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# Agronomic performance and adaptability study of New Guinea lines in sudanian and sudano-sahelian zones

**Nofou Ouédraogo[1*], Gilles Ibié Thio[1], Adama Sanou[2], Issouf Kouraogo[2], Oumar Boro[1], Armel Prisca Sawadogo[1], Djibril Yonli[1], Vernon Gracen[3], Baloua Nebie[4]**

[1] Institute of Environment and Agricultural Research (INERA), 01 BP 476 Ouagadougou 01, Burkina Faso
[2] Institute of Environment and Agricultural Research (INERA), BP 910 Bobo Dioulasso 01, Burkina Faso
[3]Department of Plant Breeding and Genetics, 520 Bradfield Hall, Cornell University, Ithaca, NY 14850, USA
[4]Intenrnational Crop Research Institute for Semi-Arid Tropics-Mali, Samanko, BP 320, Bamako-MALI
*Corresponding author Email addresses: nofou2008@yahoo.fr/ nofou2008@gmail.com

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## ABSTRACT

*Objective:* This study was conducted to evaluate agronomic performance and adaptability of new guinea lines in sudanian and sudano-sahelian agro climatic zones in Burkina Faso.

*Methodology and results***:** The study was conducted during two years in three sites (Kamboinse, Fada and Farako-Ba) located in two different agro climatic zones (sudanian and sudano-sahelian). Twenty sorghum lines including checks (Kapelga, ICSV 1049) were evaluated in a randomized complete bloc design with genotypes as studied factors. Agromorphological parameters and midge damage were collected in all studies sites. As the results, among tested lines, seven lines (Kouria, PR3009B, ISX-09004-1-3-1-3-6-7-7-3, Fambe B, Lata//Grin-9-14-1-1-vrac, ISX-09005-7-4-3-1-10-6-6-10, 12B) were well adapted to sudano-sahelian zone whereas 13 were well adapted to sudanian zone according to heading date. Three lines (Lata//DouaG-4-27-1-1-vrac, 014-SB-EPDU-1004 and ND07e21 (17x30) F2-6-v) were stable across environments and only one line (Lata//Grin-9-14 -1-1-vrac) with the two checks (Kapelga and ICSV 1049) were stable under low yielding environment characterized by high midge pressure conditions. Three lines (ISX-09005-7-4-3-1-10-6-6-10, Lata//Ridb-3-9-1-1-vrac and Fambe B were specific to high yielding environment (Kamboinse and Farako-Ba).

*Conclusions and applications of findings:* The stable lines (Lata//DouaG-4-27-1-1-vrac, 014-SB-EPDU-1004 and ND07e21 (17x30) F2-6-v) across environments constitute some promising lines to be registered in the national catalogue for vegetal varieties and will be promoted for cultivation in sudanian and sudano-sahelian zones to enhance sorghum production and to contribute to ensure food security in Burkina Faso.

**Key words**: Burkina Faso, GGE biplot, midge damage, grain yield, sorghum

## INTRODUCTION

Sorghum is a staple food crop for millions of African farmers living in the semi-arid tropics (Dora *et al.*, 2014). Burkina Faso is a semi-arid country where sorghum and millet constituted the staple for rural populations (Bal, 2005). Aside human consumption, sorghum (stem and leaves) is largely used as forage for cows and small ruminants and it is cultivated all over the different climatic zones of the country. In 2019, its production has been estimated to 1,871,792 tons on about 1,907,650 ha, which represents 37, 89% of total cereals production (MAAH, 2019). Overall, the yield is low (≤ 1 ton/ha) and the production is weak compared to yield in developed country. Sorghum production is low due to biotic and abiotic constraints that reduced considerably its yield. Biotics constraints are essentially diseases, weeds (striga) and insects' pests and among them, sorghum midge *Stenodiplosis (= Contarinia) sorghicola* (Coquillet, 1898) known as the most damaging pest on sorghum in the world (Yound and Teetes, 1997), constitutes the main constraint of sorghum production in the southern, centre-western and eastern part of Burkina (Bonzi, 1979; Dakuo, 1996) inducing grain yield loss of about 33% (Dakuo, 1996). Therefore, to enhance sorghum productivity, new varieties have been created based on known constraints and breeding product profile developed along with farmers and also criterion identified by previous studies conducted by Barro *et al.*, 2010 and Ouédraogo *et al.*, 2017. However, it is necessary to evaluate these new guinea lines in different sorghum growing areas of the country to determine their adaptability to each area and to assess their agronomic performance. In this study, new guinea lines have been evaluated in three different research station located in two different climatic zones.

## MATERIALS AND METHODS

**Study locations:** The field studies were conducted in three stations (Farako-Bâ, Kamboinse and Kouare) of the Institute of Environment and Agricultural research (INERA) during 2019 and 2020 rainy seasons. These locations were chosen based on an increasing rainfall gradient from North to South. Farako-Bâ is located in the sudanian climatic zone; Kamboinse is located in the centre of the transition zone (sudano-sahelian) whereas Kouare is located in Eastern part of the transition zone. The cumulative sum of rainfall of the two years and location data are presented in Table 1.

**Tableau 1:** Sites geographical coordinates Rainfall and planting data

| Sites / year | Rainfall (mm) | | Planting date | | Longitude | Latitude | Altitude (m) |
|---|---|---|---|---|---|---|---|
| | 2019 | 2020 | 2019 | 2020 | | | |
| **Farako-Ba** | 1308.5 | 1221.0 | 29/07 | 14/07 | 04°20' E | 11°06 N | 505 |
| **Fada** | 681.5 | 867 | 13/07 | 17/07 | 0°17'48 E | 11°56'16 N | 400 |
| **Kamboinse** | 782.5 | 908.6 | 02/07 | 07/07 | 1°32' E | 12° 28' N | 296 |

**Plant Material:** Twenty sorghum lines including checks (Kapelga, ICSV 1049) were evaluated in the three different locations. Majority (16) of lines where from guinea race except ICSV 1049 and PR3009B (Caudatum) AND 014-SB-EPDU-1004 and 12B (Caudatum-Guinea). Table 2 summarise the lines status.

**Tableau 2:** List of guinea lines involved in the evaluation

| No | Pedigree | Line race | Line status |
|---|---|---|---|
| 1 | 014-SB-EPDU-1004 | Caudatum-Guinea | Tested line |
| 2 | 12B | Caudatum-Guinea | Tested line |
| 3 | ISX-09001-7-3-1-4-1-3-21-3 | Guinea | Tested line |
| 4 | ISX-09004-1-3-1-3-6-7-7-3 | Guinea | Tested line |
| 5 | ISX-09005-11-1-5-2-5-4-14-3 | Guinea | Tested line |
| 6 | ISX-09005-11-1-7-1-5-5-9-4 | Guinea | Tested line |
| 7 | ISX-09005-11-5-2-1-6-10-8 | Guinea | Tested line |
| 8 | ISX-09005-11-5-2-9-5-9-6-11 | Guinea | Tested line |
| 9 | ISX-09005-3-1-5-11-5-8-24-7 | Guinea | Tested line |
| 10 | ISX-09005-3-1-7-2-8-7-1-7 | Guinea | Tested line |
| 11 | ISX-09005-7-4-3-1-10-6-6-10 | Guinea | Tested line |
| 12 | Fambe B | Guinea | Tested line |
| 13 | Lata//DouaG-4-27-1-1-vrac | Guinea | Tested line |
| 14 | Lata//Grin-9-14-1-1-vrac | Guinea | Tested line |
| 15 | Lata//Ridb-3-9-1-1-vrac | Guinea | Tested line |
| 16 | ICSV 166001 | Guinea | Tested line |
| 17 | PR3009B | Caudatum | Tested line |
| 18 | Kapelga | Guinea | Check |
| 19 | Kouria | Guinea | Tested line |
| 20 | ICSV1049 | Caudatum | Check |

**Experimental design** 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 m$^2$, 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.

**Crop management**: fifteen days after planting, the trial was hand weeding and NPK fertilizer was applied at a rate of 100 kg/ha. Fifteen days later, the trial was hand weeding again and urea (46%) fertilizer was applied at a rate of 25 kg/ha. At last, urea was applied forty-five dap and trial was hilling to avoid lodging.

**Data collection**: data collected were seedling vigour (SVg), days to 50% heading (HD), plant height (PH), panicles weight (PW), grain weight (GW), midge damage (MD) and grain yield (GY). 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. 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). Plant height (cm), panicles weight (kg), and grain weight (kg) were recorded by measurement. For seedling vigour, 1-nul vigour; 3-very weak vigour; 5-poor vigour; 7-normal vigour; 9-maximum vigour.

**Data analysis:** Analysis of the effect of year, location, genotypes, and their interactions on response variables was computed with SAS 9.1

software. Means were calculated from collected data and GGE biplot analyses in GenStat version 12 were performed to identify high yielding and suitable lines for grain yield across three different environments.

## RESULTS

**Analysis of variance of studied parameters:** Analysis of variance across year, environments (sites) and genotypes were highly significant (($P < 0.001$) for majority of studied traits and significantly different across year at 5% level for two traits (panicle weight and grain weight). Only midge damage was not significantly different across year at 5% level. The results of factors interaction showed that genotypes by year, genotypes by environment (sites) and genotyped by year and by environments (sites) were significant ($P < 0.001$) for all traits (Table 3).

**Table 3:** Mean square of genotype, site, year, genotype by site, genotype by year and genotype by year by site interaction analysis for all traits

| Source | df | SVg | HD | PH | PW | GW | GY | MD |
|---|---|---|---|---|---|---|---|---|
| Year | 1 | 42.6*** | 498.16*** | 27,311.8*** | 4.37* | 2.57** | 139,973.9** | 0.00ns |
| Site | 2 | 745.46*** | 3710.5*** | 148,675.3 | 214.3*** | 119.9*** | 56,302,029*** | 576.4*** |
| Rep | 3 | 2.44*** | 19.49ns | 313.5ns | 3.18* | 2.31*** | 1379381* | 2.1ns |
| Genotype | 19 | 4.96*** | 507.75*** | 71,186.7*** | 12.35*** | 4.08*** | 3,405,299.6*** | 4.3*** |
| Genotype*Site | 38 | 3.25*** | 121.24*** | 4,239.1*** | 4.18*** | 2.04*** | 1,709,851*** | 0.02*** |
| Genotype*year | 19 | 1.62**** | 10.06ns | 3,954.4*** | 2.72*** | 1.52*** | 1,026,997*** | 3.7*** |
| Genotype*year *site | 40 | 2.15*** | 220.47*** | 2,577.7*** | 2.55*** | 1.44*** | 999,856*** | 0.02ns |
| Error | | 0.6 | 20;77 | 655.8 | 1.05 | 0.55 | 462,870 | 1.5 |
| R-squ | | 0.89 | 0.81 | 0.89 | 0.72 | 0.71 | 0.65 | 0.7 |
| CV (%) | | 13.00 | 6.06 | 11.96 | 30.54 | 41.57 | 42.40 | 56.8 |
| Std dev | | 2.08 | 9.04 | 68.7 | 1.69 | 1.20 | 93.58 | 2.0 |
| F value | | 8.27 | 24.44 | 108.5 | 11.67 | 7.41 | 7.36 | 2.8 |
| Pr>F | | <0.0001 | <0.0001 | <0.0001 | <0.0001 | <0.0001 | <0.0001 | <0.0001 |

ns: non-significant, *: significant, **: highly significant ***: very highly significant

The result showed significant different with all parameters studied and analysis of Seedling Vigour trait ranging from poor vigour (4.87: ISX-09005-3-1-5-11-5-8-24-7) to normal vigour (6.71: Kouria) with the great mean 5.95. Overall, during the first-year evaluation, genotypes tended to have a normal vigour (6, 25) while during the second year (5.66) evaluation, genotypes were less vigorous. Concerning parameter that revealed adaptation to agro-climatic areas, early line headed around 63 days after planting (dap) (Kouria: 63,18) while late one headed around 82 dap (ISX-09005-11-1-7-1-5-5-9-4) Table 3. However, majority of lines headed around 75 dap, only six lines (ISX-09005-3-1-7-2-8-7-1-7, ND07 e21(17x30) F2-6-V, 014-SB-EPDU-1004, ISX-09005-11-5-2-1-6-10-8, ISX-

09005-11-5-2-9-5-9-6-11 and ISX-09005-11-1-7-1-5-5-9-4) headed after 78 dap. The tested line (Kouria) headed earlier than the checks (Kapelga: around 68 dap and ICSV 1049: 72 dap) and two (ISX-09004-1-3-1-3-6-7-7-3: 71, 19 and PR3009: 71, 9) headed earlier than the second check (ICSV 1049: 72 dap) Table 4. Kouria headed earlier in all sites than others lines and headed earlier respectively at Farako-Ba (year1: 53,5 dap; year 2: 57,5 dap), Kamboinse (year 1: 65,7 dap; year 2: 64,3 dap) and Fada (year1: 71,2 dap; year 2: 66,8 dap) while ISX-09005-11-5-2-1-6-10-8 headed lately in Farako-Ba during the two years (respectively 93,4 dap and 90,75 dap), at Kamboinse during the second year (87,25 dap) and was among the last to head at Fada (year 1: 78,5 dap and year 2: 73,5 dap). Overall, heading dates of tested lines differs across years and across sites and majority of them headed early when they were planted lately except four lines (ISX-09001-7-3-1-4-1-3-21-3, ISX-09005-11-5-2-9-5-9-6-11, Lata//Ridb-3-9-1-1-vrac and PR3009B) which headed lately when they were planted lately. Plant height (cm) ranged from 147, 53 (ISX-09001-7-3-1-4-1-3-21-3) to 350, 17 (Fambe B) with an average of 214, 36. The tallest lines were Lata//Ridb-3-9-1-1-vrac, Lata//DouaG-4-27-1-1-vrac, Lata//Grin-9-14-1-1-vrac, Kouria, Kapelga and Fambe B and measured more than 300 cm while ISX-09005-7-4-3-1-10-6-6-10, ISX-09005-11-1-7-1-5-5-9-4, 014-SB-EPDU-1004, ICSV1049, ISX-09005-11-5-2-1-6-10-8, ISX-09005-11-5-2-9-5-9-6-11, ND07 e21(17x30)F2-6-v and PR3009B height was comprised between 200 cm to 300 cm. Six lines (ISX-09001-7-3-1-4-1-3-21-3, ISX-09004-1-3-1-3-6-7-7-3, ISX-09005-3-1-5-11-5-8-24-7, 12B, ISX-09005-3-1-7-2-8-7-1-7 and ISX-09005-11-1-5-2-5-4-14-3) measured under 200 cm and were the shortest Table 4 and 5.

**Tableau 4:** Great mean of trait during evaluation across sites

| Genotypes | SVg | HD | PH | PW | GW | GY | MD |
|---|---|---|---|---|---|---|---|
| 014-SB-EPDU-1004 | 6,04 | 79,43 | 182,5 | 4,16 | 2,3 | 2031,32 | 1,7 |
| 12B | 5,21 | 74,39 | 163,18 | 3,17 | 1,65 | 1499,01 | 2,7 |
| Fambe B | 6,54 | 73,06 | 350,17 | 3,65 | 2,06 | 1807,68 | 2,5 |
| ICSV1049 | 6,21 | 71,91 | 189,89 | 3,28 | 1,74 | 1637,21 | 1,9 |
| ISX-09001-7-3-1-4-1-3-21-3 | 5,96 | 75,17 | 147,53 | 3,1 | 1,77 | 1647,93 | 1,9 |
| ISX-09004-1-3-1-3-6-7-7-3 | 5,63 | 71,19 | 150,41 | 2,81 | 1,37 | 1272,39 | 1,7 |
| ISX-09005-11-1-5-2-5-4-14-3 | 6,29 | 75,32 | 173,88 | 3,51 | 1,81 | 1595,5 | 3 |
| ISX-09005-11-1-7-1-5-5-9-4 | 5,79 | 81,65 | 195,13 | 2,33 | 1,15 | 999,36 | 2,8 |
| ISX-09005-11-5-2-1-6-10-8 | 6,21 | 80,71 | 251,49 | 2,78 | 1,31 | 1120,52 | 2,8 |
| ISX-09005-11-5-2-9-5-9-6-11 | 5,83 | 81,62 | 212,51 | 2,63 | 1,26 | 1063,43 | 2,8 |
| ISX-09005-3-1-5-11-5-8-24-7 | 4,87 | 76,64 | 154,38 | 2,46 | 1,16 | 1046,23 | 1,2 |
| ISX-09005-3-1-7-2-8-7-1-7 | 5,96 | 78,2 | 160,74 | 3,43 | 1,69 | 1538,35 | 2 |
| ISX-09005-7-4-3-1-10-6-6-10 | 6,17 | 74,07 | 183,86 | 3,54 | 2,02 | 1876,67 | 2,4 |
| Kapelga | 6,17 | 68,24 | 299,14 | 2,72 | 1,74 | 1602,04 | 1,7 |
| Kouria | 6,71 | 63,18 | 274,45 | 3,27 | 1,99 | 1779,32 | 2,2 |
| Lata//DouaG-4-27-1-1-vrac | 5,29 | 76,31 | 259,79 | 4,61 | 2,41 | 2158,01 | 2,3 |
| Lata//Grin-9-14-1-1-vrac | 6,33 | 73,78 | 262,15 | 4,89 | 2,17 | 2020,72 | 1,7 |
| Lata//Ridb-3-9-1-1-vrac | 6,13 | 76,14 | 236,27 | 4,58 | 2,62 | 2276,91 | 1,8 |
| ND07 e21(17x30) F2-6-v | 6,29 | 79,31 | 206,03 | 3,77 | 2,02 | 1808,29 | 2,6 |
| PR3009B | 5,5 | 71,9 | 233,64 | 2,67 | 1,47 | 1307,42 | 1,6 |
| Mean Year 1 | 6,25 | 74,09 | 206,77 | 3,27 | 1,71 | 1587,34 | 2,2 |
| Mean Year 2 | 5,66 | 76,13 | 221,94 | 3,46 | 1,86 | 1621,49 | 2,3 |
| Great Mean | 5,95 | 75,11 | 214,36 | 3,37 | 1,79 | 1604,42 | 2,17 |

**Lines' agronomic performance:** For agronomic performance, following parameters: panicle weight, grain weight contributed greatly to grain yield. More the panicle and grain weighted; greater is the grain yield and less they weighted, lower is the grain yield. In opposite to panicle weight and grain weight, more the midge damage score, lower is the grain yield and yield parameters (Table 4). The average midge damage was 2, 17, but the score varies from 1 to 6. In two sites (Farako-Ba and Kamboinse), yield losses due to midge damage was non-significant and all genotypes tested were recorded with less than 10% yield loss. In the third site (Fada), yield loss due to midge reached up to 60% (Table 6). Yield average was 1604, 42 kg/ha and the lowest yield was 109, 4 kg/ha (ISX-09005-11-5-2-1-6-10-8) obtained at Fada research station whereas the highest yield was obtained with Lata//Ridb-3-9-1-1-vrac (4865, 23 kg/ha) at Kamboinse research station. Lata//Ridb-3-9-1-1-vrac was also the high yielding genotype in the two others sites (Farako-Ba and Fada) and preformed respectively 2601,56 Kg/ha and 1926 kg/ha. Overall, yield was low at Fada than Farako-Ba and high yield was obtained at Kamboinse (Table 6).

**Table 5:** Mean of heading date and plant height in the three sites of evaluation

| Trait | Heading date (HD) | | | | | | Plant height (PH) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Sites | KBS | | FKB | | FADA | | KBS | | FKB | | FADA | |
| Year / Genotypes | 2019 | 2020 | 2019 | 2020 | 2019 | 2020 | 2019 | 2020 | 2019 | 2020 | 2019 | 2020 |
| 014-SB-EPDU-1004 | 86,9 | 86 | 70,5 | 81 | 79,8 | 72,3 | 213,8 | 204,1 | 132,1 | 169,3 | 198 | 182,5 |
| 12B | 76,5 | 73 | 68,2 | 80,5 | 81 | 67 | 168,6 | 180,35 | 121,5 | 166,8 | 169,3 | 175,4 |
| Fambe B | 78,7 | 76 | 61 | 74,25 | 76,7 | 70,8 | 412,1 | 400,25 | 252,5 | 331,5 | 329,4 | 379,3 |
| ICSV1049 | 72,9 | 72,75 | 63,5 | 74,5 | 74,8 | 72,5 | 217,1 | 207,5 | 152,5 | 175,1 | 205,6 | 180 |
| ISX-09001-7-3-1-4-1-3-21-3 | 75,7 | 85,25 | 65 | 78,5 | 76,8 | 70,8 | 145,3 | 152,05 | 104,1 | 141,9 | 181,5 | 155,6 |
| ISX-09004-1-3-1-3-6-7-7-3 | 71 | 70 | 60,7 | 71,75 | 78 | 74,8 | 163,7 | 153,4 | 122,4 | 145,6 | 170,1 | 155,4 |
| ISX-09005-11-1-5-2-5-4-14-3 | 77,7 | 77,75 | 65 | 79 | 76,3 | 76 | 179,3 | 181,8 | 144,9 | 173,1 | 173,2 | 187,3 |
| ISX-09005-11-1-7-1-5-5-9-4 | 91,2 | 90,25 | 70 | 84 | 80 | 73,8 | 204,2 | 222,5 | 146,2 | 199,9 | 208,3 | 195,9 |
| ISX-09005-11-5-2-1-6-10-8 | 93,4 | 90,75 | 60,5 | 87,25 | 78,5 | 73,5 | 226,6 | 257,75 | 253,8 | 217,5 | 335,9 | 222 |
| ISX-09005-11-5-2-9-5-9-6-11 | 87,5 | 89,25 | 70,5 | 85,5 | 83,3 | 73,3 | 227,6 | 245,35 | 163 | 212,6 | 204,6 | 217,2 |
| ISX-09005-3-1-5-11-5-8-24-7 | 86,9 | 83,25 | 63,8 | 78,75 | 78,7 | 69,8 | 165,6 | 172,15 | 117,4 | 146,9 | 158,9 | 158,1 |
| ISX-09005-3-1-7-2-8-7-1-7 | 86,5 | 85 | 63,5 | 77,75 | 79,5 | 76,8 | 172,6 | 159,95 | 122,1 | 151,1 | 212,8 | 148,7 |
| ISX-09005-7-4-3-1-10-6-6-10 | 74,2 | 74,5 | 65,8 | 75,5 | 84,5 | 69,5 | 202,7 | 203,35 | 135,9 | 173,4 | 203,4 | 182,2 |
| Kapelga | 71 | 74,25 | 56,2 | 63,5 | 73 | 72,5 | 391,9 | 356,85 | 213,8 | 270,7 | 269,9 | 292 |
| Kouria | 65,7 | 64,25 | 53,5 | 57,5 | 71,2 | 66,8 | 357 | 339,4 | 218,6 | 235,9 | 221,3 | 274,8 |
| Lata//DouaG-4-27-1-1-vrac | 85,5 | 79,5 | 64,7 | 76,75 | 79,5 | 74 | 298,3 | 311,95 | 200,1 | 252,5 | 206,6 | 287,7 |
| Lata//Grin-9-14-1-1-vrac | 85,3 | 76,75 | 59,3 | 75 | 74,5 | 71,5 | 319 | 303,85 | 187 | 234,2 | 264,5 | 266 |
| Lata//Ridb-3-9-1-1-vrac | 84,6 | 86,5 | 64 | 73 | 78,7 | 72 | 285,4 | 329,55 | 116,3 | 226,4 | 201,8 | 255,6 |
| ND07 e21(17x30) F2-6-v | 88 | 85,75 | 64,7 | 82 | 82,8 | 71,8 | 236 | 246,2 | 131,7 | 215,7 | 152,7 | 246,4 |
| PR3009B | 66,8 | 70,75 | 69,3 | 76,5 | 72,3 | 74,8 | 257,3 | 236,2 | 192,1 | 214,6 | 266,1 | 234,9 |
| Mean SED | 2,4 | 4,19 | 1,2 | 1,48 | 3,7 | 4,6 | 14,9 | 12,38 | 8,3 | 11,4 | 35,4 | 9,3 |
| Mean LSD | 4,9 | 8,38 | 2,4 | 2,95 | 7,4 | 9,2 | 29,8 | 24,76 | 16,7 | 22,9 | 70,9 | 18,6 |

**Table 6:** Grain yield mean and midge damage scores in the three sites of evaluation

| **Trait** | **Grain Yield (GY)** | | | | | | **Midge damage (Mdg)** | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Sites** | **KBS** | | **FKB** | | **FADA** | | **KBS** | | **FKB** | | **FADA** | |
| **Year / Genotypes** | **2019** | **2020** | **2019** | **2020** | **2019** | **2020** | **2019** | **2020** | **2019** | **2020** | **2019** | **2020** |
| 014-SB-EPDU-1004 | 3657,7 | 2647,6 | 1954,7 | 2371,1 | 667,4 | 804,7 | 1 | 1 | 1 | 1 | 2,8 | 2,8 |
| 12B | 2640,3 | 2374,0 | 733,1 | 1601,6 | 657,9 | 1023,4 | 0,9 | 1 | 1 | 0,9 | 6 | 6 |
| Fambe B | 2148,8 | 2541,9 | 2189,8 | 2121,1 | 1047,8 | 921,9 | 1,2 | 1,3 | 1 | 1,2 | 4,7 | 4,3 |
| ICSV1049 | 2589,6 | 2038,1 | 1383 | 882,9 | 1457,4 | 1429,7 | 1 | 0,9 | 0,9 | 1 | 3,7 | 3,8 |
| ISX-09001-7-3-1-4-1-3-21-3 | 2145,8 | 1821,3 | 1533,2 | 1472,7 | 1351,6 | 1523,4 | 0,9 | 1,2 | 0,9 | 0,9 | 3,9 | 4,3 |
| ISX-09004-1-3-1-3-6-7-7-3 | 1771,6 | 1104,5 | 1593,3 | 1238,3 | 746,5 | 1253,9 | 0,9 | 0,9 | 0,9 | 0,9 | 3 | 2,8 |
| ISX-09005-11-1-5-2-5-4-14-3 | 2440,7 | 1919,9 | 1489,4 | 2183,6 | 781 | 664,1 | 1 | 1 | 1,2 | 1 | 6,6 | 6,3 |
| ISX-09005-11-1-7-1-5-5-9-4 | 1380,7 | 1395,5 | 796,1 | 1667,9 | 308,8 | 418 | 0,9 | 1 | 0,9 | 0,9 | 6,1 | 5,8 |
| ISX-09005-11-5-2-1-6-10-8 | 1100,2 | 1546,9 | 1890,3 | 1050,8 | 1146,4 | 109,4 | 1,5 | 1,5 | 1,5 | 1,5 | 5,4 | 5,3 |
| ISX-09005-11-5-2-9-5-9-6-11 | 872 | 1683,9 | 1493 | 1515,6 | 515,2 | 234,4 | 1 | 1 | 1 | 1 | 6 | 5,5 |
| ISX-09005-3-1-5-11-5-8-24-7 | 925,2 | 1583,0 | 973,8 | 1050,8 | 995,8 | 835,9 | 1 | 1 | 1 | 1 | 2 | 2,5 |
| ISX-09005-3-1-7-2-8-7-1-7 | 2060,2 | 1494,1 | 1783,6 | 1691,4 | 852,5 | 1132,8 | 1 | 1 | 1 | 1 | 3,8 | 3,8 |
| ISX-09005-7-4-3-1-10-6-6-10 | 3609,8 | 2031,3 | 1314,5 | 2242,2 | 391 | 1820,3 | 1 | 1 | 1 | 1 | 5,5 | 6 |
| Kapelga | 1346,1 | 2246,1 | 1136 | 2042,9 | 1196,5 | 1906,3 | 0,9 | 0,9 | 0,9 | 0,9 | 3,6 | 4 |
| Kouria | 1813 | 3088,9 | 1719,3 | 1210,9 | 1615,6 | 1093,8 | 0,9 | 1 | 0,9 | 0,9 | 4,5 | 4,5 |
| Lata//DouaG-4-27-1-1-vrac | 2646,6 | 2505,9 | 2417,4 | 2421,9 | 1544,9 | 1460,9 | 1,5 | 1 | 1,5 | 1,5 | 4,3 | 4,5 |
| Lata//Grin-9-14-1-1-vrac | 2907,3 | 1932,6 | 2179,2 | 1472,7 | 1926 | 1726,6 | 0,9 | 0,9 | 0,9 | 0,9 | 3,1 | 3,3 |
| Lata//Ridb-3-9-1-1-vrac | 3367,9 | 4865,2 | 1104,8 | 2601,6 | 1155,7 | 683,6 | 1 | 1 | 1 | 1 | 3,4 | 3,5 |
| ND07 e21(17x30) F2-6-v | 3703,4 | 1923,8 | 1992,7 | 1804,7 | 380,4 | 660,2 | 1 | 0,9 | 1 | 1 | 5,6 | 5,3 |
| PR3009B | 1789,1 | 1900,4 | 797,4 | 1730,5 | 1111 | 566,4 | 0,9 | 0,9 | 1 | 0,9 | 3 | 3,3 |
| Mean SED | 658,6 | 392,6 | 365,3 | 470,9 | 460,7 | 279,8 | 0,2 | 0,2 | 0,2 | 0,2 | 1,4 | 1,5 |
| Mean LSD | 1318,9 | 785,2 | 731,4 | 942,1 | 922,4 | 559,7 | 0,4 | 0,4 | 0,4 | 0,4 | 2,8 | 3 |

SED: Standard Deviation, LSD: Least Significant Difference

**Environment stability study through effect of genotype-by-environment interaction (GGE):** Genotype and genotype-by-environment interaction (GGE) biplots allow identification of the Genotype-by-Environment Interaction (GEI) pattern of the data and helps to identify stable genotypes associated with the best environments. The relationship among genotypes and environments is described by Figure 1. The environment vectors displayed information about discriminating power of environments and their relationships with genotypes. In fact, a long environment vector revealed a high capacity to discriminate genotypes and the cosine of the angle between two environments enlightened about correlation between them. According to the angles of environments vectors, the sites are grouped into two major groups. The first group Kamboinse and Farako-Ba was closely correlated due to small angle between them while the second group was constituted of one site (Fada). Overall, all angles between first group and second group were inferior to 90° and longest vectors from origin was obtained respectively with Kamboinse following by Farako-Ba suggesting they were more discriminating and also indicating high yielding environments while Fada was less discriminating with the shortest vectors from origin and linked to the low yielding environments.

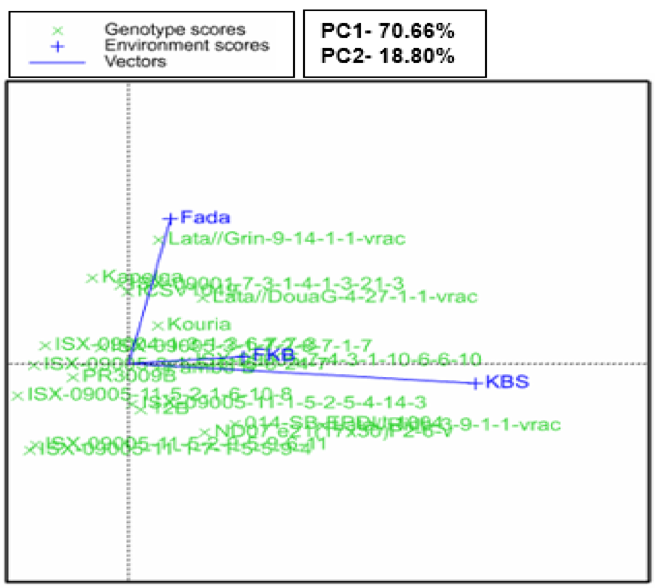


**Figure 1:** GGE plot showing 20 genotypes and three different environments based on environment scaling Key: FKB= Farako-Ba, KBS= Kamboinse

Stable and unstable environments information is provided by IPCA-1 score. Positive and negative IPCA-1 scores revealed status of environments (stable or unstable). Thus, Fada and Farako-Ba had a positive IPCA-1 score and low mean yield in the stable environments. On the contrary, Kamboinse had negative IPCA-1 score and high mean yield above the grand mean in the unstable environments. In this study, genotype's reaction was different according to environmental variation; as a result, the best AMMI model allows to select relatively best genotypes that suit to a specific environment. The four best genotypes selected by AMMI model for each environment are presented in Table 7. Accordingly, only one genotype (Lata//DouaG-4-27-1-1-vrac) performed well in high yielding environment (Farako-Ba) and low yielding environment (Fada) while two genotypes (014-SB-EPDU-1004 and ND07e21(17x30) F2-6-v) were the best for high yielding environments (Kamboinse and Farako-Ba). Fambe B was specifically adapted to low high yielding and stable environment (Farako-Ba) while genotypes Lata//Ridb-3-9-1-1-vrac and ISX-09005-7-4-3-1-10-6-6-10 were the best and specifically adapted to high yielding and unstable environment (Kamboinse). Three genotypes (Lata//Grin-9-14-1-1-vrac, Kapelga and ICSV1049) were specifically adapted to the low yielding and stable environment (Fada). The other genotypes that were evaluated did not show a distinct pattern of adaptation and more specific adapted either to low or to high yielding environments.

**Table 7:** Four best genotypes per site.

| Num | Env | Mean | IPCA 1 Score | The first four AMMI selected genotypes1 | | | |
|---|---|---|---|---|---|---|---|
| | | | | 1 | 2 | 3 | 4 |
| E1 | Fada | 1003 | 30.85 | Lata//Grin-9-14-1-1-vrac | Kapelga | Lata//DouaG-4-27-1-1-vrac | ICSV1049 |
| E2 | FKB | 1621 | 6.95 | Lata//DouaG-4-27-1-1-vrac | 014-SB-EPDU-1004 | Fambe B | ND07 e21 (17x30) F2-6-v |
| E3 | KBS | 2189 | -37.80 | Lata//Ridb-3-9-1-1-vrac | 014-SB EPDU-1004 | ND07e21 (17x30) F2-6-v | ISX-09005-7-4-3-1-10-6-6-10 |

AMMI: Additive Main effects and Multiplicative Interaction model, E1: Environment 1, E2: Environment 2, E3: Environment 3.

**Identification of stable genotypes across sites:** In GGE biplot, the best genotype is the one with large PC1 scores (high mean yield) and near zero PC2 scores (high stability). In this study, PC1 and PC2 accounted respectively for 70.66% and 18.80% of the total GGE (genotype and genotype by environment interaction) and a total of 89.46% of GGE. In this study, GGE biplot was used to identify stables genotypes through stability superiority measure coefficients. In this case, genotypes with smaller values are more stable than other. Table 8 provides the ranking of tested sorghum lines from more stable to more unstable. Among the tested genotypes, the six most high yielder and stable genotypes were Lata//Ridb-3-9-1-1-vrac, 014-SB-EPDU-1004, Lata//DouaG-4-27-1-1-vrac, ISX-09005-7-4-3-1-10-6-6-10, ND07 e21(17x30)-F2-6-v and Lata//Grin-9-14-1-1-vrac while ISX-09004-1-3-1-3-6-7-7-3, ISX-09005-11-5-2-1-6-10-8, ISX-09005-11-5-2-9-5-9-6-11, ISX-09005-11-1-7-1-5-5-9-4, ISX-09005-3-1-5-11-5-8-24-7 and PR3009B were the six low yielder and unstable genotypes across the test environments. The remaining genotypes including checks (Kapelga and ICSV 1049) had medium yield and were comprised in between stable and unstable genotypes.

**Table 8:** 20 most stable genotypes according to stability superiority measure coefficients

| Genotypes | Cultivar superiority | Means | Ranking |
|---|---|---|---|
| Lata//Ridb-3-9-1-1-vrac | 190,658 | 2,277 | 1 |
| 014-SB-EPDU-1004 | 332,761 | 2,031 | 2 |
| Lata//DouaG-4-27-1-1-vrac | 395,009 | 2,158 | 3 |
| ISX-09005-7-4-3-1-10-6-6-10 | 436,467 | 1,877 | 4 |
| ND07 e21(17x30)F2-6-v | 510,707 | 1,808 | 5 |
| Lata//Grin-9-14-1-1-vrac | 510,712 | 2,021 | 6 |
| Kouria | 578,892 | 1,777 | 7 |
| Fambe B | 652,477 | 1,808 | 8 |
| ICSV1049 | 806,750 | 1,637 | 9 |
| ISX-09005-11-1-5-2-5-4-14-3 | 813,899 | 1,596 | 10 |
| 12B | 828,468 | 1,499 | 11 |
| ISX-09001-7-3-1-4-1-3-21-3 | 886,043 | 1,648 | 12 |
| ISX-09005-3-1-7-2-8-7-1-7 | 996,723 | 1,538 | 13 |
| Kapelga | 1,075,161 | 1,602 | 14 |
| PR3009B | 1,218,081 | 1,302 | 15 |
| ISX-09004-1-3-1-3-6-7-7-3 | 1,459,486 | 1,272 | 16 |
| ISX-09005-11-5-2-1-6-10-8 | 1,692,200 | 1,121 | 17 |
| ISX-09005-11-5-2-9-5-9-6-11 | 1,740,399 | 1,063 | 18 |
| ISX-09005-11-1-7-1-5-5-9-4 | 1,769,149 | 999 | 19 |
| ISX-09005-3-1-5-11-5-8-24-7 | 1,820,200 | 1,046 | 20 |

**Identification of mega environments:** GGE biplot has also an ability to show the which-won-where pattern and mega environment differentiation from the genotype by environment interaction and revealed a precise summary of the G × E pattern on a multi environment trial. Mega environment is a group of sites (environments) sharing almost the same and best genotypes. The polygon in Figure 2 is formed by the connection of genotypes that are fur away from the biplot origin such that all the remaining genotypes are contained in the polygon. The biplot displayed six sectors with the best or poorest genotypes (Lata//Grin-9-14-1-1-vrac, Kapelga, Lata//Ridb-3-9-1-1-vrac, ND07e21(17x30) F2-6-v, ISX-09005-7-4-3-1-10-6-6-10, ISX-09005-3-1-5-11-5-8-24-7 and ISX-09005-11-1-7-1-5-5-9-4) located on the vertices of the polygon. In fact, according to Yan and Kang (2003) genotypes located on the vertices of the polygon performed either the best or the poorest in one or more environments. The GGE biplot graph identified clearly two different sorghum-cultivating mega-environments for grain yield linked to discrimination provided earlier by environment vectors. The first environment includes higher yielding E3 (Kamboinse) and medium yielding E2 (Farako-Ba) environment, with the best genotype Lata//Ridb-3-9-1-1-vrac and the second environment contains the lower yielding environment E1 (Fada) with the winner yielding genotype Lata//Grin-9-14-1-1-vrac in Figure 2. On the contrary, the result also displayed some genotypes, which were not link to any locations at all. These genotypes are poorly adapted to three testing locations (PR3009B, ISX-09004-1-3-1-3-6-7-7-3, ISX-09005-11-5-2-1-6-10-8, ISX-09005-11-5-2-9-5-9-6-11, ISX-09005-11-1-7-1-5-5-9-4 and ISX-09005-3-1-5-11-5-8-24-7.

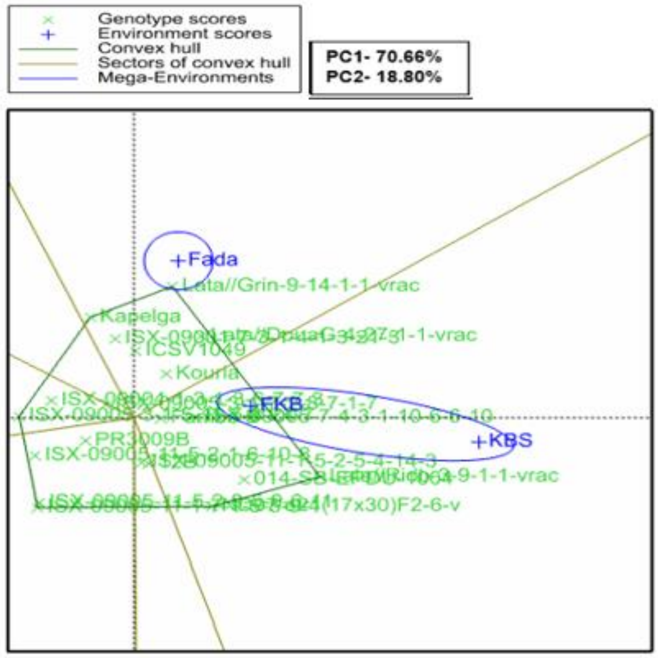


**Figure 2:** Polygon view of GGE biplot graph for which-won-where of grain yield based on environment scaling **Key**: FKB= Farako-Ba, KBS= Kamboinse

## DISCUSSION

The highly significant mean squares of year, environments and genotypes for studied traits including grain yield indicated that climatic condition across year were variable, the environments were diverse across sites and genotypes reacted differently from each other. The highly significant mean squares of environments for different traits revealed that the environments were diverse, which is in agreement with the previous results reported by Gezahegn *et al.* (2017) on napier grass. According to the cumulative rainfall data, it appears clearly that the wetter site is Farako-Ba following by Kamboinse and Fada was the less wet site. In fact, Farako-Ba is located in the sudanian climatic zone while Kamboinse and Fada are located in sudano-sahelian with lower rainfall. Geographical coordinates (longitude, latitude and altitude) displayed diversity within studied sites. Interaction factors such genotypes by year, genotypes by environment (sites) and genotyped by year and by environments also displayed significant ($P < 0.001$) different for all traits, this indicated that genotypes interacted differently across year and across environments. Across years and sites, cumulative rainfall was different during the two years of evaluation and planting dates were delayed across year and sites. During year 1 evaluation, cumulative rainfall was important at Farako-Ba than year 2. In contrary, it was less important at Kamboinse and Fada in year 1 than year 2 and trials were set up earlier respectively at Kamboinse and Fada during year 1 than year 2, in opposite to Farako-ba where trials were set up earlier year 2 than year 1. In fact, genotypes may react differently according to planting dates in relation to photoperiodism (Zongo, 1991; Gapili *et al.*, 2015). Overall, climatic condition is less harsh in sudanian zone than sudano-sahelian zones in Burkina Faso and this could explain the highly significant different reaction of genotypes across year and across environment. Lines adaptation to different growing areas was revealed through the seedling and heading parameter. Concerning seedling, genotypes had approximatively the same vigour during the two years of evaluation, this, may due to guinea race potential as their well-adapted in semi-arid condition and also to good rainfall set up and good agronomic practices before sowing. For the heading, the references varieties are the checks [Kapelga (68, 42 dap) and ICSV1049 (71, 91 dap)] and all evaluated lines that headed earlier or around the same days (before 75 dap) than the checks are well adapted to sudano-sahelian growing areas of the country. Seven lines [Kouria (63,18 dap), PR3009B (71,9 dap), ISX-09004-1-3-1-3-6-7-7-3 (71,19 dap), Fambe B (73,06 dap), Lata//Grin-9-14-1-1-vrac (73,78 dap), ISX-09005-7-4-3-1-10-6-6-10 (74,07 dap), 12B (74,39 dap)] headed before 75 dap and could reach physiological maturity around 105 dap, corresponding to the end of rainy season (early October). However, lines that heading date were comprised between 75 dap and 85 dap may be cultivated in sudanian agro ecological zone (Farako-Ba) because in this area moisture last up to end of October. All the remaining lines (11) headed among 75 and 85 dap at Farako-Ba and Fada except Kamboinse were they headed after 85 dap. In fact, trials have been planted earlier at Kamboinse (02-07-2019 during year 1 and 07-07-2020 during year 2) than the two others sites and the late heading date of lines may be due to photoperiodism response (Zongo, 1991; Gapili *et al.,* 2015). Lines were taller at Kamboinse than in the two other sites (Farako-Ba and Fada), due to enough time, they had for vegetative development before heading in reference to their planting date. Agronomic performance of evaluated lines was linked to midge damage across sites. Lines yielded more in sites of Kamboinse and Farako-Ba with less midge damage than in site of Fada with more midge damage. In fact, the high score of midge damage reported was 6 indicating a yield loss from 51-60% of yield loss at Fada. This damage was beyond the result reporting by Dakuo *et al.* (2005) who revealed that midge damage could reach 33% in the south, central west and the eastern zones of the country. Genotype and genotype-by-environment interaction (GGE) biplots help to identify the best environments as well as the best genotypes. In this study, two distinct groups of environments for Grain Yield (GY) evaluation were displayed. The relationship among environments and which won were pattern showed that Kamboinse and Farako-Ba were similar while Fada was different. Earlier studies conducted by Hamidou *et al.,* 2018, Teodoro *et al.,* 2016 reported two mega-environments in sorghum evaluation over five different environments, Rakshit *et al.,* 2012 reported three mega-environments for meta data evaluation over twelve environments while De Figueirodo *et al.,* 2015 revealed several mega-environments for green mass yield and total soluble solids in sweet sorghum using GGE biplot analysis. In terms of stability, the IPC-1 scores revealed that Fada and Farako-Ba even belonging to different mega-environments were stable while Kamboinse were not stable. In terms of GY performance, Lata//DouaG-4-27-1-1-vrac was leading in a stable, medium and low yielding (Farako-Ba and Fada) while genotypes 014-SB-EPDU-1004 and ND07e21(17x30) F2-6-v were leading in unstable high yielding environment (Kamboinse) and stable medium yielding environment (Farako-Ba). This makes the three genotypes to be identified as the best performing lines of this study. Massoudou *et al.* (2018), reported two genotypes while Al-Naggar *et al.* (2018) documented four genotypes based on GY performance and stability.

## CONCLUSION

Adapted to lines to sudanian and sudano-sahelian zone were identified through the study according to heading date. Seven lines (Kouria, PR3009B, ISX-09004-1-3-1-3-6-7-7-3, Fambe B, Lata//Grin-9-14-1-1-vrac, ISX-09005-7-4-3-1-10-6-6-10, 12B) were adapted to sudano-sahelian zone and the remaining (13) cycle fitted in the sudanian growing area. Among the adapted lines, stables ones for grain yield across environments were identified along with suitable environment for sorghum growing and evaluation. Overall, Lata//DouaG-4-27-1-1-vrac, 014-SB-EPDU-1004 and ND07e21(17x30) F2-6-v were found to be stable for grain yield under both stable and non-stable environments whereas Lata//Grin-9-14 -1-1-vrac, Kapelga and ICSV 1049 performed well under low yielding environment characterized by high midge pressure conditions. ISX-09005-7-4-3-1-10-6-6-10, Lata//Ridb-3-9-1-1-vrac and Fambe B performed only under high yielding environment.

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## REFERENCES

Al-Naggar AMM, Abd El-Salam RM, Hovny MRA, Walaa YSY, 2018. Genotype×environment interaction and stability of Sorghum bicolor lines for some agronomique and yield traits in Egypt. *Asian Journal of Agricultural and Horticultural Research* 1 : 1–14.

Bal AB, 2005. Entomofaune des panicules de sorgho et effet des dates de semis et des variétés sur les populations de *Stenodiplosis sorghicola* (Diptera. Cecidomyiidae) et *Eurystylus oldi* (Hemiptera : Miridae) et les pertes de rendement. *Tropicultura*, 23 (3): 177-182.

Barro-Kondombo PC, Chantereau j, Goze E, Weltzien E, Trouche G, Brocke VK. 2010. Participatory variety development for sorghum in Burkina Faso: Farmers' selection and farmers' criteria. *Field Crops Research* 119 :183–194.

Bonzi M, 1979. *La cécidomyie du sorgho,* Contarinia sorghicola *Coq. En Haute Volta, Possibilités de lutte.* Comptes rendus du congrès sur la lutte contre les insectes en milieu tropical, Chambre de Commerce et d'Industrie de Marseille, 13-16 mars 1979 : 531-41.

Dakouo D, Trouche G, Ba M, 2005. La lutte génétique contre la cécidomyie du sorgho, *Stenodiplosis sorghicola* au Burkina Faso. *Cahiers d'Agriculteurs*. 14 : 201-208.

Dakouo D, 1996. La cécidomyie du sorgho : bioécologie et pertes. In: Ratnadass A, Ajayi O, Marley PS, Akintayo I, eds. *Les insectes ravageurs du sorgho en Afrique de l'Ouest et du Centre*. Actes de l'atelier de formation ROCARS-Icrisat-Cirat, 14-23 octobre 1996, Samanko (Mali). Colloques. Montpellier : Centre de coopération internationale en recherche agronomique pour le développement (Cirad, 2001 ; 4 p. (*cédérom*).

De Figueiredo UJ, Nunes JAR, Parrella RDC, Souza ED, da Silva AR, Emygdio BM, Machado JRA and Tardin FD, 2015. Adaptability and stability of genotypes of sweet sorghum by GGE biplot and

Toler methods. *Genetics and Molecular Research* 14: 11211–11221.

Dora SVVN, Polumahanthi S, Sarada MN, 2014. Efficient callus induction protocol for *Sorghum bicolor*. *Asian Journal of Plant Science and Research* 4(3):14-21.

Gapili N, Sawadogo M, Nanéma KR, Nebié B, Sawadogo N, Zongo JD, 2015. Étude du photopériodisme des écotypes de sorgho du Burkina Faso. *International Journal of Innovation and Applied Studies* 13(4) : 901-909.

Hamidou M, Souleymane O, Ba NM, Danquah YE, Kapran I, Gracen V, Kwadwo O, 2018. Identification of stable genotypes and genotype by environment interaction for grain yield in sorghum (Sorghum bicolor L. Moench), *Plant Genetic Resources*; 1–6.

Gezahegn K, Getnet A, Fekede F, Mengistu A, Alemayehu M, Aemiro K, Kassahun M, Solomon M, Estifanos T, Shewangizaw W, Mergia A. 2017. Genotype × environment interaction and stability analysis for dry matter yield of napier grass (*Pennisetum purpureum* (L.) Schumach) genotypes tested across diverse environments in Ethiopia. *International Journal of Science,* 1: 1-14.

MAAH, 2019. Rapport général des résultats définitifs de la campagne agricole 2018/2019 et des perspectives de la situation alimentaire et nutritionnelle. Ouagadougou. Burkina Faso. 95p.

Ouedraogo N, J Sanou, H Kam, H Traore, M Adam, V Gracen and E Y Danquah. 2017: Farmers' perception on impact of drought and their preference for sorghum cultivars in Burkina Faso, *Agricultural Science Research Journal* Vol. 7(9): 277-284.

Sànchez-Blanco J, Rodr gue P, orales A, Ortu O F, Orrecillas A, 2002. Comparative growth and water relations of *Cistus albidus* and *Cistus monspeliensis* plants during water deficit conditions and recovery. *Plant Science* 162(1):107-113. https://doi.org/10.1016/s0168-9452%2801%2900540-4.

Sujay R, Ganapathy KN, Gomashe SS, Rathore A, Ghorade BR, Nagesh Kumar VM, Ganesmurthy K, Jain KS, Kamtar YM, Sachan SJ, Ambekar SS, Ranwa RB, Kanawade GD, Balusamy M, Kadam D, Sarkar A, Tonapi VA, Patil VJ, 2012. GGE biplot analysis to evaluate genotype, environment and their interactions in sorghum multi-location data. *Euphytica*, 185:465–479.

Teodoro PE, Almeida FJ, Daher RF, Menezes CB, Cardoso MJ, Godinho VP and Tardin FD, 2016. Identification of sorghum hybrids with high phenotypic stability using GGE biplot methodology. *Genetics and Molecular Research*: GMR 15: 234–239.

Yan W, Kang MS 2003. GGE biplot analysis: A graphical tool for breeders, In: Kang, M. S. (ed.), *Geneticists and Agronomist*. FL: CRC Press, Boca Raton. pp. 63-88.

Young WR, Teetes GL, 1997. Sorghum entomology. *Ann Rev Entomol* 1997; 22: 193-218.

Zongo J. D., 1991. Ressources génétiques des sorghos (Sorghum bicolor L. Moench) du Burkina Faso : Évaluation agro-morphologique et génétique. Thèse de doctorat, Université d'Abidjan, Côte d'ivoire, 219p.