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STABILITY AND EXTENT OF RESISTANCE OF COWPEA LINES TO FLOWER BUD THRIPS IN UGANDA

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ABSTRACT

Cowpea (*Vigna unguiculata* (L.) Walp.) is a legume attacked by several field insect pests, with flower thrips (*Megalurothrips sjostedti* Trybom) being the most damaging. It causes 20 to 100% yield losses. Cowpea constitutes an important source of protein for resource poor households in Africa. The objective of this study was to identify cowpea lines that are resistant to flower thrips as a step in developing sustainable thrips management strategies. Seventy two cowpea cultivars were screened in three locations and two rainy seasons in Uganda, for thrips damage and yield components. Up to 11 cultivars (IT2841*Brown (1.50), MU20B (1.58), EBELAT*NE39 (1.61), WC17 (1.63), WC29 (1.65), MU24C (1.65), WC5 (1.66), NE46 (1.67), WC30 (1.68), NE67 (1.69), and NE51 (1.71)) were the most resistant and stable across locations. However, thrips damage was negatively correlated with the number of days to flowering (r = -0.32), indicating that the resistance in the cultivars was explained by the flower thrips infestation escape due to later flowering. Cultivar MU9 was high yielding (813.87 kg ha^{-1}) and the most adapted genotype to all the locations; while cultivars WC26, NE48, and NE5 were the most adapted to Arua and Serere, and WC48A was the most adapted to Makerere University Agricultural Research Institute, Kabanyolo (MUARIK). There is potential of finding resistance sources in the cultivars tested.

Key Words: GGE biplot, *Megalurothrips sjostedti, Vigna unguiculata*

RÉSUMÉ

Le niébé (*Vigna unguiculata* (L.) Walp.) est une légumineuse attaquée par plusieurs insectes au champ avec thrips (*Megalurothrips sjostedti* Trybom) le plus nuisible causant 20-100% de perte de rendement. Le niébé constitue une source de protéine bon-marché pour beaucoup de pauvres ménages en Afrique. L'objectif de cette étude était d'identifier des variétés plus résistantes au thrips pour le développement des stratégies de lutte durable. Soixante-douze variétés du niébé ont été évaluées dans trois environnements pendant deux saisons en Uganda pour les dommages, le rendement et ses composantes. Les données ont été soumises aux analyses de variance et biplot de l'effet de génotype et l'interaction entre génotype et environnement (GGE). Les résultats ont montré un effet significatif (P<0.001) de l'interaction entre génotype, environnement pour les scores de dommages causés par thrips. Les variétés les plus résistantes et stables étaient IT2841*Brown (1.50), MU20B (1.58), EBELAT*NE39 (1.61), WC17 (1.63), WC29 (1.65), MU24C (1.65), WC5 (1.66), NE46 (1.67), WC30 (1.68), NE67 (1.69), and NE51 (1.71). Toutefois, une corrélation négative (r = -0.32) a été observée entre les scores de dommage et le nombre de jours de floraison indiquant que la résistance observée, était due à un échappement par une floraison tardive. Le cultivar MU9 avait le rendement le plus élevé (813, 87 kg ha^{-1}) et constituait le plus adapté aux différents environnements alors que les cultivars WC26, NE48, and NE5 étaient les plus adaptés à Arua et Serere, et WC48A était le plus adapté à l'Institut de Recherches Agricoles de l'Université de Makerere, Kabanyolo (MUARIK). Il y a potentiel de trouver de source de résistance parmi les variétés évaluées.

Mots Clés: GGE biplot, *Megalurothrips sjostedti*, *Vigna unguiculata*

INTRODUCTION

Cowpea [*Vigna unguiculata* (L.) Walp.] is the most well-known *Papilionaceae* species with an African origin (Omo-Ikerodah *et al.,* 2009). The crop is an important staple food legume and inexpensive source of protein for many resource poor African households. Cowpea also contributes 30-125 kg of nitrogen ha^{-1} in the soil through its nitrogen fixing properties, which is crucial in restoring soil fertility (Gbaguidi *et al.,* 2013). Coupled with these attributes, its quick growth and rapid ground cover have made it an essential component of sustainable subsistence agriculture in marginal lands and drier regions of the tropics, where rainfall is scanty and soils are sandy with little organic matter (Singh *et al.,* 1997).

In Uganda, about 90% of the crop is grown in the eastern and northern regions. Cowpea grain yield potential on-station is 3 t ha^{-1} but in farmers' fields, yields average a miserly 0.2-0.4 t ha^{-1} in most African countries (Akande *et al*., 2012). This low level of productivity is attributed to a complex of insect pests and diseases, poor agronomic practices and use of low yielding cultivars (Boukar *et al*., 2016). Several insect pests attack cowpea in the field and studies have indicated flower bud thrips (*Megalurothrips sjostedti* Trybom) to be the most damaging in Africa (Karungi *et al.*, 2000; Ngakou *et al*., 2008; Muchero *et al.,* 2009). The yield reduction due to flower buds thrips ranges from 20 to 80%, but under severe infestation, complete yield loss may occur (Omo-Ikerodah *et al.*, 2009).

The control of cowpea flower bud thrips using the available pest management options in Uganda has not been successful (Ssemwogerere *et al*., 2013). Chemical control measures are the most widely known form of control of thrips in cowpea; however, the rapid development of insecticide resistance in thrips populations has rendered the chemical treatments ineffective (Morse and Hoddle, 2006). Furthermore, in cases where cowpea leaves and green pods are eaten fresh as a vegetable, insecticides pose a threat to the consumers,in addition to other hazardous effects to the environment (Oyewale and Bamaiyi, 2013).

Host plant resistance offers the potential to reduce or eliminate dependence on chemicals control. However, there have been no targeted studies on cowpea germplasm reaction to flower bud thrips in Uganda and farmers are still growing the susceptible cultivars (Asio *et al.,* 2005). Studies under natural infestation indicated possible existence of thrips resistant lines among the local cowpea cultivars (Karungi *et al.,* 2000; Mbeyagala *et al.*, 2014). The objective of this study was to identify the cowpea lines that are resistant to flower thrips for the development of sustainable thrips management strategies.

MATERIALS AND METHODS

Screening of seventy two cowpea genotypes was conducted at Makerere University Agricultural Research Institute, Kabanyolo (MUARIK), National Semi-Arid Resources Research Institute, Serere (NaSARRI), and at Abi-Zonal Agricultural Research and Development Institute, Arua (Abi ZARDI). All these sites are considered as flower thrips hotspot in Uganda. The study was conducted for two consecutive seasons, namely the short rainy season of 2015 (2015B) and long rainy season of 2016 (2016A). Information of coordinates, climatic and soil characteristics of the experimental sites are provided in Table 1.

The cowpea cultivars used in this study were obtained from the cowpea collection at MUARIK that contained eight breeding lines from the International Institute of Tropical Agriculture (IITA), 16 breeding lines from Uganda,and 48 Ugandan landraces. The characteristics of the cultivars used are listed in Table 2.

The seventy two cowpea cultivars were screened in an alpha lattice design (8 blocks x 9 genotypes per block), with two replications. Three seeds were planted per hole and the seedlings were thinned to two plants per stand, 10 days after sprouting. Each plot consisted of 4 rows of 5 m long and 0.75 m apart with an intra-rows space of 0.25 m.

The cultivars were given protection against aphids during the vegetative stage,by spraying with the insecticide chlorpyrifos (as Ascoris 48 EC) applied at the rate 2.5 g (a.i.) ha^{-1}, once at 15 days after planting. They were also protected against podding stage pests using l-cyhalothrin (as Karate 2.5 EC), sprayed at the rate 2.5 g (a.i.) ha^{-1}, with a CP-15 knapsack sprayer. This was done once at 75 days after planting at 50% podding stage. The above spraying regimes were selectively done to eliminate their confounding effects (Abudulai *et al.,* 2006).

Data were collected on number of days to 50% flowering per plot, number of days to 50% pod maturity (physiological maturity) per plot, number of peduncles per plant, number of pods per peduncle, number of seeds per pod, 100 seeds weight and total dried grain weight per plot. Harvesting was done twice and the yield was estimated from the total dried grain weight per plot.

Data were also collected on thrips damage scores from twenty plants selected randomly within the two middle rows, on a scale of 1-9, from 30 days after planting; and subsequently at weekly intervals, for five weeks. Scores were defined as: 1-3 = resistant, 4-6 = moderately resistant and 7-9 = very susceptible. Rating was based on a combination of varying intensities of thrips-induced browning of the stipules and flower buds, non-elongation of peduncles, and flower bud abscission (Table 3) (Jackai and Singh, 1988).

Number of thrips per flower was estimated from 10 racemes on each flower, randomly picked in a plot. The samples were taken once a week, in mornings, between 08:00 - 10:00 am, during the flowering stage, starting 30 days after planting in five subsequent weeks. The flowers after collection, were conserved in a glass bottle containing 70% ethanol before extracting the thrips. Identification of the species of flower thrips was done in the Entomology Laboratory of Kawanda (Uganda) using the Morphological Methods (Palmer, 1990).

TABLE 1. Geographic characteristics of the study locations in Uganda

Locations	Geographical coordinates		Altitude (m.a.s.l)	Average annual temperature (°C)	Average annual rainfall (mm)	Soils
	Latitude	Longitude				
MUARIK (Wakiso)	0°28'N	32°37'E	1200	21.50	1150	Sandy clay loam
Abi-ZARDI (Arua)	3°4.58'N	30°56'E	1206	24	1250	Sandy clay loams
NaSARRI (Serere)	1°35'N	33°35'E	1140	26.05	1419	Black clays

m.a.s. l = meters above sea level

Source: Fungo *et al.* (2011); Sserumaga *et al.* (2015)

TABLE 2. Cowpea cultivars used in the study of flower thrips resistance in Uganda

No.	Cultivars	Origin	Growth type	Seed coat characteristics	Hilium characteristics
1	2419	Uganda	Semi-erect	Cream	Cream and black ring
2	EBELAT X NE 39	Uganda	Semi-erect	Cream	Cream and brown ring
3	EBELAT X NE 51	Uganda	Erect	Gray tainted black	Cream and narrow
4	IT 109	IITA	Semi-erect	Creamish white	Cream and brown ring
5	IT 2841	IITA	Semi-erect	Light brown	Cream and narrow
6	IT 2841* Brown	IITA	Erect	Cream	Cream and round
7	IT 71	IITA	Semi-erect	Cream	Cream and round
8	IT 84	IITA	Erect	Light brown	Cream, small
9	IT 889	IITA	Erect	Gray tainted black	Cream and narrow
10	IT 91	IITA	Erect	Light brown	Cream, small
11	IT 97	IITA	Semi-erect	Cream	Cream, wide
12	KVU27-1	Uganda	Erect	Coffee brown	Cream, small and sideways
13	MU 15	Uganda	Erect	Cream	Cream and brown ring
14	MU 17	Uganda	Semi-erect	Cream	Cream
15	MU 19	Uganda	Erect	Cream	Cream
16	MU 20B	Uganda	Erect	Black	White, small
17	MU 24C	Uganda	Semi-erect	Cream	Cream and black ring
18	MU 9	Uganda	Erect	Brown	Cream, small
19	NE 13	Uganda	Semi-erect	Brown	Cream, small
20	NE 15	Uganda	Semi-erect	Gray tainted black	Cream, small
21	NE 18	Uganda	Semi-erect	Brown	Cream
22	NE 20	Uganda	Semi-erect	Cream	Cream and black ring
23	NE 21	Uganda	Erect	Cream	Cream
24	NE 23	Uganda	Semi-erect	Brown	Cream
25	NE 30	Uganda	Semi-erect	Light brown	Cream
26	NE 31	Uganda	Semi-erect	Cream	Cream
27	NE 32	Uganda	Erect	Coffee brown	Cream and brown ring
28	NE 36	Uganda	Erect	Cream	Cream
29	NE 37	Uganda	Semi-erect	Cream	Cream and brown ring
30	NE 39 X SEC 2	Uganda	Erect	Cream	Cream, broad and brown ring
31	NE 39 X SEC 4	Uganda	Semi-erect	Light brown	Cream, small
32	NE 4	Uganda	Semi-erect	Cream	Cream
33	NE 40	Uganda	Semi-erect	Cream	Cream and black ring
34	NE 41	Uganda	Erect	Creamish white	Cream and brown ring
35	NE 45	Uganda	Semi-erect	Cream	Brown
36	NE 46	Uganda	Erect	Light brown	Cream, small
37	NE 48	Uganda	Erect	Brown	Cream, small
38	NE 49	Uganda	Semi-erect	Cream	Cream, wide and brown ring
39	NE 5	Uganda	Semi-erect	Cream	Cream and brown ring
40	NE 50	Uganda	Erect	Gray tainted black	Cream, wide
41	NE 51	Uganda	Erect	Light brown	Cream and broad
42	NE 53	Uganda	Erect	Gray tainted black	Cream
43	NE 6	Uganda	Erect	Coffee brown	Cream, small and sideways
44	NE 67	Uganda	Erect	Light brown	Cream, small
45	NE 70	Uganda	Semi-erect	Cream	Cream with a black ring
46	SEC 1 X SEC 3	Uganda	Erect	Brown	Cream
47	SEC 5 X NE 51	Uganda	Semi-erect	Cream	Cream and brown ring
48	SEC5 X NE 39	Uganda	Semi-erect	Cream	Cream
49	WC 17	Uganda	Erect	Black	White

TABLE 2. Contd.

No.	Cultivars	Origin	Growth type	Seed coat characteristics	Hilium characteristics
50	WC 18	Uganda	Semi-erect	Cream	Cream
51	WC 2	Uganda	Erect	Light brown	Cream and narrow
52	WC 26	Uganda	Semi-erect	Cream	Cream
53	WC 27	Uganda	Erect	Cream	Cream
54	WC 29	Uganda	Semi-erect	Cream	Cream
55	WC 30	Uganda	Erect	Brown	Cream
56	WC 32 * SEC 5	Uganda	semi-erect	Cream	Cream and brown ring
57	WC 35A	Uganda	Erect	Cream	Cream and black ring
58	WC 36	Uganda	Semi-erect	Cream	Cream
59	WC 41	Uganda	Semi-erect	Cream	Cream and brown ring
60	WC 44	Uganda	Semi-erect	Black	White
61	WC 48A	Uganda	Erect	Brown	Cream and narrow
62	WC 5	Uganda	Semi-erect	Cream	Cream and brown ring
63	WC 52	Uganda	Semi-erect	Cream	Cream
64	WC 55	Uganda	Semi-erect	Creamish white	Cream, wide
65	WC 63	Uganda	Erect	Gray tainted black	Cream and narrow
66	WC 64	Uganda	Erect	Gray tainted black	Cream and narrow
67	WC 66	Uganda	Erect	Gray tainted black	Cream
68	WC 67	Uganda	Semi-erect	Black	White
69	WC 67 A	Uganda	Semi-erect	Creamish white	Cream and brown ring
70	WC 68	Uganda	Semi-erect	Brown	Cream and brown ring
71	WC 8	Uganda	Erect	Brown	Cream and brown ring
72	WC68A	Uganda	Semi-erect	Cream	Cream and brown ring

NE = Northern and Eastern Uganda lines, WC = Western and Central Uganda lines, MU = Makerere University lines, IT = IITA lines

TABLE 3. Scale for rating flower bud thrips damage on cowpea

Rating	Appearance
1	No browning/drying (i.e scaling) of stipules, leaf or flower buds; no bud abscission
3	Initiation of browning of stipules, leaf or flower buds; no bud abscission
5	Distinct browning/drying of stipules and leaf or flower buds; some bud abscission
7	Serious bud abscission accompanied by browning/drying of stipules and buds; non-elongation of peduncles
9	Very severe bud abscission, heavy browning, drying of stipules and buds; distinct non-elongation of (most or all) peduncles

Source: Jackai and Singh (1988)

The data collected were subjected to analysis of variance, using linear mixed model (REML) procedure in GenStat 12.0 software (Payne *et al.,* 2009).The model described by Smith *et al.* (2005) was used for the analysis of variance across locations:

$$y_{ijklm} = \mu + \rho_i + \iota_j + b_{m(l)} + \rho\iota_{ji} + \varepsilon_{ijklm}$$

Where:

y_{ijklm} is the observed value for the i^{th} genotype from j^{th} location, m^{th} block nested within the l^{th} replication; μ is the general mean effect;

ρ_i is the i^{th} genotype effect (considered as fixed effect);

ι_j is the j^{th} location effect (considered as fixed effect);

$b_{m(l)}$ is the effect of m^{th} replicated nested within the l^{th} replication (considered as random);

$\rho\iota_{ji}$ is the interaction effect of j^{th} location and i^{th}genotype (considered as random); and

ε_{ijklm} is the experimental error considered as random

The means for each trait were separated using the Least Significant Difference (LSD) at 5% level.

Thrip damage scores and grain yield were also analysed using genotype plus genotype by environment (GGE) biplot methodology, to visualise the genotype by environment interaction (GEI) pattern (Yan and Holland, 2010). Thrip damage scores were transformed using inverse function plus one. Pearson's correlation analysis was performed between thrips parameters (damages scores and counts) and yield and yield components to assess the degree of association between the parameters.

RESULTS

Thrips damage scores. Location and genotypes significantly (P<0.001) influenced thrips damage on cowpea (Table 4). Genotypes also significantly (P<0.001) interacted with location for thrips damage on cowpea.

Locations significantly (P<0.001) influenced thrips counts in flowers; while genotypes had no significant (P>0.05) effect. However, genotype by location interaction significantly (P<0.001) affected thrips occurrence in flowers.

A total of 100% of the thrip specimens extracted from the flowers for all genotypes, belonged to the species *Megalurothrips*

TABLE 4. Mean squares for thrips damages scores and thrips population/flower across locations

Source of variation	Degree of freedom	Thrips damage scores	Thrips counts per flower
Locations	2	0.55*	2944.38***
Locations.Rep	3	1.64^{ns}	140.15***
Locations/Rep/Blocks	37	0.41^{ns}	10.85^{ns}
Genotypes	71	2.44***	13.43^{ns}
Genotypes.Locations	142	0.68***	11.16***
Residual	176	0.1629	5.18
Range		1.00 - 7.32	0.00 - 31.58

***, **, * = significant at P<0.001; 0.01 and at 0.05, respectively and ns = non-significant at 0.05

sjostedti Trybom, with 64.56% being females and 35.44% males.

The trends in the number of thrips per flower and the thrips damage scores over time (30-58 days after planting) per location are presented in Figures 1 - 3. The trend in thrips damage on cowpea was consistent for all the three locations, with the susceptible check WC36 standing out from the resistant counterparts. Scores for thrips damage peaked at a score of 2 at 58 DAP in MUARIK and Arua but at 44 DAP in Serere for the resistant varieties. On the other hand, scores peaked at a score of 7 at 44 DAP for the susceptible WC36 at MUARIK, 8 at 58 DAP in Arua, and 5 at 44 DAP in Serere (Figs. 1A, 2A and 3A). The trend in thrips counts in flowers was not consistent in the different locations (Figs. 1B, 2B, 3B). The susceptible WC 36 did not always have the highest counts. Populations of thrips

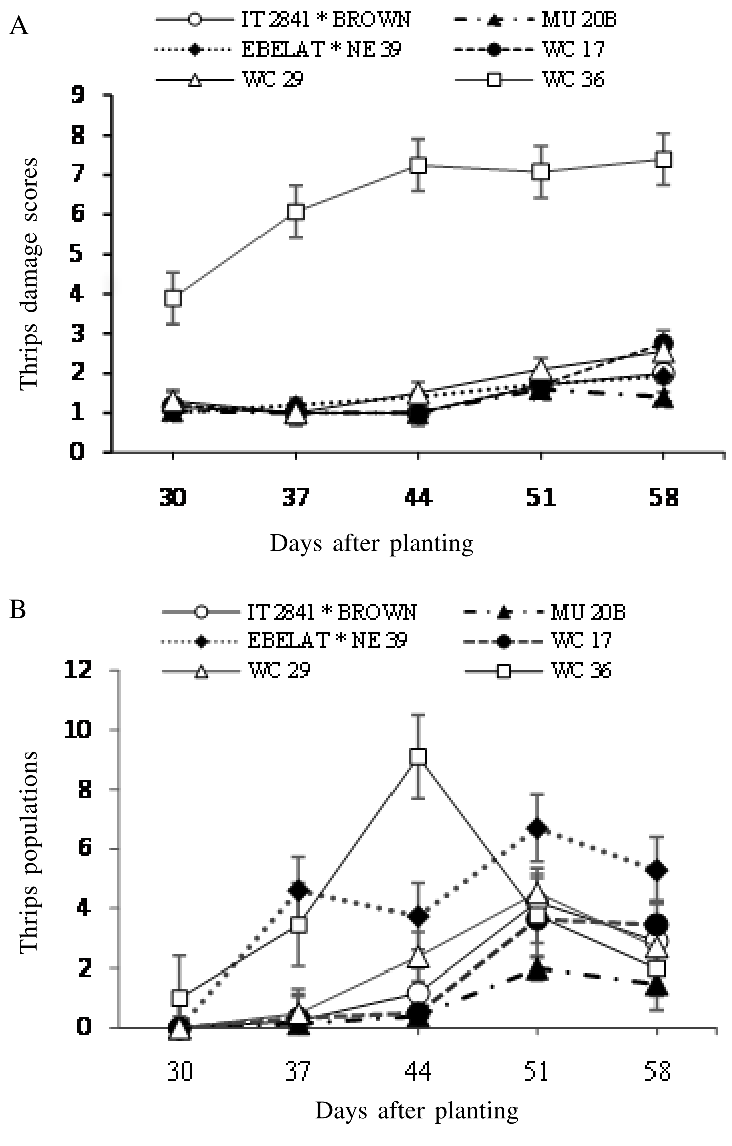
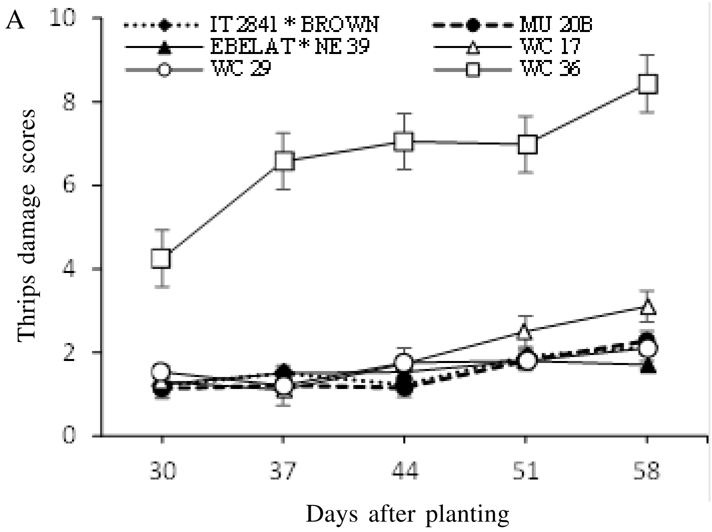


Figure 1. Trends in thrips damages scores (A) and thrips population in flowers (B) over time for selected six cowpea cultivars at MUARIK.



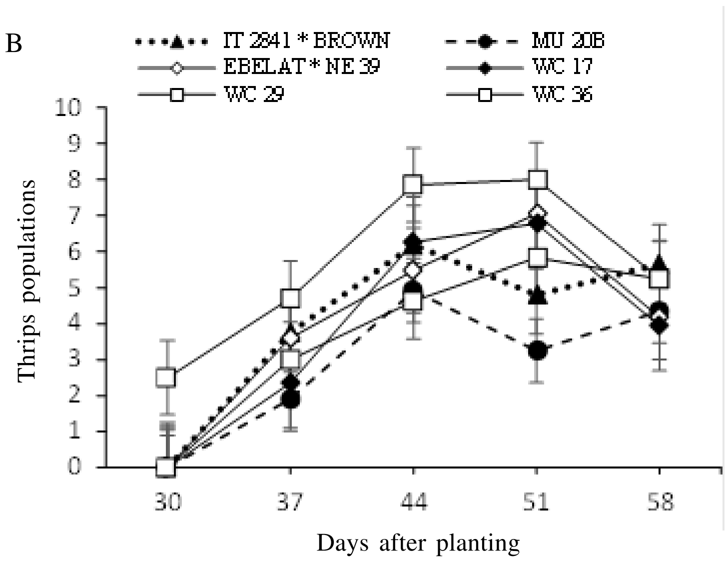
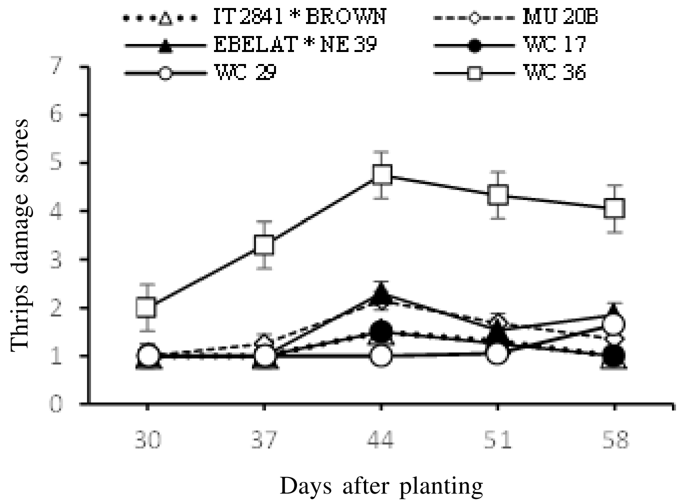


Figure 2. Trends in thrips damages scores (A) and thrips population in flowers (B) over time for selected six cowpea cultivars at Arua.

peaked at different dates for different genotypes in particular location (Figs. 1B, 2B, and 3B). In MUARIK, WC36 had the highest peak of thrips per flower, and peaked at thrips number of 9 per flower at 44 DAP. In Arua, WC36 had consistently highest thrips counts and had a peak of 8 thrips per flower at 44DAP. In Serere, which had the highest thrips population, it was EBELAT*NE39 that stood out at a peak of close to 40 thrips per flower at 51 DAP (Figs.1B, 2B, and 3B).

Stability of thrips damages. The genotype plus genotype by environment (GGE) biplot performed on the damage scores, revealed that the first principal component (PC1) accounted for up to 73.58%; while the second principal component (PC2) was responsible for only

A



B

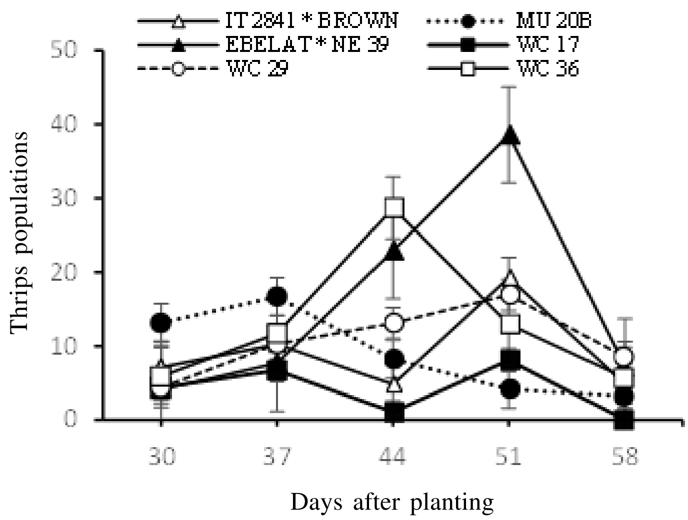


Figure 3. Trends in thrips damages scores (A) and thrips population in flowers (B) over time for selected six cowpea cultivars at Serere.

18.26% of the total G+GE variation in thrips damage scores. The first two PCs explain 91.83% of the variability in the data.

From the biplot of which-won-where (best genotype adapted to an environment or a group of environments) pattern visualisation (Fig. 4), it was observed that a polygon was formed by genotype connectors that were furthest away from the biplot origin; while the perpendicular lines to the sides of the polygon separate mega-environments. As seen in Figure 4, ten rays divided the biplot into ten sections and two mega-environments were formed. The first mega-environment contained MUARIK and Arua; while the second was formed by Serere. The vertex genotypes for each quadrant were the ones that were the most correlated to the environments (most adapted to the environments) that fell within that quadrant. In the first mega-environment,

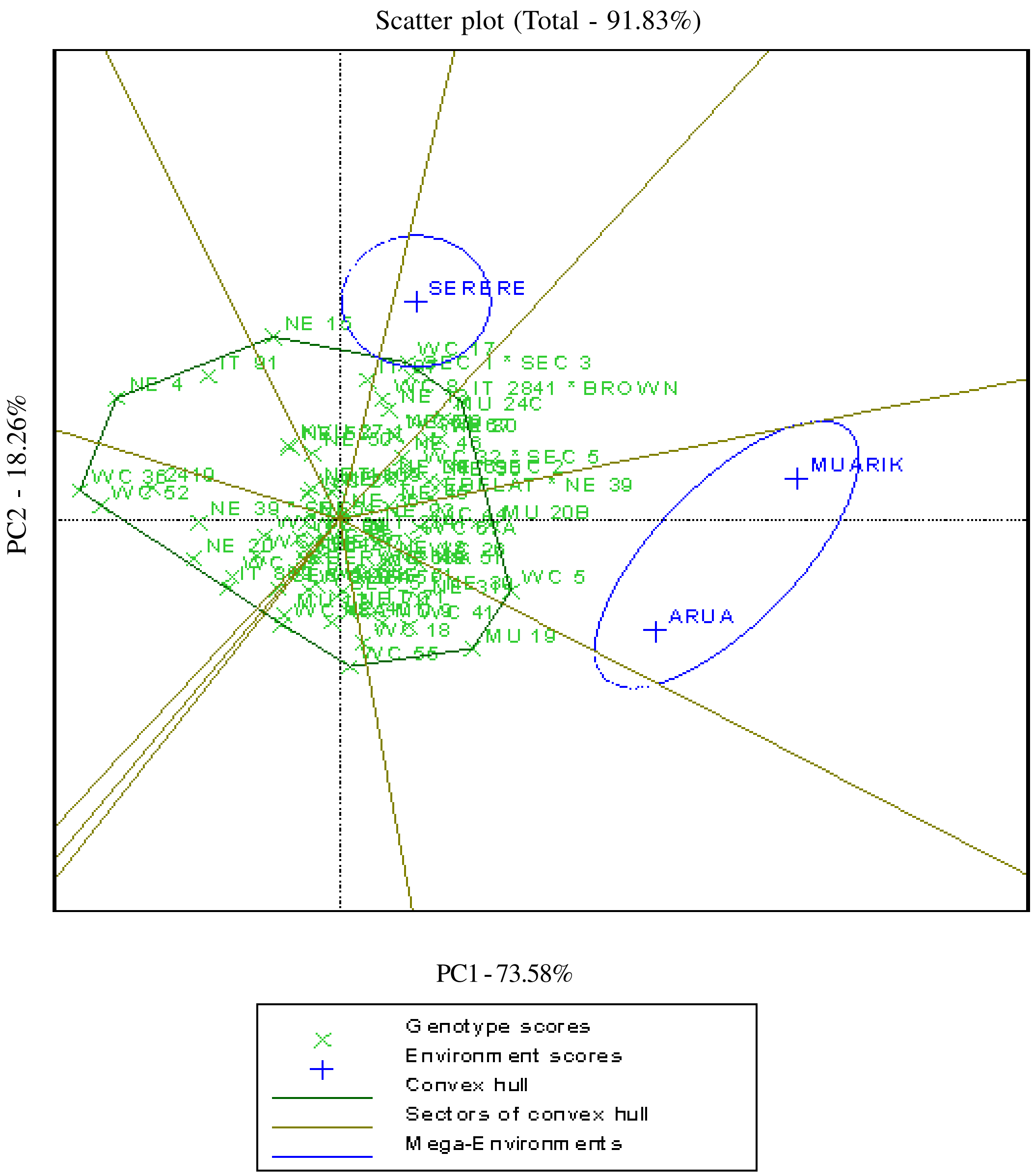


Figure 4. Polygon view of the GGE biplot for thrips damages scores in cowpea across the three locations in Uganda.

genotypes WC5 and MU20B were identified as the winning genotypes. In the second mega-environment, genotypes WC17, SEC1*SEC3, IT 2841*Brown and IT97were the winning genotypes.

Genotypes comparison biplot (Fig. 5) visualised the cultivars IT2841*Brown, MU20B and MU24C as being near or close to the direction of the ideal genotype (with the highest vector on the Average Environment Coordination (AEC) abscissa). This was followed by EBELAT*NE39, WC17, WC29, MU24C, WC5, NE46, WC30, NE67, NE51 and MU19.

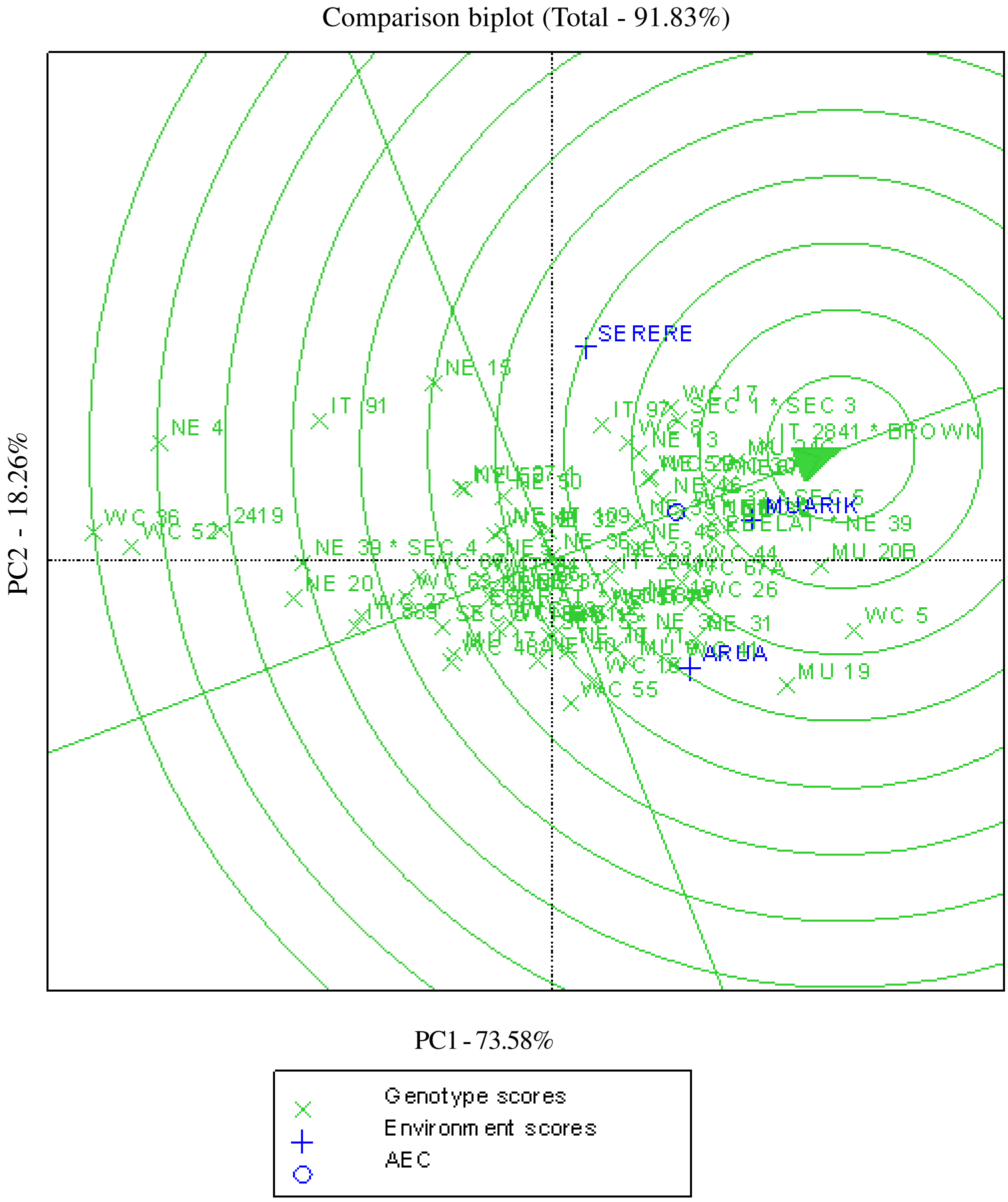


Figure 5. GGE biplot in relation with the "ideal" genotype based on genotype-focused scaling method for thrips damages scores in cowpea.

Overall, 2419, WC52, NE4 and WC36 had the lowest vector, being located on the last concentric circles of the biplot and near its axis. On one hand, cultivars IT2841*Brown, MU20B, EBELAT*NE39, WC17, WC29, MU24C, WC5, NE46, WC30, NE67, NE51 and MU19 with highest vector on the Average Environment Coordination abscissa, presented low thrips damage scores (Table 7). On the other hand, cultivars 2419, NE4, WC52 and WC 36, with lowest vector, had the highest thrips damage scores (Table 7) across locations.

The stability of the genotypes for thrips damage scores, was conferred by the second Principal Component (PC2); whereby genotypes with PC2 scores close to zero (PC2~0) would be the highly stable ones. From the biplot visualisation (Fig. 6), the genotypes with PC2 scores close to zero were MU20B, EBELAT*NE39, WC67A, WC30, WC44, MU24C, WC17, WC29, NE67, NE46 and NE51.

The biplot (Fig. 6) visualised MUARIK as being near or close to the direction of the ideal environment, with the highest vector on the Average Environment Coordination (AEC) abscissa. This was followed by Arua; while Serere had the lowest vector, located on the

Comparison biplot (Total - 91.83%)

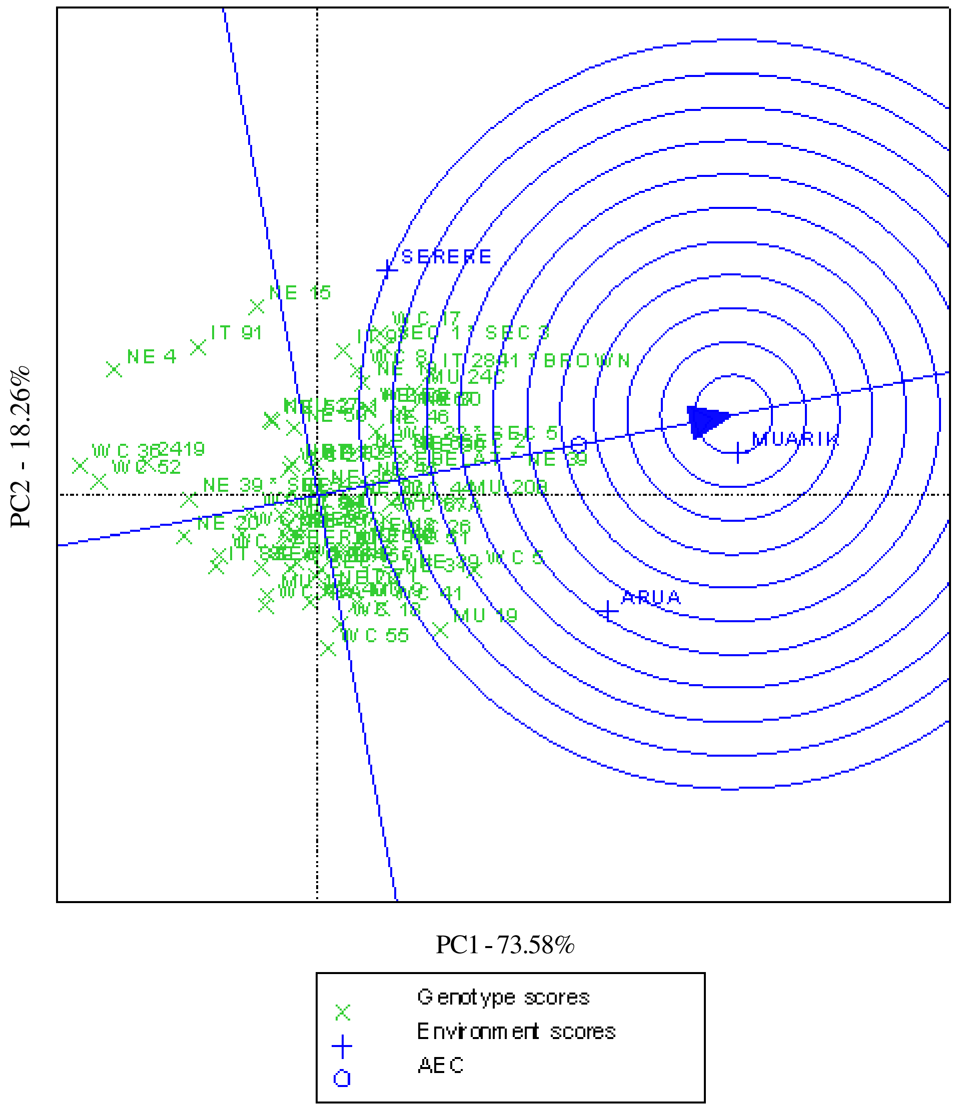


Figure 6. GGE biplot in relation with the "ideal" environment, based on environment-focused scaling method for thrips damage scores in cowpea.

last concentric circles of the biplot with lowest vector.

Grain yield and yield components. Genotypes significantly (P<0.001) interacted with locations for the number of days to 50% flowering and the yield (Table 5). Number of days to pod maturity recorded the least variation 4.82 %, in contrast, with the number of peduncles per plant, grain yield and number of pods per peduncle; which recorded high coefficients of variation of 34.62, 25.65 and 24.81%, respectively.

Correlation analysis performed between thrips and plant parameters are presented in Table 6. Number of thrips per flower were significantly (P<0.001) correlated with the number of damaged flowers (r=0.37). Number of thrips per flower was negatively correlated with yield (r=- 0.21). Thrips damage scores were also significantly (P<0.001) but positively correlated with the number of damaged flowers per plant (r=0.33 and r = 0.35), number of pod per peduncle; but negatively correlated with the number of days to flowering, and number of days to pod maturity (r= -0.32; r= -0.38). However, the correlation between thrips damage scores and thrips counts was not significant (r=0.08). Apart from the yield components, it was only the number of days to pod maturity that was negatively correlated to yield (r= - 0.35).

Not all the genotypes that were resistant to thrips damages yielded highest (Table 7). Some of the least yielding genotypes like WC29, had the lowest damage scores. The number of days to flowering fluctuated between 47 days in WC36 and 54 days in NE4. The number of days to pod maturity varied from 72 days in WC52 a susceptible cultivar, to 79 days in WC17 a resistant one. Yield ranged from 313.94 kg ha^{-1} in IT109, to 813.87 kg ha^{-1} in MU9. The 100-seeds weight varied from 9.27 g in WC8 to 16.84 g in NE51. The number of peduncles per plant was from 7.75 in KVU 27-1 to 20.08 in NE20. The number of pods per peduncle varied from 1.22 in WC2 and NE32 to 2 in WC27. The number of seeds per pod ranges from 10.25 in EBELAT*NE39 to 15.75 in IT84.

Yield stability. The GGE biplot analysis revealed that the first principal component (PC1) accounted for up to 60.96%; while the second principal component (PC2) was responsible for only 38.56% of the total G+GE variation in the grain yield (Fig. 7). The first two PCs explained up to 99.52% of the total variability. The biplot showed that Arua and Serere formed one mega-environment with WC26, NE48, NE5 and MU9 the winning genotypes (high PC1 scores in that quadrat);while MUARIK formed the second mega-environment with WC48A being the winning genotype (high PC1 in that quadrat). Since the first principal component (PC1) was highly correlated with the yield (60.96%), the high yielding and most adapted genotypes in the first mega-environment (Serere and Arua), were WC26 (614.73 kg ha^{-1}), NE48(650.07 kg ha^{-1}), NE15(514.65 kg ha^{-1}) and MU9 (813.87 kg ha^{-1}) while in the second mega-environment (MUARIK), the high yielding and most adapted genotype was WC48A (683.57 kg ha^{-1}) (Table 7).

From the biplot visualisations (Fig. 8), it was observed that the Average Environment Axis pointed in the direction of the ideal genotype MU9.

Cultivar MU9 was visualised to have the highest positive correlation with the first principal components, followed by WC66, and WC68; whereas the cultivar IT 109 was negatively correlated with the PC1 (located on the last concentric circle). The first principal component of the GGE biplot analysis indicated genotype performance, which was highly correlated with yield (60.96 %). Cultivar MU 9 was the highest yielding genotype (813.87 kg ha^{-1}) across locations; followed by WC66 (712.12 kg ha^{-1}), and WC68 (686.36 kg ha^{-1}); whereas the lowest yield was observed on IT 109 (313.94 kg ha^{-1}) (Table 7).

TABLE 5. Means squares for yield and yield components across locations

Source of variation	Df	Means squares						
		NPed	NPod	NS	NDF	NDM	100GW	Yield
Locations	2	7865.42***	0.663**	832.31***	1556.46***	6535.3***	114.21***	27721030.00***
Locations.Rep	3	4502.42***	0.20ns	249.35***	4.80ns	1.98ns	74.49***	77435.00ns
Locations/Rep/Blocks	42	78.99***	0.18ns	10.47**	13.89	8.67ns	12.14ns	33662.00ns
Genotypes	71	35.01ns	0.22**	7.57ns	14.86**	16.92***	13.84ns	62043.00ns
Genotypes.Locations	135	18.73ns	0.13ns	5.41ns	7.56**	7.10ns	9.88ns	46936.00***
Residual	196	20.52	0.12	5.555	5.17	7.473	8.9	14964
Range		3.00 - 63.00	0.00- 3.25	0.00 -21	40 - 63	62.00 - 99.00	0.00- 36.37	0.00 - 1587
Standard error of difference	4.66	0.4	2.74	2.87	3.64	3.29	130.73	
Coefficient of variation (%)	34.62	24.81	20.91	5.73	4.82	26.15	25.65	

***, **, * = Significant at $P<0.001$; 0.01 and at 0.05 respectively and ns = non-significant at 0.05

NPed = Number of peduncles per plant, NPod = Number of pods per peduncle, NS = Number of seeds per pod, NDF = Number of days to 50% flowering, NDM = Number of days to 50% maturity, 100GW = 100 grains weight (g), Yield = Grain yield (kg ha^{-1})

TABLE 6. Correlation coefficients among thrips resistance parameters and yield components in cowpea cultivars

Traits	100GW	DF	NDF	NDM	Nped	Npod	NS	NT	TDS	Yield
100GW	-									
DF	0.04^{ns}	-								
NDF	0.03^{ns}	-0.4**	-							
NDM	-0.09^{ns}	-0.27*	0.55***	-						
Nped	-0.18^{ns}	0.32**	-0.19^{ns}	-0.25*	-					
Npod	-0.17^{ns}	0.35**	-0.18^{ns}	-0.1^{ns}	0.08^{ns}	-				
NS	0.18^{ns}	0.24*	-0.14^{ns}	-0.12^{ns}	-0.15^{ns}	0.01^{ns}	-			
NT	-0.15^{ns}	0.37**	-0.14^{ns}	-0.07^{ns}	0.12^{ns}	0.19^{ns}	0.12^{ns}	-		
TDS	-0.03^{ns}	0.33**	-0.32**	-0.38***	0.2^{ns}	0.35**	0.09^{ns}	0.08^{ns}	-	
Yield	0.23^{ns}	0.03^{ns}	-0.05^{ns}	-0.35**	-0.04^{ns}	0.14^{ns}	0.17^{ns}	-0.21*	0.01^{ns}	-

***, **, * = correlation is significant at P<0.001; 0.01 and at 5% (2 tailed) and ns = correlation is non-significant at 5% (2 tailed). 100GW = 100 grains weight (g), DF = Number of damaged flowers per plant, NDF: = Number of days to 50% flowering, NDM = Number of days to 50% of pod maturity, NPed = Number of peduncles per plant, NPod = Number of pods per peduncle, NS = Number of seeds per pod, NT = Number of thrips per flower, TDS = Thrips damages scores, Yield = Grain yield (kg ha^{-1})

Yield stability, however, was conferred by the second principal component (PC2); whereby genotypes with PC2 scores close to zero (PC2~0) were the highly stable ones. Cultivars NE36, WC66, and WC68 had the most stable yield across locations (Fig. 8).

The biplot (Fig. 9) visualised Arua as being near to the direction of the ideal environment (with the highest vector on the Average Environment Coordination (AEC) abscissa), while Serere had the lowest vector being located on the last concentric circles of the biplot and near its axis.

DISCUSSION

Thrips damage scores. Up to 100% of the specimens extracted from the flowers for all genotypes, belonged to the species *Megalurothrips sjostedti* Trybom with 64.56% females and 35.44% males. This shows that both male and female of *M. sjostedti* infested the cowpea crop. Similar results were reported in Kenya by Nyasani*et al.* (2013) where they found that both male and female flower thrips were aggregated in cowpea flowers. The presence of both male and female of flower thrips in flowers with the male half of the female,could be for feeding andoviposition, as reported in *M. sjostedti* and other thrips (Gahukar, 2004). These current results also confirmed that *M. Sjostedti* is the major type of thrips on cowpea as reported in other previous studies in Uganda (Karungi*et al.*, 2000); Nigeria (Alabi*et al.*, 2003); in Ghana (Abudulai*et al.*, 2006); and Cameroon (Ngakou*et al.*, 2008).

The absence of significant genotype and the presence of highly significant location effects for thrips counts in flowers (Table 4) indicates that thrips population in flowers was more determined by the variations between locations than the variations among genotypes. Thus, any study on flower thrips counts in cowpea should focus more on locations to cover all the climatic variations. Among the three locations, higher numbers of thrips were observed at Serere than MUARIK and Arua. This difference could be ascribed to the lower altitude, hot climate and higher rainfall in Serere which are among the preferred growth conditions for *M. sjostedti* and its host as reported by Ekesi *et al.* (1999) and Murage *et al.* (2012) in Kenya.

TABLE 7. Means of thrips and plant parameters on 20 most resistant and 20 most susceptible cowpea cultivars for three locations

Cultivars	NPed	Npod	NS	NT	DF	TDS	NDF	NDM	100 GW	Yield
IT 2841 * BROWN	9.87	1.51	11.83	4.99	0.98	1.50*	51.50	77.58	13.43	406.86
MU 20B	13.78	1.68	13.00	4.23	1.07	1.58	51.58	77.33	12.27	529.50
EBELAT * NE 39	13.14	1.59	10.25*	8.03	1.11	1.61	49.92	77.17	9.55	409.88
WC 17	8.20	1.51	12.92	3.13	0.68*	1.63	52.17	79.42*	11.27	494.94
WC 29	11.82	1.34	13.50	5.47	0.80	1.65	52.00	76.58	12.16	360.19
MU 24C	15.27	1.55	13.67	6.60	1.42	1.65	50.50	76.92	11.48	381.51
WC 5	12.27	1.72	13.58	10.71*	1.00	1.66	51.67	75.83	12.04	447.94
NE 46	12.20	1.34	12.00	4.04	0.72	1.67	51.92	77.33	11.12	552.48
WC 30	16.69	1.30	13.00	4.63	1.07	1.68	51.00	77.17	10.29	479.40
NE67	14.81	1.43	12.75	5.90	0.73	1.69	53.75	78.33	11.67	596.23
NE 30	11.93	1.51	14.50	5.36	1.15	1.70	51.50	75.58	14.18	632.62
NE 51	14.43	1.63	11.33	4.18	0.85	1.71	52.42	76.92	16.84*	567.06
SEC 1 * SEC 3	9.91	1.47	13.42	5.15	0.88	1.72	51.08	75.00	11.55	442.00
NE 6	11.29	1.44	12.25	3.11*	0.92	1.76	47.67	76.17	14.38	478.23
WC 8	16.51	1.68	13.58	4.85	0.72	1.83	51.25	77.08	9.27*	414.19
MU 19	14.36	1.72	12.50	7.06	1.43	1.87	50.17	75.67	11.98	447.17
MU 9	12.84	1.55	13.33	4.91	1.21	1.97	48.75	73.58	11.02	813.87*
NE 48	12.60	1.72	14.00	6.72	1.13	2.03	49.83	77.08	16.33	650.07
WC 2	14.76	1.22*	13.08	5.71	1.08	2.03	51.92	78.08	15.35	424.19
IT 109	12.78	1.55	12.42	4.70	0.99	2.04	48.92	77.17	15.43	313.94*
NE 32	13.98	1.22*	12.17	3.38	1.08	2.04	51.75	76.50	13.87	493.71
IT 84	12.07	1.63	15.75*	6.53	1.44	2.12	51.50	75.17	13.55	545.18
WC 55	12.80	1.80	14.25	6.36	2.05*	2.17	49.50	75.67	12.44	530.26
WC 66	13.41	1.80	14.08	4.28	1.35	2.24	48.67	71.83	14.61	712.12
WC 67	14.76	1.80	13.42	5.60	1.28	2.33	49.83	73.75	11.94	614.29
KVU 27-1	7.75*	1.51	14.75	4.65	1.39	2.35	49.42	75.92	13.67	582.58
WC 64	17.79	1.63	12.08	5.21	1.20	2.44	48.67	73.50	12.19	596.50
WC 48A	12.56	1.97	14.08	6.60	1.49	2.45	50.50	75.83	12.97	683.57
NE 15	10.20	1.59	11.50	3.40	0.74	2.50	51.67	74.83	10.55	514.65
EBERAT * NE 51	16.36	1.47	14.75	4.54	1.25	2.50	48.33	73.08	12.10	635.02
WC 63	13.01	1.97	15.08	4.36	1.13	2.51	49.58	76.42	12.05	605.12
WC 27	15.05	2.00*	12.92	4.00	1.33	2.62	48.25	74.00	13.52	498.38

TABLE 7. Contd.

Cultivars	NPed	Npod	NS	NT	DF	TDS	NDF	NDM	100 GW	Yield
IT 889	17.38	1.63	12.75	4.48	1.48	2.75	53.42	75.17	13.24	615.22
NE 39 * SEC 4	11.78	1.55	13.50	5.65	1.16	2.90	50.42	75.17	12.89	481.23
IT 91	10.38	1.55	15.08	8.58	1.34	3.16	49.67	75.08	15.71	548.10
NE 20	20.08*	1.72	12.08	5.81	1.39	3.23	48.83	72.75	11.04	575.82
2419	15.66	1.84	11.58	4.94	1.63	3.57	47.42	74.08	10.81	505.63
NE 4	11.67	1.93	11.50	4.55	1.13	4.12	54.17*	79.08	12.01	360.23
WC 52	13.26	1.59	14.75	7.99	1.31	4.49	47.58	71.67*	12.90	461.24
WC 36	17.56	1.88	12.75	6.81	1.34	5.10*	46.67*	73.75	11.08	447.47
LSD	4.24	0.31	2.19	2.31	0.45	0.62	2.55	3.09	2.44	156.8

* = Least Significant Differences of means significant at $P<0.05$. 100GW = 100 grains weight (g), DF = Number of damaged flowers per plant, NDF = Number of days to 50% flowering, NDM = Number of days to 50% maturity, NPed = Number of peduncles per plant, NPod = Number of pods per peduncle, NS = Number of seeds per pod, NT = Number of thrips per flower, TDS = Thrips damages scores, Yield = Grain yield (kg ha^{-1})

With regards to thrips damage, genotype effects were significant (Table 4) indicating the presence of genetic diversity among the evaluated cultivars. The range of thrips damages scores (1-7) recorded, indicated the possibility of obtaining sources of thrips resistance among the evaluated genotypes. The lowest damage scores were recorded on the cultivars IT2841*brown, MU20B, WC17, WC29, MU24C, and WC5 (most resistant cultivars); while the highest scores were recorded on WC36 (most susceptible) suggesting some factors conferring the resistance in these cultivars, since resistance to insects can be through their biology, physiology or even their behaviour (Alabi *et al.*, 2004). In fact, cryptic behaviour of some cowpea lines possessing leafy floral structures and growing vigorously could favour gathering of thrips population (Alabi *et al.,* 2003). For instance, cultivars IT2841*Brown and MU20B had smaller racemes and flowers, and probably did not provide enough shelter for thrips compared to the susceptible (WC36) with leafy racemes and flowers. A similar observation was made by Abudulai *et al.* (2006) on Sanzi cultivars as resistant genotype to flower thrips under natural infestation in Ghana. The significant locations effects for thrips damages scores indicated the variation in the reaction of cowpea genotypes to thrips damages between locations. This could be attributed to the variation in environmental factors (climate and soils characteristics), since the expression of genes controlling the resistance is influenced by locations (Cramer *et al.*, 2011). Thus, different cultivars must be developed for a specific environment.The highly significant effects of the genotype and location interaction for thrips damage scores indicated an instability in the resistance of cowpea to thrips damage across locations. However, since there was genetic diversity in the reaction of cowpea genotypes to thrips damage, MU20B, EBELAT*NE39, WC67A, WC30, WC44, MU24C, WC17, WC29, NE67, NE46 and NE51 cultivars expressed stability in terms of thrips damage across locations (Fig. 6).

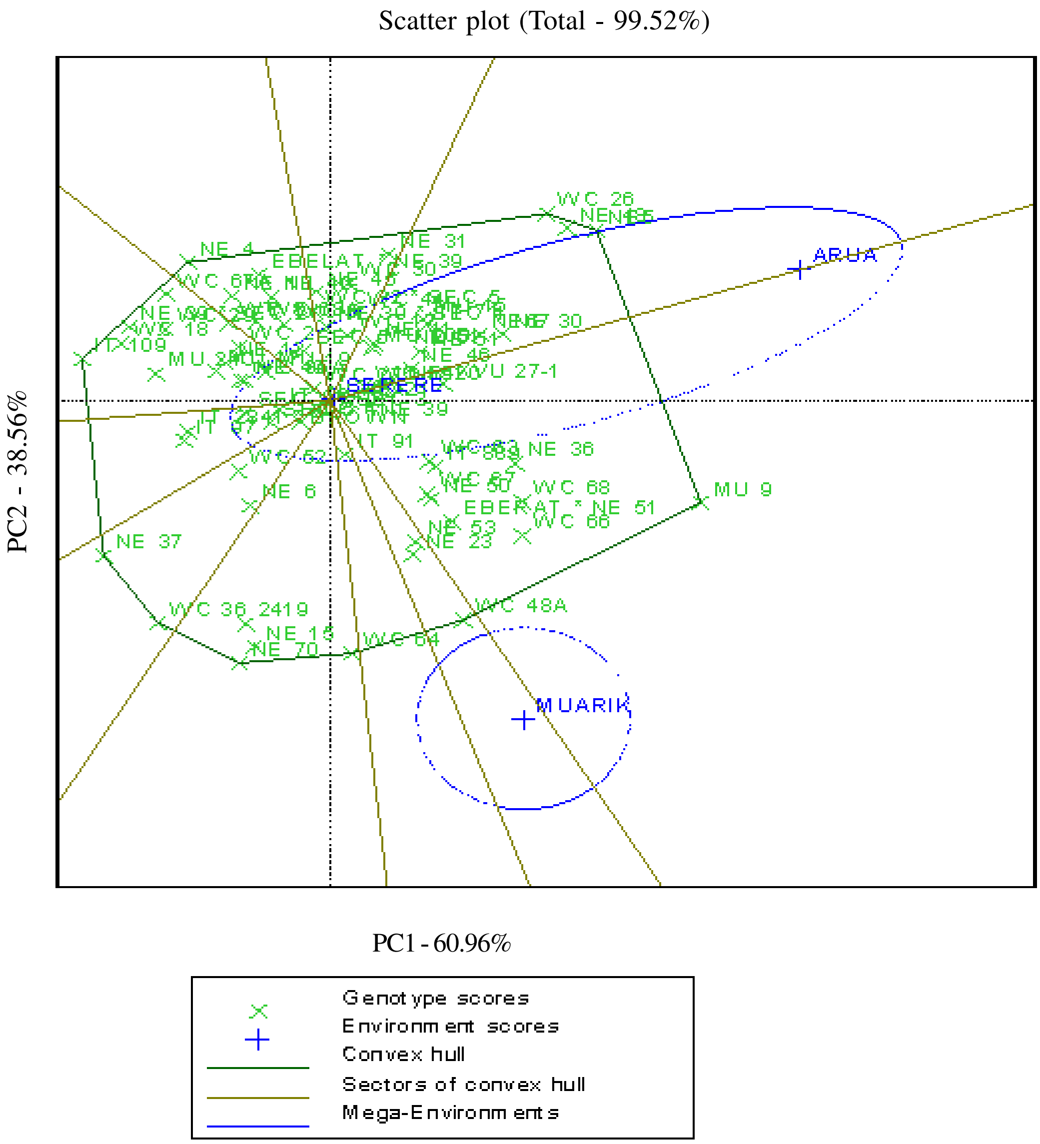


Figure 7. Polygon view of the GGE biplot for cowpea yield (kg ha^{-1}) across three locations in Uganda.

The trends in thrips counts in different locations were not similar to the trends in thrips damage scores since the susceptible check (WC36) did not have the highest counts as in the case of damages scores (Fig. 1, 2, 3). The trends in thrips damage indicated that as the number of post-planting days increased, damage done by thrips increased. The trends in thrips damages over time, per location, showed a lower peak on resistant cultivars than on the susceptible check; suggesting the involvement of antibiosis or non-preference as resistance mechanism to thrips in these varieties. Antibiosis and non-preference have been reported in cowpea resistance to flower thrips by Alabi *et al.* (2004) in Nigeria under laboratory conditions. Further assessment of the biochemical constituents in these resistant

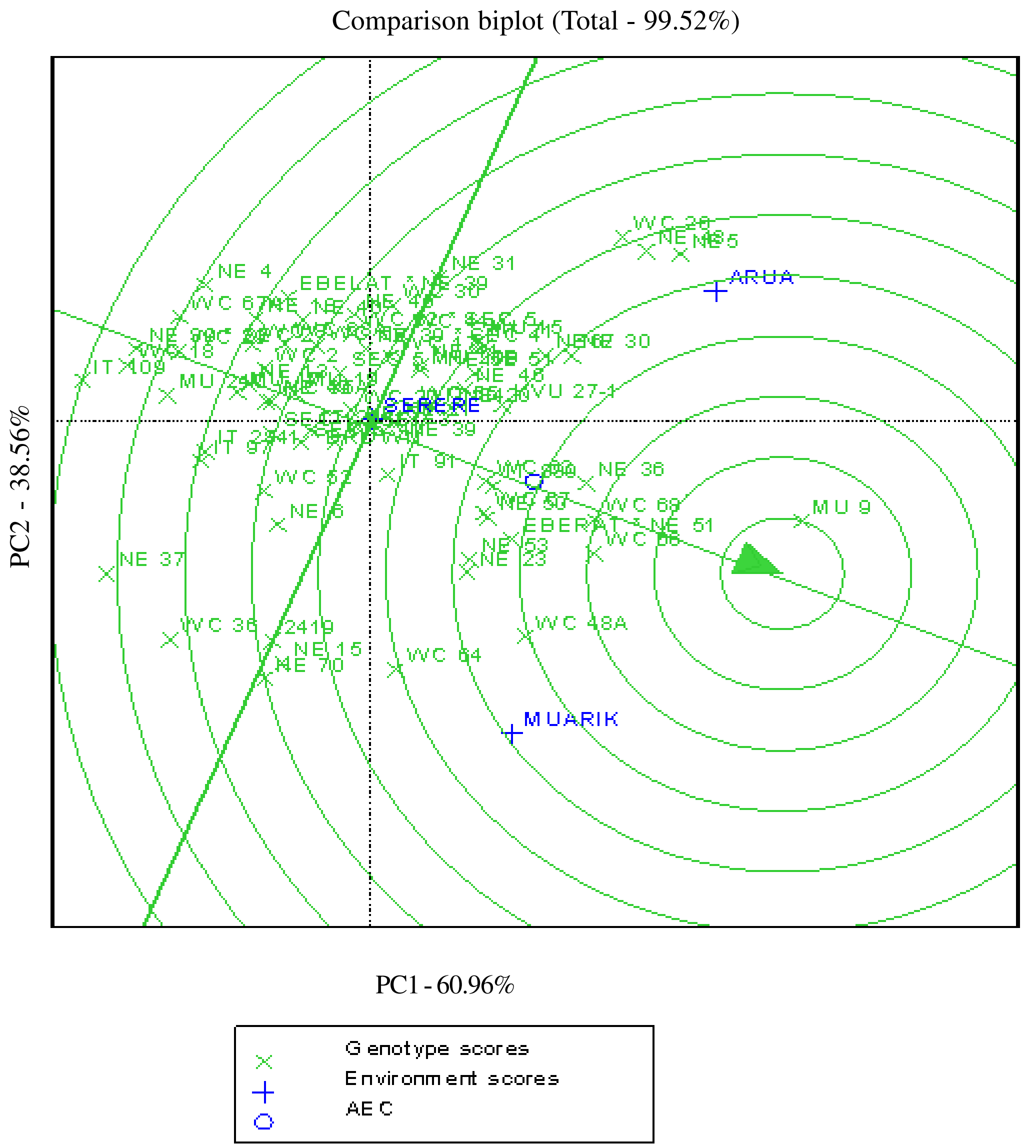


Figure 8. GGE biplot in relation with the “ideal” genotype based on genotype-focused scaling method for cowpea yield (kg ha^{-1}) in three locations in Uganda.

and susceptible cowpea cultivars as regards to *M. sjostedt,* could reveal additional cues of resistance mechanism of cowpea to thrips.

The trends in thrips population showed an increase with time and peaked from 44 to 51 DAP (Fig. 1B, 2B, 3B), depending on genotype, which coincided with the peak of flowering in all the cultivars. Several authors had observed such trends in flower thrips population under natural infestation in Kenya (Kasina *et al.*, 2009; Nyasani *et al.,* 2013).

It was also observed that cultivar EBELAT*NE9 had higher thrips counts in flower than the susceptible check (WC36) and showed low damage score in Serere (Fig. 3B), suggesting its tolerance to thrips. However, there was a non-significant positive correlation between thrips damage scores and thrips

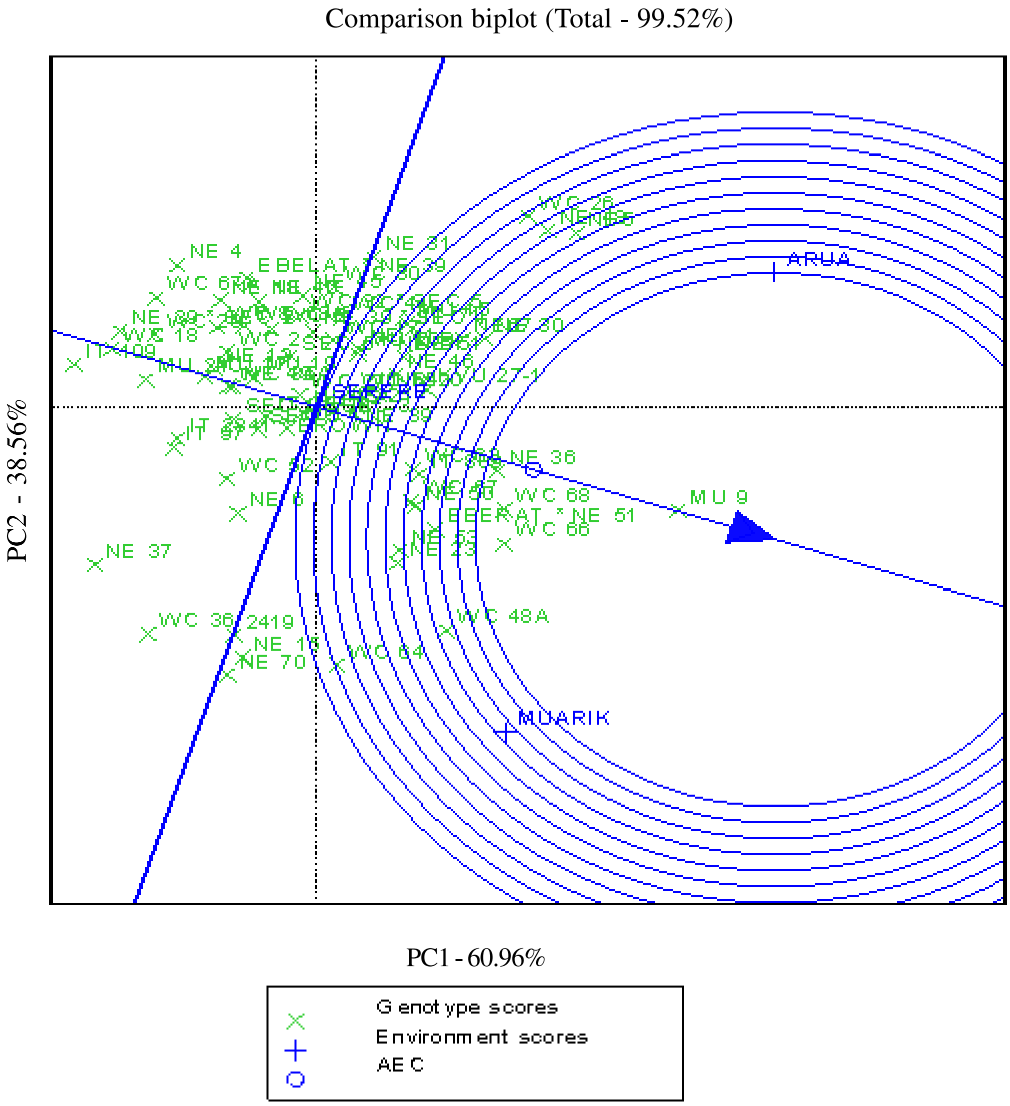


Figure 9. GGE biplot in relation with the "ideal" environment based on environment-focused scaling method for cowpea yield (kg ha^{-1}).

counts in flowers. Thus, the selection of resistant cowpea varieties should not be based on the number of thrips counted per flower. Contrastingly, Alabi *et al.* (2003) found a strong positive correlation (r=0.86) between thrips damages scores and thrips counts in flowers in Nigeria. This kind of variation among studies are always attributed to genotype and environmental factors (Olawale and Bukola, 2016).

Stability of thrips damages. The GGE biplot on thrips damage scores showed two mega-environments with the winning genotypes (Fig. 4). The environments that failed within each mega-environment presented similar thrips damage scores on the winning genotypes, as reported by Yan (2001). In MUARIK and Arua, the most adapted (most resistant) genotypes were WC5 and MU20B by presenting low thrips damages scores. In

Serere, WC17, SEC1*SEC3, IT2841*Brown and IT97 were the most resistant cultivars. These resistant cultivars could be recommended in each of these mega-environment, according to which won where pattern in GGE biplot analysis (Yan and Tinker, 2006). Stability analysis of genotypes for thrips damage scores revealed that the cultivars IT2841*Brown, MU20B, EBELAT*NE39, WC17, WC29, MU24C, WC5, NE46, WC30, NE67, and NE51 were the most resistant and most stable across locations (Fig. 6). These cultivars had PC2 scores close to zero and presented consistently low thrips damage scores.

The above results showed potential for resistance sources in the cultivars IT2841*Brown, MU20B, EBELAT*NE39, WC17, WC29, MU24C, WC5, NE46, WC30, NE67, and NE51. The results also showed that MUARIK (Fig. 6) was close to the direction of the ideal environment because the lowest thrips damage scores in cowpea cultivars (most resistant cultivars) were recorded in that location; while the highest thrips damage scores (most susceptible cultivars) were recorded in Serere. In this study, cultivars 2419, NE4, WC52, and WC 36 were identified as the most damaged in the test locations.

Grain yield and yield components. There was a highly significant effects of genotype and location interaction for the grain yield (Table 5), indicating an instability of the grain yield between locations. The expression of wide genetic variability recorded in this study offers opportunity for quality improvement that would allow selection of individuals with better attributes for maturity period and grain yield. Reports on wide genetic variability in cowpea phenotypic attributes are available (Manggoel *et al.*, 2012; Nwosu *et al.*, 2013). The range of values recorded for flowering and pod maturity, suggest that the varieties were predominantly early to medium maturing; and the range values for the grain yield indicated that the selected cowpeas comprised low to very high yielding varieties.

Correlation coefficients revealed that thrips damage scores were negatively correlated with the number of days to flowering and days to pod maturity (Table 6), suggesting that the resistance in the cultivars can be explained by the thrips infestation escape due to late flowering, at 52 days after planting. Similar findings were reported by Omo-Ikerodah *et al.* (2009) in Nigeria under field conditions, while evaluating the resistance of Sanzi, and TVu 1509 to flower thrips. In contrast, Alabi *et al.* (2003) in Nigeria and Abudulai *et al.* (2006) in Ghana, reported that the resistance in some cowpea cultivars under natural infestation was due to flower thrips infestation escape due to early flowering. Based on these results, it can be deduced that the mechanism of resistance to flower thrips depends on the genotype.

The highest grain yield in all locations was recorded on MU9 indicating that this cultivar may escape thrips damage due to the later flowering and could be a potential candidate cultivar for selection in cowpea breeding program. Cultivar MU 9 was also reported to have high yield in a previous study done in Uganda under filed conditions (Asio *et al.*, 2005). Cultivar NE 20 had the highest number of peduncles per plant across locations, but showed a high thrips damage score (Table 7) indicating that this cultivar was able to recover after thrips damages. This could be explained by the indeterminate flowering habit of the cultivar NE 20. However, improved cowpea varieties must combine high grain yield, and early to medium maturity cycle (Olawale and Bukola, 2016); but none of the evaluated cultivars in this study presented a combination of these traits.

Yield stability. The GGE biplot analysis performed on the variety yields, revealed that cultivars WC26, NE48, NE5 and MU9 were the winning genotypes in Arua and Serere; and WC48A was the winning genotype in MUARIK. They constituted the best genotypes (high yielding) in these mega-environments. In fact, genotypes with PC1 scores > 0 were recognised as high yielders; and those with PC1 scores < 0 were low yielders (Kaya *et al.*, 2006). Thus, cultivar MU9 was the high yielding cultivar in all locations; followed by WC66, NE36, and WC68. The results also showed that Arua was the ideal test environment, being the most representative of the overall environments and the most powerful to discriminate genotypes. Yield stability was conferred by the second principal component (PC2); whereby genotypes with PC2 scores close to zero (PC2~0) were the highly stable ones (Balestre *et al.*, 2009). This explains why NE36, WC66, and WC68 were the highest yielding and most stable cultivars.

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REFERENCES

Abudulai, M., Salifu, A.B. and Haruna, M. 2006. Screening of cowpea for resistance to the flower bud thrips, *Megalurothrips sjostedti* Trybom (Thysanoptera: Thripidae). *Journal of Applied Science* 6:1621-1624.

Akande, S.R., Olakojo, S.A., Ajayi, S.A., Owolade, O.F., Adetumbi, J.A., Adeniyan, O.N.and Ogunbodede, B.A. 2012. Planting date affects cowpea seed yield and quality at southern guinea savanna, *Nigerian Journal of Seed Technology* 34: 51-60.

Alabi, O.Y., Odebiyi, J.A. and Jackai, L.E.N. 2003. Field evaluation of cowpea (*Vigna unguiculata* (L.) Walp.) for resistance to flower bud thrips (*Megalurothrips sjostedti* Trybom (Thysanoptera: Thripidae). *International journal of pest management* 49(4): 287-291.

Alabi, O.Y., Odebiyi, J.A. and Tamo, M. 2004. Effect of host plant resistance in some cowpea (*Vigna unguiculata* {L.} Walp.) cultivars on growth and developmental parameters of the flower bud thrips, *Megalurothrips sjostedti* (Trybom). *Journal of Crop Protection* 23: 83–88.

Asio, M.T., Osiru, D.S.O. and Adipala, E. 2005. Multi-locational evaluation of selected local and improved cowpea lines in Uganda. *African Crop Science Journal* 13 (4): 239-247.

Balestre, M., De Souza, J.C., Von Pinho, R.G., De Olivereira, R.L. and Paes, J.M.V. 2009. Yield stability and adaptability of maize hybrids based on GGE biplot analysis characteristics. *Crop Breeding and Applied Biotechnology* 9:219-228.

Boukar O., Christian A.F., Huynh B.L., Roberts P.A. and Close T.J. 2016. Genomic Tools in Cowpea Breeding Programs: Status and perspectives.*Frontiers in Plant Science* 7:757.

Cramer, G.R., Urano, K., Delrot, S., Pezzotti, M. and Shinozaki, K. 2011. Effects of abiotic stress on plants: a systems biology perspective. *BMC Plant Biology* 11:163.

Ekesi, S., Maniania, N.K. and Onu, I. 1999. Effects of temperature and photoperiod on development and oviposition of the legume flower thrips, *Megalurothrips sjostedti*. *Entomologia Experimentalis et Applicata* 93: 145–155.

Fungo, B., Grunwald, S., Tenywa, M.M., Vanlauwe, B. and Nkedi-Kizza, P. 2011. Lunnyu soils in the Lake Victoria basin of Uganda: Link to toposequence and soil type. *African Journal of Environmental Science and Technology* 5(1): 15 – 24.

Gahukar, R.T. 2004. Bionomics and management of major thrips species on agricultural crops in Africa. *Outlook on Agriculture* 33: 191–199.

Gbaguidi, A.A., Dansi, A., Loko, L.Y., Dansi, M. and Sanni, A. 2013. Diversity and agronomic performances of the cowpea (*Vigna unguiculata* Walp.) landraces in Southern Benin. *International Journal of Agronomy and Plant Production* 4(5): 936-949.

Jackai, L.E.N. and Singh, S.R. 1988. Screening techniques for host plant resistance to insect pests of cowpea. *Tropical Grain Legume Bulletin* 35: 2-18.

Karungi, J., Adipala, E., Nampala, P., Ogenga-Latigo, M.W. and Kyamanywa, S. 2000. Pest management in cowpea. Part 3. Quantifying the effect of cowpea field pests on grain yields in eastern Uganda. *Journal of Crop Protection* 19: 343-347.

Kasina, M., Nderitu, J., Nyamasyo, G., Waturu, C., Olubayo, F., Obudho, E. and Yobera, D. 2009. Within-plant distribution and seasonal population dynamics of flower thrips (Thysanoptera: Thripidae) infesting French beans (Phaseolus vulgaris L.) in Kenya. *Spanish Journal of Agricultural research* 7(9): 652-659.

Kaya, Y., Akcura, M. and Taner, S. 2006. GGE biplot analysis of multi-environment yield trials in bread wheat. *Turkish Journal of Agriculture and Forestry* 30: 325-337.

Manggoel, W., Uguru, M.I., Ndam, O.N. and Dasbak, M.A. 2012. Genetic variability, correlation and path coefficient analysis of some yield components of ten cowpea (*Vigna unguiculata* L. Walp) accessions. *Journal of Plant Breeding and Crop Science* 4: 80-86.

Mbeyagala, E.K., Mukasa, B.S., Tukamuhabwa, P. and Bisikwa, J. 2014. Evaluation of cowpea genotypes for virus resistance under natural conditions in Uganda. *Journal of Agricultural Science* 6 (10): 1-12.

Morse, J. G. and Hoddle, M. S. 2006. Invasion biology of thrips. *Annual Review of Entomology* 51: 67-89.

Muchero, W., Diop, N.N., Bhat, P.R., Fenton, R.D., Wanamaker, S., Pottorff, M., Hearne, S., Cisse, N., Fatokun, C., Ehlers, J.D., Roberts, P.A. and Close, T. J. 2009. A consensus genetic map of cowpea [*Vigna unguiculata* (L) Walp.] and synteny based on EST-derived SNPs. *Proceedings of the National Academy of Sciences* 106 (43): 18159–18164.

Murage, A.W., Obare, G., Chianu, J., Amudavi, D.M. and Midega, C.A.O. 2012. The effectiveness of dissemination pathways on adoption of 'push-pull' technology in Western Kenya. *Quarterly Journal of International Agriculture* 51: 51–71.

Ngakou, A., Tamò, M., Parh, I.A., Nwaga, D., Ntonifor, N.N., Korie, S. and Nebane, C.L.N. 2008. Management of cowpea flower thrips, *Megalurothrips sjostedti* (Thysanoptera: Thripidae), in Cameroon. *Journal ofCrops Protection* 27: 481–488.

Nwosu, D.J., Olatunbosun, B.D. and Adetiloye, I.S. 2013. Genetic variability, heritability, and genetic advance in cowpea genotypes in two agro-ecological environments. *Greener Journal of Biological Sciences* 3: 202-207.

Nyasani, J.O., Meyhofer, R., Subramanian, S. and Poehling, H.M. 2013. Seasonal abundance of western flower thrips and its natural enemies in different French bean agroecosystems in Kenya. *Journal of Pest Science* 86: 515–523.

Olawale, M.A. and Bukola, O.M. 2016. Phenotypic Analysis of Seed Yield and Yield Components in Cowpea (*Vigna unguiculata* L., Walp). *Plant Breeding and Biotechnology* 4(2):252-261.

Omo-Ikerodah, E.E., Fatokun, C.A. and Fawole, I. 2009. Genetic analysis of resistance to flower bud thrips (*Megalurothrips sjostedti*) in cowpea (*Vigna unguiculata* [L.] Walp.). *Euphytica* 165:145–154.

Oyewale, R.O.and Bamaiyi, L.J. 2013. Management of cowpea insect pests.

Scholars Academic Journal of Biosciences 1:217- 226.

Palmer, J.M. 1990. Identification of the common thrips of Tropical Africa (Thysanoptera: Insecta). *Tropical Pest Management* 36 (1): 27-49.

Payne, R.W. 2009. The Guide to Genstat: Release 12, Part 2, Statistics. Lawes Agricultural Trust, Rothamsted, Experimental Station, Harpenden, Herts, UK.

Singh, B.B., Chamblis, O.L. and Sharma, B. 1997. Recent advances in cowpea breeding. In: Advances in cowpea research. Singh, B.B., Mohan Raj, D.R., Dashiell, K.E. and Jackai, L.E.N. (Eds.). Co-publication of International Institute of Tropical Agriculture (IITA) and Japan International Research Center for Agricultural Sciences (JIRCAS), IITA, Ibadan, Nigeria. pp. 30-49.

Smith, A.B., Cullis, B.R. and Thompson, R. 2005. The analysis of crop cultivar breeding and evaluation trials: An overview of current mixed model approaches. *The Journal of Agricultural Science* 143 (6): 449-462.

Ssemwogerere, C., Ochwo-Ssemakula, M.K.N., Kyamanywa, J.K.S. and Karungi, J. 2013. Species composition and occurrence of thrips on tomato and pepper as influenced by farmers' management practices in Uganda. *Journal of Plant Protection Research* 53(2):158–164.

Sserumaga, J.P., Oikeh, S.O., Mugo, S., Otim, G.A.M., Beyene, Y., Abalo, G. and Kikafunda, J. 2015. Genotype by environment interactions and agronomic performance of doubled haploids testcross maize (*Zea mays* L.) hybrids. *Euphytica* doi 10.1007/s10681-015-1549-2.

Yan, W. 2001. GGE biplot-A windows application for graphical analysis of multi-environment trial data and other types of two-way data. *Agronomy Journal* 93:1111-1118.

Yan, W. and Tinker,N.A. 2006. Biplot analysis of multi-environment trial data: Principles and applications. *Canadian Journal of Plant Science* 86:623-645.

Yan,W. and Holland, J.B. 2010. A heritability-adjusted GGE biplot for test environment evaluation. *Euphytica* 171(3): 355-369.