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Genotypic response of brachiaria (Urochloa spp.) to spider mite (Oligonychus trichardti) (Acari: Tetranychidae) and adaptability to different environments

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ABSTRACT

Grasses in the genus Urochloa, commonly known as brachiaria, are grown as forage crops in sub-Saharan Africa, with some genotypes being used in management of insect pests. However, spider mite, Oligonychus trichardti Meyer (Acari: Tetranychidae), has recently been reported as its major pest in the region. We evaluated 18 brachiaria genotypes to identify sources of resistance to O. trichardti, and to determine their adaptability to different environments in western Kenya. Response to artificial infestation with O. trichardti was evaluated under controlled conditions in a screenhouse while adaptability to different environments and field resistance to mites was evaluated in three locations for two cropping seasons in 2016 and 2017 under farmers' conditions. The parameters evaluated as indicators of resistance to pest damage included leaf damage, chlorophyll content re-duction, plant height, leaf area, number of tillers and shoot biomass. Rainfall played a role in reducing mite infestation and increasing biomass yield of the genotypes. Significant correlations between parameters were only observed between leaf damage and yield ($r = -0.50$), and leaf damage and chlorophyll loss ($r = 0.85$). The cultivar superiority index (Pi) ranked Xaraes, Piata, ILRI 12991 and ILRI 13810 as reliable genotypes that combined moderate resistance to the mite ($Pi \le 48.0$) and high biomass yield ($Pi \le 8.0$). Since this is the first documentation of interactions between O. trichardti and different brachiaria genotypes, we propose these gen-otypes as potential candidates for improved forage yields in areas prone to O. trichardti infestation in Africa.

1. Introduction

Urochloa genotypes (Poaceae, commonly referred to as brachiaria) are common forage crops native to Africa (Renvoize et al., 1996), and are extensively grown in tropical Latin America, Africa and south Asia (Hare et al., 2015; Phaikaew et al., 1997). There are over 100 species in this genus but only a few, such as Urochloa brizantha (A. Rich.) Stapf (palisade grass), U. ruziziensis (R. Germ. & C.M. Evrad) (ruzi grass), U. decumbens Stapf (signal grass), and U. humidicola (Rendle) Schweick (koronivia grass), have been commercially exploited as forage crops (Miles et al., 2004). In addition to its use as a pasture crop, U. brizantha cv. Mulato II, has been adopted in combination with greenleaf des-modium, Desmodium intortum (Mill.) Urb., in a climate-smart push-pull strategy for management of cereal stemborers, including Chilo partellus (Swinhoe) (Lepidoptera: Crambidae), the main pests of maize, Zea mays L., in eastern Africa (Khan et al., 2016; Pickett et al., 2014). The technology involves intercropping maize with drought tolerant greenleaf desmodium, and planting Mulato II as a trap crop around this intercrop (Midega et al., 2015a, 2015b). Greenleaf desmodium emits semiochemicals that are repugnant to the moths (push) while Mulato II emits attractive volatile organic compounds (pull). The pest is thus repelled from the maize crop and is subsequently attracted to the trap plant using a stimulo-deterrent strategy (Khan et al., 2014; Midega et al., 2011; Miller and Cowles, 1990). Additionally, brachiaria exhibits highly sophisticated responses to C. partellus herbivory that involves multitrophic interactions with some of its natural enemies (Bruce et al., 2010). The climate-adapted push-pull strategy thus effectively reduce infestations of stemborers, and in combination with other benefits such as suppression of the parasitic Striga weed, Striga hermonthica (Del.) Benth and improvements in soil fertility, result in significant increases in crop yields (Khan et al., 2016, 2014a; Midega et al., 2015b; Pickett et al., 2014). The benefits of brachiaria as trap plant for C. partellus and forage crop are however limited by biotic and abiotic challenges asso-ciated with climate change.

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Tetranychid mites are responsible for significant yield losses in many economically important crops. The most common species of spider mites in Kenya are Tetranychus evansi Baker and Pritchard, Tetranychus urticae Koch which attack solanaceous crops such as tomato (Solanum lycopersicum L.), aubergine (S. melongena L.), potato (S. tu-berosum L.) and tobacco (Nicotiana tabacum L.) while rapidly expanding its host and geographic range (Boubou et al., 2010; Ferragut et al., 2013; Toroitich 2011; Tsagkarakou et al., 2007). Depending on the species, spider mites have a wide range of alternate hosts including wild grasses and broad-leafed plants (Meyer, 1987) where they can survive and infest the next crop. There is also a possibility of the mites surviving on remaining parts of cut stems, and plant residues in the field. Under extreme conditions, they diapause in the soil (Wilson, 1995). Phyto-phagous mites feed by piercing the leaf surface with their stylets and sucking out the cell contents (Tomczyk and Kropczynska, 1985), concomitantly reducing chlorophyll content and net photosynthetic rates of leaves (Park and Lee, 2005). In sub-Saharan Africa, spider mites have recently been observed in brachiaria grasses and were reported as the main pest of these grasses (Maass et al., 2015; Njarui et al., 2016). In this region, crop losses of up to 90% as a result of the mite damage have been documented (Saunyama and Knapp, 2004). Damage caused by the tetranychid mites on this forage crop is expected to increase in response to increasing climate change effects such as increasing temperatures and drought.

Pesticides are one of the control methods against these mites (Toroitich et al., 2014). However, their use, especially in small farming systems, have been linked to human health implications and adverse environmental impacts which are often ascribed to their incorrect and inappropriate use, a common scenario in Africa (Azandémè-Hounmalon et al., 2015; Mbakaya et al., 1994; Ngowi et al., 2007; Van den Berg and Nur, 1998). Application of pesticides onto non-cash crops is also not a common practise in Africa (Orr and Ritchie, 2004; Van den Berg and Nur, 1998). Application of pesticides on grasses that are used as forage and in an eco-friendly management strategy for stalk borers, would therefore defy the general aims of integrated pest management (IPM) and specifically the push-pull strategy (Khan et al., 2016). Significant suppression of mite populations has been achieved through biological control approaches including the use of natural enemies such as Phy-toseiulus longipes Evans (Bugeme et al., 2015; Ferrero et al., 2011, 2007). There is much interest in host-plant resistance as a management strategy since it is also compatible with other IPM strategies.

Host plant resistance to insect pests is influenced by the environ-mental conditions which further complicates testing and selection of superior genotypes. According to Eberhart and Russell (1966), a de-sirable genotype is one which has the highest yield over a broad range of environments. This principle is important in achieving good crop yields across an array of environments (Faris et al., 1979). Further, the cultivar superiority index (Pi) (Lin and Binns, 1988) has been employed to evaluate genotypes for such adaptability to different environments. Regression analyses also serve as a useful tool for measuring genotypic stability of resistance traits under conditions of varying biotic/abiotic stresses (Finlay and Wilkinson, 1963). Although the spider mite is known to be an important constraint to brachiaria cultivation, espe-cially in sub-Saharan Africa, no study of interactions between O. tri-chardti and different brachiaria genotypes have been documented. Therefore, the present study was undertaken to identify potential sources of resistance to O. trichardti among brachiaria genotypes and to select candidate genotypes that are resistant to the mite and adaptable across different environments.

2. Materials and methods

2.1. Experimental plants

Seeds of brachiaria cultivars used in this study were sourced from International Center for Tropical Agriculture (CIAT), Cali, Columbia and the International Livestock Research Institute (ILRI), Ethiopia. The accessions were grown in an on-station nursery at the International Center of Insect Physiology and Ecology - Thomas Odhiambo Campus (ITOC), Mbita Point (0°25S, 34°12E; 1200 m above sea level) in Kenya for preliminary observation and selection based on agronomic perfor-mance.

Table 1
Brachiaria genotypes that were evaluated over two cropping seasons in three locations in Kenya.

Entry	Source	Accession no.	Genotype	Variety name
1	CIAT	606	Urochloa decumbens	Basilisk
2	CIAT	1752	U. ruziziensis x U. decumbens x U. brizantha.	Cayman
3	CIAT	6294	U. brizantha	Marandu
4	CIAT	16125	U. brizantha	Piata
5	CIAT	26110	U. brizantha	Xaraes
6	CIAT	36087	U. ruziziensis x U. decumbens x U. brizantha	Mulato II
7	ILRI	11553	U. brizantha	–
8	ILRI	13648	U. brizantha	–
9	ILRI	12991	U. brizantha	–
10	ILRI	12995	U. brizantha	–
11	ILRI	13344	U. brizantha	–
12	ILRI	13368	U. brizantha	–
13	CIAT	679	U. humidicola	–
14	ILRI	13497	U. brizantha	–
15	ILRI	13810	U. brizantha	–
16	ILRI	13545	U. brizantha	–
17	ILRI	14807	U. brizantha	–
18	CIAT	36061	U. brizantha x U. ruziziensis	Mulato

The 18 genotypes that were evaluated in this study are listed in Table 1. A commercial and locally adapted hybrid, Mulato II, was in-cluded as a check. The latter variety is preferred by smallholder farmers in sub-Sahara African as an animal fodder (Khan et al., 2014). Ad-ditionally, Mulato II plays a major role in the ‘push-pull’ habitat man-agement strategy due to its phytochemical properties that make it highly attractive to stemborer oviposition (Midega et al., 2015a, 2011). Mulato II was however observed to be highly susceptible to spider mites especially in hot and drier ecologies (Maass et al., 2015). Spider mite samples were collected from a susceptible genotype Mulato II grown in field experiments in ITOC-Mbita, Siaya and Homabay. The samples were identified as Oligonychus trichardti Meyer at the Arachnology unit-Agricultural Research Council, South Africa.

2.2. Screenhouse experiments

Susceptibility of brachiaria genotypes to O. trichardti was evaluated by artificially infesting the plants in an insect-proof screenhouse under natural conditions (25 °C, 65% r.h., and L12:D12)

at ITOC. Propagules were planted individually in plastic pots (22 cm in diameter, 21 cm high) filled with soil and placed on 30 cm high benches covered with metal mesh. One plant was grown per pot. Phosphorus was applied at planting at 12 kg^{-ha} P as di-ammonium phosphate (DAP), while nitrogen was applied at 16.2 kg^{-ha} N in the form of calcium ammonium nitrate (CAN), two weeks later. The ar-rangement followed a complete randomized design (CRD) with three replicates. Plants were grown following standard agronomic practices and artificially infested with mites two weeks after planting. Mites were obtained from the susceptible brachiaria variety Mulato II maintained in an on-station nursery at ITOC.

Infestation with O. trichardti was done by placing two fully infested leaves of Mulato II on the adaxial surface of the experimental plants. One on a youngest fully expanded and the other on second young fully expanded leaf of the plant. The damage on leaves was visually esti-mated 14 days after infestation using a modification of a rating score used by Hussey and Parr (1963), as described by Murungi et al. (2014).

Table 2

Agro-ecological zones, coordinates, elevation and cumulative rainfall of three locations in Kenya at which 18 genotypes of brachiaria was evaluated over two cropping seasons.

Location	Agro-ecological zone	Coordinates	Elevation (m a.s.l.)	Season	Total rainfall (mm) during experiment period
Mbita	Lower midland 5	0°25'S, 34°12'E	1200	Season 1/2016	410.5
				Season 2/2017	1455.6
Homabay	Lower midland 3	0°52'S, 34°26'E	1302	Season 1/2016/17	127.1
				Season 2/2017	383.1
Siaya	Lower midland 2	0°23'N, 34°17'E	1319	Season 1/2017	565.0
				Season 2/2017	1039.0

According to the 0–5 damage score, 0 = no damage, 1 = 1–19%, 2 = 20–39%, 3 = 40–59%, 4 = 60–79% and 5 = 80–100% of leaf surface exhibiting damage i.e., the total plant leaf area showing chlorotic stippling or death caused by mite feeding. To assess chlor-ophyll content of plants, an average of 10 SPAD chlorophyll meter readings (SCMR) taken at regular intervals from the base to the tip of a second young fully expanded leaf was recorded. This was done by means of a portable chlorophyll meter SPAD-502 Plus (Konica Minolta Sensing Inc., Japan).

2.3. Field experiments

Agronomic performance of brachiaria genotypes under natural infestation of O. trichardti was assessed in three agro-ecological zones in western Kenya: Siaya (lower midland 2), Mbita (lower midland 5) and Homabay (lower midland 3), over two cropping seasons (Table 2). These are arid and semi-arid areas suitable for maize (Zea mays) and forage production but vary in rainfall distribution and soil character-istics. The sites are also relatively dry with extended periods of drought (Khan et al., 2014) and mite infestation.

For the first season at each site, propagules of uniform size, taken from mature plants were planted in plots of 1.5 × 1.5 m. This followed an alpha lattice design (6 rows x 3 columns) with three replications, at an inter row and inter plant spacing of 50 cm (16 plants per plot). Rows, columns and replicates were separated by a 1.5 m wide path. To serve as a source of mite infestation, three rows of Mulato II were planted around the experimental plot as spreader and guard rows. Phosphorus was applied as a basal application at 12 $\text{kg}^{-\text{ha}}$ P in form of di-ammonium phosphate (DAP) and nitrogen applied as top dresser two months after planting at 16.2 $\text{kg}^{-\text{ha}}$ N in form of calcium ammonium nitrate (CAN). Recommended agronomic practices except pesticide application were followed to ensure good crop stand and growth. At three months after planting, four plants were randomly se-lected per plot and tagged for observations. The numbers of tillers (TL) per plant were counted. Plant height was determined by measuring the length of the tiller shoot from the soil surface to the tip of the youngest fully expanded leaf. Leaf area (LA) of the second fully expanded leaf was calculated by measuring its length from the tip to the junction of the petioles and the width at its widest part. Leaf damage was assessed on four plants in the middle rows of each plot by visual estimation of percentage of the total plant leaf area showing chlorotic stippling or death caused by mite feeding To assess chlorophyll content reduction (CCR) due to leaf damage, an average of 10 SPAD chlorophyll meter readings (SCMR) taken at regular intervals from the base to the tip of a second young fully expanded injured leaf (IL) and non-injured leaf (NIL) were recorded. The percentage reduction in chlorophyll content was calculated as follows:

$$CCR\,(\%) = \frac{(NIL \times IL)}{NIL} \times 100$$

The above ground parts of the tagged plants were harvested and air-dried to between 12 and 14% moisture content which is recommended for making grass hay (Muck and Shinners, 2001). The biomass yield was then determined and expressed as per hectare values.

2.4. Data analysis

Analysis of variance (ANOVA) was performed on leaf damage score (0–5) to compare the resistance levels of the genotypes that were arti-ficially infested with mites in the screenhouse. Field data were com-bined for genotypes, locations and cropping seasons using restricted maximum likelihood (REML) procedure and factor effects were tested using Wald chi-square tests REML. Genotypes, locations and cropping seasons were considered fixed terms whereas replications, rows and columns were considered random terms. Data on leaf damage percen-tage were arcsine transformed prior to analysis. Untransformed means are presented in the tables. Treatment means were compared by cal-culating the least significant differences (LSD). Simple correlations were determined between plant traits using the combined means. Finlay and Wilkinson (1963) regression analysis and the cultivar-superiority measure described by Lin and Binns (1988) were used to assess geno-typic stability and overall consistency of performance across environ-ments (locations and seasons). Bi-plots were used to explore relation-ships between genotypes and/or environments. All analyses were done using the GENSTAT 14th edition statistical software programme (GenStat, 2014).

3. Results

3.1. Responses of brachiaria genotypes to mite infestation under screenhouse conditions

There were significant differences ($p \leq 0.01$) between the degrees of damage observed on genotypes in the screenhouse (ANOVA table not shown). Mean damage scores ranged between 0 (CIAT 679) and 4.7 on the susceptible hybrid check Mulato II (Table 3). U. brizantha genotypes Piata, Xaraes, ILRI 13344 and ILRI 13810 showed low levels of damage (damage score = 1). Significant ($p \leq 0.05$) variation in chlorophyll content of damaged leaves was observed with U. humidicola CIAT 679, and U. brizantha genotypes ILRI 12991, ILRI 13344, ILRI 13497 and Piata having higher values of SCMR (> 36). A simple regression ana-lysis revealed a significant ($p \leq 0.01$) linear and inverse relationship between leaf damage scores and SCMR ($Y = -5.35 + 40.3$, s.e = 1.25, $R^2 = 24.7$).

3.2. Agronomic performance of brachiaria genotypes under natural infestation of spider mites

Significant main effects ($p \leq 0.05$) of genotypes, locations and seasons were observed in all the traits evaluated. The two-way inter-action between genotypes (G) and seasons (S) (GS) and genotypes by location (L) (GL) were also significant ($p \leq 0.05$). Means of the mea-sured parameters across seasons and locations are provided in Table 3. The total leaf area damaged ranged between 0 (CIAT 679) to 17.5% (hybrid Mulato) while the susceptible hybrid check, Mulato II recorded a mean of 11.9%. Infestation by O. trichardti caused the highest

Table 3

Means of agronomic traits of 18 brachiaria genotypes evaluated in a screenhouse over two seasons under natural infestation of Oligonychus trichardti at Mbita, Homabay and Siaya, Kenya.

	Screenhouse		Field experiment					
Genotype	Damage score[a]	SCMR	Leaf damage (%)	CCR (%)	Plant height (cm)	Leaf area (cm^2)	Tillers	Dry biomass (t ha^{-1})
Basilisk	4.3 g	14.6	8.6	6.4	111	44.1	113.5	5.12
Cayman	4.3 g	26	8	7.2	110.4	69.1	116.8	5.71
Marandu	3.3ef	23	7.6	7.7	103.7	88.5	84.8	6
Piata	1.0b	35.3	2.7	1.8	141.6	121.9	81.6	8
Xaraes	1.0b	27.7	2	1.6	140.7	133.9	88.7	6.22
Mulato II	4.7g	4.2	11.9	20.1	97.4	75.4	106.2	6.15
ILRI 11553	2.3cd	27.2	10.3	13.5	135.5	68.1	81.2	4.85
ILRI 13648	4.0fg	20.9	15.6	11.5	123.6	84	77.8	4.86
ILRI 12991	1.7bc	46.5	4.8	9.3	140.9	54	90.8	7.03
ILRI 12995	3.0de	13.5	8.9	12.3	127.3	47.2	85	5.82
ILRI 13344	1.0b	44.9	10.1	9.9	115.5	67.7	83.6	5.13
ILRI 13368	3.0de	26.4	7.9	12.2	141.4	51.4	75.7	5.04
CIAT 679	0.0a	45.3	0	0	97.3	11.7	78.8	4.8
ILRI 13497	1.3b	36.3	12	15.2	133.4	62.4	67.1	4.94
ILRI 13810	1.0b	27	7.4	12.8	122.6	70.5	70.5	5.78
ILRI 13545	1.3b	29	7.8	9.1	107.4	50.2	87.4	5.03
ILRI 14807	1.3b	22.5	8.2	11.2	124.5	40.6	96.8	6.78
Mulato	4.3 g	20.3	17.5	19	89.4	77.6	103.2	4.48
Mean	2.4	27.2	8.4	10	120.2	67.7	88.3	5.65
SE(±)	0.4	11.3	1.5	1.6	9.53	5.3	8.4	0.84
LSD	0.7	23.1	2	2.8	11.05	9.5	14	1.28

SCMR, SPAD chlorophyll meter readings; CCR, chlorophyll content reduction.

Means within columns followed by the same letter do not differ significantly at $p < 0.05$ (LSD).

[a] Damage score 1–5 where, 0 = no damage, 1 = 1–19%, 2 = 20–39%, 3 = 40–59%, 4 = 60–79% and 5 = 80–100% of leaf area damaged.

chlorophyll content reduction (CCR) of 20.1% in leaves of the check variety, while minimal effects of mite feeding were observed on chlorophyll content of leaves of Xaraes (1.6% CCR) and Piata (1.8% CCR). Plant height ranged between 89.4 cm (Mulato) and 141.6 cm (Piata), which was closely followed by ILRI 13368 (141.4 cm), ILRI 12991 (140.9 cm), Xaraes (140.7 cm), ILRI 11553 (135.5 cm) and ILRI 13497 (133.4 cm). The leaf area ranged between 11.7 cm^2 (CIAT 679) and 133.9 cm^2 (Xaraes), while the number of tillers varied between 67.1 (ILRI 13497) and 113.5 (U. decumbens cv. Basilisk). High dry biomass yield under mite infestation were recorded in Piata (8.0 t ha^{-1}), Xaraes (6.2 t ha^{-1}), ILRI 14807 (6.8 t ha^{-1}), ILRI 12991 (7.0 t ha^{-1}) and Mulato II (6.1 t ha^{-1}).

A simple correlation analysis showed a significant negative corre-lation between percentage leaf damage ($p \le 0.05$) and CCR ($p \le 0.01$). Correlations between other traits were not significant at either of the p values (Table 4). Positive correlation was also observed between rainfall amount and biomass yield ($r = 0.82$; $p = 0.04$), while rainfall was negatively correlated with leaf damage ($r = - 0.76$; $p = 0.07$).

3.3. Stability analysis for spider mite resistance and yield

The significant ($p \le 0.01$) three-way interaction indicated that plant biomass was highly dependent on genetic and environmental factors, including, but not limited to location, season and O. trichardti infestation. Means of the different genotypes in each environment (lo-cation and season) are presented in Table 5. Based on stability analysis of the area (%) of leaf damaged, the hybrid Cayman and U. brizantha genotypes ILRI 12991, ILRI 13810, ILRI 12995 and ILRI 11553 were stable across locations and seasons (b-values close to 1). The highly sensitive genotypes to environmental variations were CIAT 679, Mar-andu, and ILRI 13368 which recorded lowest b values, and ILRI 13648 and Mulato I which recorded highest b values (> 1) (Table 6). Geno-types CIAT 679, Piata, Xaraes, ILRI 12991 and Marandu exhibited low cultivar superiority index values (Pi) (Pi ≤ 35.03) for leaf damage. Stable genotypes (b values close to 1.0) in regard to dry biomass yield were CIAT 679, ILRI 13810 and Mulato II. The lowest values of Pi for biomass yield were observed in Piata, ILRI 12991, ILRI 14807 and Mulato II (Pi 0–5.42).

Table 4

Correlation coefficients between measured parameters of brachiaria genotypes evaluated over two seasons under natural infestation of Oligonychus trichardti at Mbita, Homabay and Siaya, Kenya.

	Leaf damage	Dry biomass	Plant height	Leaf area	CCR
Leaf damage					
Dry biomass	−0.498*	–			
Plant height	−0.3106	0.4221	–		
Leaf area	−0.004	0.4085	0.306	–	
CCR	0.8354**	−0.3168	−0.209	−0.1229	–
Number of Tillers	0.1447	0.0965	−0.464	−0.0345	0.057

CCR, chlorophyll content reduction.

* significance $p < 0.05$.

** significance at $p < 0.01$.

Table 5

Means of measured parameters of 18 brachiaria genotypes measured in six environments in Kenya.

	Mbita season 1	Mbita season 2	Homabay season 1	Homabay season 2	Siaya season 1	Siaya season 2
Leaf damage (%)	14.7	5.1	12.5	9.0	6.7	2.6
CCR	19.4	6.2	16.0	10.4	5.8	2.4
Plant height (cm)	116.4	115.8	77.9	165.3	113.1	132.9
Leaf area (cm^2)	69.5	69.7	44.2	71.3	80.7	70.7
Tillers	32.7	130.6	23.7	95.8	59.8	187.2
Dry biomass (t ha^{-1})	5.94	10.16	1.96	5.90	1.90	8.06

CCR, chlorophyll content reduction.

The relationships between mean dry biomass yield and area of leaf damaged (%) across environments are illustrated in a scatterplot (Fig. 1). Genotypes Piata, Xaraes, ILRI 12991, ILRI 14807, ILRI 13810, Marandu and Cayman recorded high biomass yields (> 5.7 t ha^{-1}) and lower leaf damage (< 8.4%). CIAT 679 was among the most stable genotypes across environments, however, it recorded low dry biomass

Table 6

Genotypic means and stability for leaf damage and dry biomass yield of 18 brachiaria genotypes evaluated over two seasons under natural infestation of Oligonychus trichardti at Mbita, Homabay and Siaya, Kenya.

	Leaf damage			Dry biomass yield			
Genotype	Mean damage (%)	Regression equation	Pi	Mean yield (t ha^{-1})	Regression equation	Pi	Rank
Basilisk	8.6	Y = 0.35X + 31.82	48.84	5.12	Y = 0.88X + 4.22	11.83	14
Cayman	8.0	Y = 0.85X + 20.13	45.8	5.71	Y = 0.87X + 3.37	8.65	8
Marandu	7.6	Y = 0.19X + 17.12	35.03	6.00	Y = 1.11X + 0.58	6.08	5
Piata	2.7	Y = 0.35X + 3.77	6.04	8.00	Y = 1.37X + 0.80	0.94	1
Xaraes	2.0	Y = 0.34X + 5.90	5.07	6.22	Y = 0.66X + 2.44	8.21	7
Mulato II	11.9	Y = -0.34X + 1.82	72.72	6.15	Y = 1.09X + 0.56	5.42	4
ILRI 11553	10.3	Y = 0.86X + 28.71	69.92	4.85	Y = 0.72X + 2.08	12.55	16
ILRI 13648	15.6	Y = 3.92X + 19.81	272.69	4.86	Y = 0.92X + 3.16	11.47	13
ILRI 12991	4.8	Y = 0.91X + 3.93	20.78	7.03	Y = 1.26X + 2.42	3.71	2
ILRI 12995	8.9	Y = 1.13X + 19.65	58.57	5.84	Y = 0.69X + 1.25	9.06	10
ILRI 13344	10.1	Y = 0.75X + 30.15	66.66	5.13	Y = 1.27X + 3.25	9.01	9
ILRI 13368	7.9	Y = 0.16X + 19.18	37.51	5.04	Y = 0.64X + 3.64	12.78	17
CIAT 679	0.0	0	0.00	4.80	Y = 1.01X + 2.00	11.02	12
ILRI 13497	12.0	Y = 0.23X + 66.61	95.09	4.94	Y = 0.89X + 7.85	12.42	15
ILRI 13810	7.4	Y = 1.13X + 27.38	48.86	5.78	Y = 1.04X + 1.84	7.10	6
ILRI 13545	7.8	Y = 0.88X + 62.94	58.49	5.03	Y = 1.22X + 1.93	9.70	11
ILRI 14807	8.2	Y = 1.25X + 10.12	51.54	6.78	Y = 1.56X + 2.88	3.88	3
Mulato	17.5	Y = 3.04X + 42.44	255.17	4.48	Y = 0.77X + 1.98	13.71	18

Pi, Cultivar superiority index.

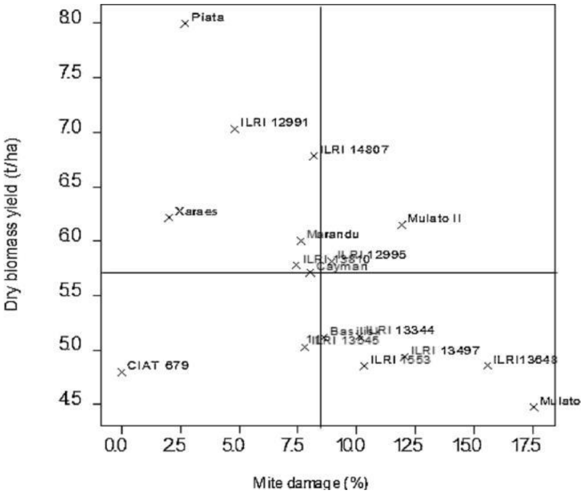

Fig. 1. Expression of field resistance to the red spider mite Oligonychus trichardti in 18 brachiaria genotypes and their dry biomass yield potential over two seasons under natural infestation of O. trichardti at Mbita, Homabay and Siaya, Kenya. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article).

yield (4.8 t ha^{-1}). The GE biplot presentation of average biomass yield of the different genotypes under natural infestation of mites across the six environments (cropping seasons and locations) is presented in Fig. 2. The first and the second

principal components accounted for 67.6% of the total variation. Both Seasons 1 and 2 at Siaya (SY_SN1; SY_SN2), and both Seasons in Homabay (HB_SN1; HB_SN2) were separated by acute angles indicating these environments to be similar. All the genotypes recorded lower mean yields in these environments (Table 5). Obtuse angles between season 1 in Mbita (MB_SN1) and all other environments except Mbita season 2 (MB_SN2) indicate negative correlations demonstrating that the genotypes ranked differently at Mbita during season 2 (MB_SN1). In general, both SY_SN2 and MB_SN2 displayed the largest projections from the biplot origin, which implies that they played major roles in discriminating between the genotypes. Genotypes that performed comparatively better in specific environments, based on their proximity to the environments, were ILRI 13344 (MB_SN1), and ILRI 14807 (MB_SN2) (Fig. 2).

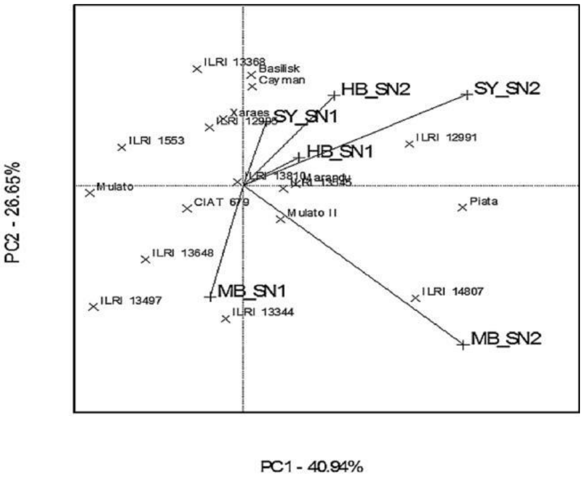

Fig. 2. Biplot of dry biomass yield for 18 genotypes of brachiaria grown over two seasons under natural infestation of Oligonychus trichardti at Mbita, Homabay and Siaya, Kenya. Genotypes are indicated by numbers and the treatments by vectors (HB = Homabay, SY = Siaya, MB = Mbita; SN = season).

4. Discussion

Several brachiaria genotypes with considerable level of resistance to O. trichardti damage were identified in this study. Notably, genotypes responded differently in different environments which makes it possible to select and recommend cultivation of specific genotypes for different agro-ecological zones. The use of resistant genotypes is therefore a vi-able option for the management of O. trichardti in western Kenya, with possibility of use in other areas with similar agro-ecological conditions and farming systems in east Africa. Host plant resistance to arthropod pests has been reported as one of the most effective, economical and environment friendly strategies for pest management (Van den Berg and Nur, 1998; Sharma et al., 2015). Other than morphological char-acteristics, plants have sophisticated defense systems that make use of toxic or anti-feedant secondary metabolites. However, the defense systems vary between and within plant species (Franceschi et al., 2005; Mithoefer and Boland, 2012). This explains the variation of resistance to O. trichardti in our study with hybrid Mulato II being the most susceptible. Past studies have highlighted success in host-resistance of grasses to mites (Quisenberry, 1990). High to moderate resistant gen-otypes of bermuda grass (Cynodon spp.) to bermuda grass mite Erio-phyes cynodoniensis Sayed (Acari: Eriophyidae), were identified by Johnson (1975). Similarly, a variety of zoysia grass (Zoysia tenuifolia) with high level of resistance to bank grass mite Oligonychus pratensis (Banks) (Acari: Tetranychidae) was identified by Busey et al. (1982). Host plant resistance to mites have also been identified in maize (Bynum et al., 2004; Kamali et al., 1989).

To exploit host plant resistance as a management tool for a pest, exposure to the pest and evaluation of plants of candidate crop varieties in endemic areas is a prerequisite as it contributes to identification of superior varieties. In our study, the importance of O. trichardti was evident. Regression analysis of damage score and chlorophyll index of plants grown under screenhouse conditions revealed a negative corre-lation. Similar effects of spider mite damage were observed in cotton (Gossypium hirsutum L.) (Bondada et al., 1995). Notably, chlorophyll content of brachiaria is highly and positively correlated with crude protein content, an important nutritional quality of forage crops (Hughes et al., 2014). This shows that mite infestations could lower the nutritional value of plant biomass intended for animal feed. Of all the plants that were exposed to artificial infestation in the screenhouse, the species CIAT 679 was completely resistant genotype to the mites while U. brizantha genotypes Piata, Xaraes, ILRI 13344 and ILRI 13810 re-corded significantly lower levels of infestation with a damage score of 1 (10–19% of leaf damaged). This highlights the genetic variation in brachiaria and more so the existence of sources of resistance to mite pests.

Results of the GxE interaction (genotype by location and season) indicate genetic variation among brachiaria genotypes which could be exploited through selection based on genotypic resistance to O. tri-chardti, biomass yield and yield related traits (plant height, leaf area and the number of tillers). Leaf damage was notably lower in the field than in the screen house. This may be due to effects of the weather patterns on biology of the mites as previously reported for Oligonychus coffeae Nietner (Acari: Tetranychidae) (Ahmed et al., 2012). Under hot and dry conditions, mites have a short life cycle and high reproductive potential (Ahmed et al., 2012). For example, the life cycle of T. evansi is completed in 13.5 days at 25 °C (Knapp et al., 2003). Re-infestation usually begins as soon as the crop regenerates and spreads faster within the plant. However, this is hampered when there is precipitation as the rain washes them off the leaves and creates unfavourable humid con-ditions. In the current study, at all locations, lower mite damage re-corded during the previous season. Notably, average rainfall recorded over the entire cropping season was higher in season 2, than in season

1. The negative correlation between leaf damage and the amount of rainfall received, though non-significant, indicates that precipitation probably played a role in reducing mite severity. With increasing ar-idification due to climate change (Burke et al., 2009; Fischer et al., 2005; Jones and Thornton, 2003), the pest status of phytophagous mites may increase in future. A similar trend of variation in loss of chlorophyll due to mite feeding was observed in this study (Table 4). Regression analysis showed that O. trichardti played a significant role in reducing biomass yield. Although correlation analysis showed that biomass yield also depended on the amount of rainfall, this was not always the case. For example, higher biomass yield was recorded at Mbita despite this locality receiving lower rainfall than Siaya. This highlights the role of environmental factors including soil fertility in crop growth and yield.

In general, a few genotypes (Piata, ILRI 12991, Xaraes, Marandu and ILRI 13810) combined both resistance to O. trichardti (≤8.4% of leaf damaged) and high biomass yield (≥5.7 t ha^{-1}) across all en-vironments (Fig. 1). Moreover, these genotypes recorded low cultivar superiority index values for leaf damage (%) (≤48.86) and biomass yield (≤8.21) (Table 6), indicating that they are reliable across diverse environments. Such genotypes are useful to farmers since they would provide comparative yield advantages under mite infestation in drier conditions which are common to arid and semi-arid environments. Despite of the potential of brachiaria in improving cereal-livestock based productivity in Kenya, it is constrained by high cost and limited availability of seed. This arises from inability of most flowers to form seed coupled with less effective harvesting methods. Phaikaew et al. (1997) reported that seed production in the humid lowland tropics near the equator is usually difficult. However, studies in Kenyan highlands have shown that high yielding brachiaria varieties, for example Xaraes, do produce seed, although poorly (Gitari and Njarui, 2016; Kamidi et al., 2016).

In summary, results of our study highlight a wide variation in the levels of resistance to the O. trichardti and biomass yield potential of brachiaria genotypes evaluated in different environments. From this multi-trial screenings, genotypes Piata, ILRI 12991, Xaraes, Marandu and ILRI 13810 emerged as candidate genotypes for utilization by African farmers in different agro-ecologies where frequent outbreaks of O. trichardti are experienced. The apomictic nature of these genotypes presents an advantage to farmers since they can propagate the grasses without losing their vigour. To fully evaluate the value of such genetic materials, we propose that the candidate genotypes be evaluated in a farmer participatory approach. There is also a need to evaluate seed production of the candidate genotypes in diverse highland conditions and for more seasons to determine their actual potential.

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