.00	1347.66	1515.06	956.22	Susceptible
PR3009B	65.00	68.75	3.50	3.00	742.19	1170.25	555.37	Susceptible
Sariaso 38	69.00	74.75	2.50	3.00	1035.16	784.57	720.63	Susceptible
Sariaso 39	72.25	81.25	6.25	4.50	1523.44	352.68	938.06	Susceptible
Sariaso 40	83.50	75.50	6.25	4.50	644.53	1454.12	1049.33	Tolerant
Sariaso 41	83.25	71.25	7.00	5.00	488.28	1925.88	1207.08	Tolerant
Sariaso 42	82.75	75.25	8.00	4.75	566.41	1020.45	397.53	Susceptible
Sariaso 43	85.75	79.25	7.00	7.00	175.78	619.28	793.43	Susceptible
Mean	75.40	74.31	4.96	4.08	887.04	1054.94	970.99	Tolerant

Gr Yield: Grain yield

3.1.4 Midge population evolution on studied site in 2022

Overall, the population dynamic study revealed a slight increase of midge number from mid-September to early-October corresponding to 74 das to 87 das. Midge number was very few and estimated below 100 insects that were collected and counted on yellow traps. From early to mid-October (around 100 das), midge population raised out rapidly to reach out a pick (833 insects) and drop down about 354 to 377 around October 20th (around 104 das), then raised again to reach a second pick (791 insects) around October 25th (around 110 das), From October 25th to 31st (around 115 das), the insect number decreased drastically and was estimated to 225 insects. From the end October to November 18th (more than 130 das), the insects number increased slightly to a third pic (593 insects) and finally decrease to at the end of November to a few insects captured on the different traps (Fig 1).

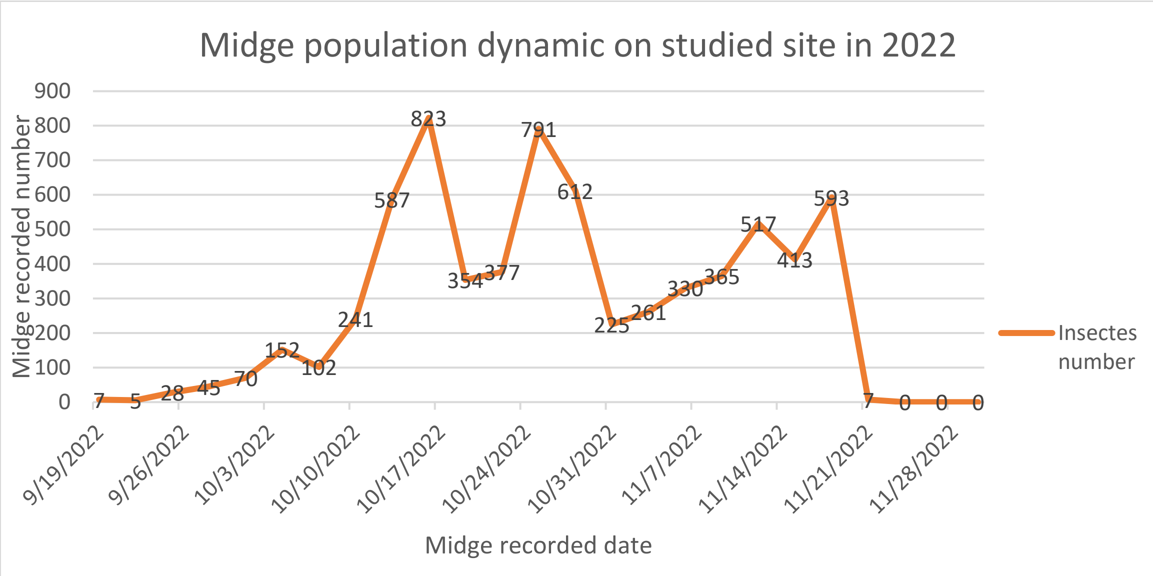

Fig. 1. Curve illustrating midge population dynamic in studied site during rainy season 2022

3.1.4 Midge population evolution on studied site in 2023

The analysis of Fig 2 shows the evolution of midge population in studied site in 2023. From mid to end September, meaning 59 das to 72 das, midge number increased slightly but remain below 100 insects captured by yellow traps. Four picks were observed, respectively around October 3rd (76 das) with 235 insects, October 13th (84 das) with 748 insects, October 22th (93 das) with 1209 insects, and at last November 3rd (106 das) with 1650 insects. From November 3rd to 24th, midge insects number dropped down constantly to reach zero insect captured by trap (Fig 2).

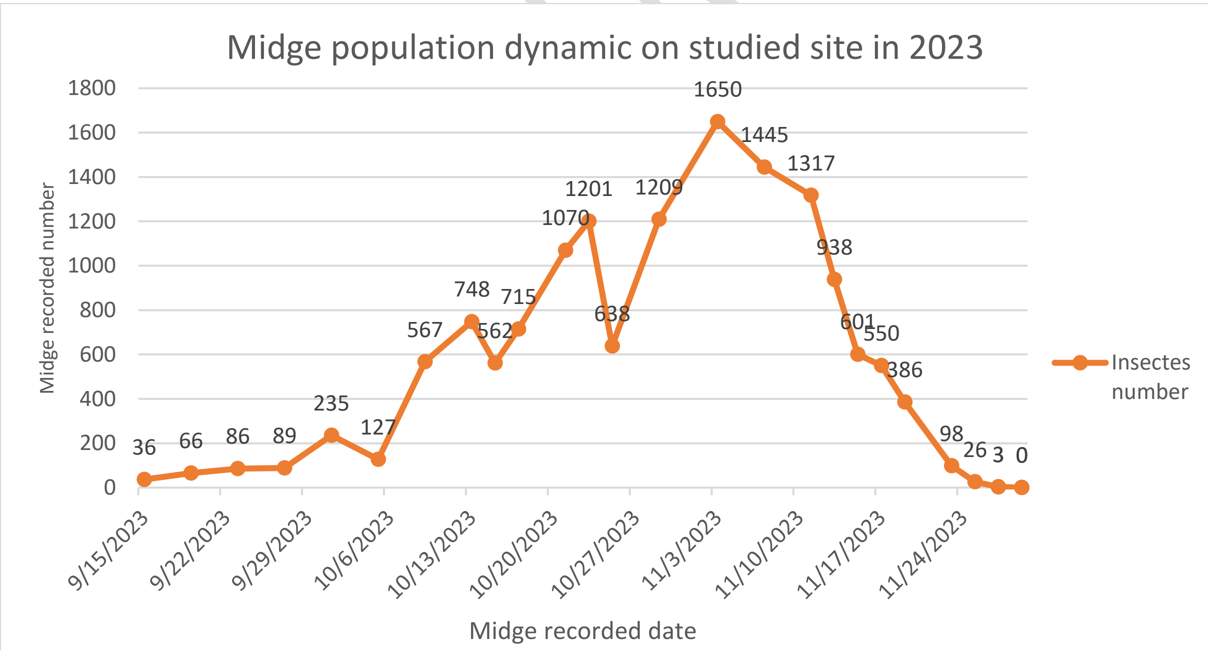

Fig. 2. Curve illustrating midge population dynamic in studied site during rainy season 2023

3.2 DISCUSSION

The highly significant mean squares of genotypes and genotypes across year for heading time, plant height and grain weight indicated that tested genotypes have different plant cycle, different plant height and different grain weight. The result is confirmed by descriptive analysis which revealed that some varieties headed earlier while other headed lately. Four varieties (Kouria, Sariaso 38, Kapelga, PR3009B) headed below 70 das across year and the remaining varieties (014-SB-EPDU-1004, 12B, Sariaso 39, Sariaso 40, Sariaso 41, Sariaso 43, Sariaso 42) headed beyond 70 das. In fact, differences between heading time among genotypes within site and across years are probably due to different planting dates across years and to genetic characteristics linked to photo sensibility. Genetically, sorghum plant cycle is governed by 4 genes (Ma1, Ma2, Ma3 and Ma4) which are independent and partially dominant [13]. In other hand, sorghum is a short-day plant within the tropics and may often exhibits high sensitivity to photoperiod in normal growing seasons [14, 15]. So, for the same planting date, high photo sensitive genotypes tend to reduce heading time compared to low or non-photo sensitive genotypes while for different planting date within same year or across year, susceptible genotypes will have long heading time for early planting date and short heading time for late planting date. Concerning plant height, the important difference among genotypes is probably linked to genetic expression and diversity of genotypes races including in the trials. Tested materials included Guinea lines, Caudatum lines and interracial material such as Guinea-caudatum lines and according to Chantereau [16] and Dogget [17], aside key trait such as panicle and grain shape, some sorghum from guinea race are commonly taller than lines from other races. Zongo [6] by comparing Burkina sorghum, most from guinea races to dwarf sorghum lines from America revealed that genotypes from Burkina are tall due to important internodes number and length. In fact, according to Dumont [18] sorghum plant height depends on internodes number and length. High differences exhibited by those variables (heading time, plant height, grain weight and grain yield), was almost similar with result obtained by Barro/Kodombo [7] by comparing Guinea gambicum lines, Guinea margaritiferum lines, Durra-Bicolor lines and Bicolor lines. Particularly, for midge damage, the analysis revealed a fairly significant damage level within genotypes. This result may probably due to a dual factor. It may be linked to plant cycle in one hand and in other hand to genetic ability of some genotypes to cope with midge damage. Genotypes with short plant cycle tend to escape midge attack while genotypes with long heading time tend to tolerant or susceptible [12]. Therefore, they behave differently to midge damage.

Agronomic performances of varieties evaluated across years in midge hotspot site was strongly affected by the insect damage (midge). Heading time, midge damage and yield performance were tightly linked to each other. According to the analysis, varieties that headed earlier were associated with low midge damage score and consequently with grain yield beyond 1000 kg/ha. Those varieties (Kouria, Kapelga and ICSV 1049) had a short plant cycle and headed below 72 das. This indicates that they probably escape to midge damage due low infestation or low insect number in the field. According to Diarrisso *et al* [19] this is explained by the asynchrony of the flowering time, particularly between the period of the glumes opening and egg-laying activity of gall midge which allow varieties to escape attack. In opposite, six of tested varieties (PR3009B, 014-SB-EPDU-1004, 12B, Sariaso 39, Sariaso 42 and Sariaso 43) that headed lately across years were associated with high midge damage score (ranking from 5 to 8) along with lowest yield (below 1000 Kg/ha). According to Diarrisso *et al* [19], this could be explained by the synchrony of the flowering time with egg-laying activity of gall midge, inducing massive damage of inflorescence, and therefore, correlated with low yield. Among tested varieties, one variety (Sariaso 38) with short plant cycle was observed with low yield and two varieties (Sariaso 40 and Sariaso 41) with long plant cycle along with average midge damage score comprised between 5 to 6 were observed with grain yield above 1000 kg/ha. This particular result indicates that Sariaso 38 is susceptible to midge attack while Sariaso 40 and Sariaso 41 seemed to be more tolerant to midge attack.

Across years, midge population was very weak from mid-September to early-October, corresponding to the heading and flowering time of early maturity varieties. This means that midge infestation was low due to few numbers of varieties that headed and flowered at that period of plant cycle. From early October to almost end October (October 25th), midge population raised and reached out many picks. This evolution matches with heading and flowering time of intermediate and late maturity varieties. This corresponds to varieties that headed respectively 75 das to 80 das and finally late materials that headed around 85 das. This could be explained by the fact early varieties were used as support for gall-midge to enhance slightly their egg-laying activity and then, pullulated and reached out the maximum insect number with heading and flowering time of intermediate and late maturity varieties. This synchrony of of heading and flowering time of intermediate and late varieties with the maximum of midge population in the field explained also why majority of them were susceptible to midge damage across years. However, despite this synchrony, two varieties (Sariaso 40 and Sariaso 41) grain yield were not affected considerably. Theses varieties, aside escapism, have certainly other mechanism of tolerance or resistance. In fact, there are several mechanisms of resistance to the sorghum midge [20] and these include mechanical factors linked to the morphology of the glumes (short and tough glumes) preventing either oviposition [21] or larvae development [22]. Other mechanism of resistant is the tannin content on some varieties linked to production of anti-biotic that have an effect on midge larvae development.

4. CONCLUSION

Tested varieties cycle (heading times), midge damage and grain yield performance varied slightly across years. Overall, varieties performances in hotspot site were strongly linked to heading time and midge damage. The study revealed three groups status of tested varieties to midge attacks. The first group (Kouria, Kapelga and ICSV 1049) was constituted of materials that heading time or glume opening stage did not synchronized well with gall midge egg-laying period and are there tolerant to the insect by escapism mechanism. The second group (Sariaso 40 and Sariaso 41) was constituted of varieties that heading time synchronized with insect egg-laying period and important insect number in the field but with less damage on grain yield was recorded. Those varieties are tolerant and are probably using combination of mechanism (to be clarified) to avoid midge attacks. The third groups (PR3009B, 014-SB-EPDU-1004, 12B, Sariaso 39, Sariaso 42 and Sariaso 43) are constituted of varieties that headed lately with synchronization of glumes opening time to gall-midge egg-laying period. Unfortunately, midge attacks were important and damaged considerably their yield. Those varieties are susceptible to the insects.

DEFINITIONS, ACRONYMS, ABBREVIATIONS

CIMMYT: International Maize and Wheat Improvement Center
INERA : Institut de l'Environnement et de Recherches Agricoles

CONSENT (WHERE EVER APPLICABLE)

Not applicable in this study

ETHICAL APPROVAL (WHERE EVER APPLICABLE)

Not applicable in this study

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