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Research Article

Screening Maize (*Zea mays* L.) Germplasm for Non-Parasitic Weed Tolerance in a Tropical Rainforest Agroecology

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Abstract

The high economic and environmental costs of weed management have led to interest in studying the genetics of non-parasitic weed stress tolerance in maize (*Zea mays* L.). The objectives of this study were to determine genotypic effects of weed infestation on maize, identify plant traits conditioning weed-stress tolerance, and identify maize varieties that are weed-stress tolerant for further improvement. One hundred open-pollinated maize varieties were planted in five environments in the early and late seasons of 2018 using a 10 x 10 lattice design with three replications. Data were collected on emergence, vegetative, and flowering traits as well as grain yield and its components. Analysis of variance showed that under uncontrolled weed stress, there were significant ($p \leq 0.01$) varietal (G), environmental (E), and G × E effects for emergence, vegetative vigor, flowering, grain yield, and yield component traits. There was significant positive correlation between clean weeding and zero weeding for number of leaves, tasseling-silking interval, number of ears/plot, and grain yield. Broad sense heritability estimates were 73.8% for emergence percentage, 67.75% for emergence index, and 59.48% for days to tasseling. Rank summation index (RSI) identified ten varieties as promising for weed-stress tolerance, including TZEE-W POP STR 108 BC2, (2 X TZE COMP. 3 DT/WHITE DT STR SYN) C2, TZEE-W POP STR C5, ACR.06 TZL COMP. 3 C4, EVDT-W 99 STR and five others. It was concluded that genotypic variation for non-parasitic weed stress tolerance exists in the available maize germplasm in Nigeria, is highly heritable, and promising varieties have been identified for further improvement.

Keywords: maize; weed stress; non-parasitic weed; tolerance

Worldwide, maize (*Zea mays* L.) is the third most important cereal crop after wheat (*Triticum aestivum* L.) and rice (*Oryza sativa* L.) in terms of cultivated land area and total production, thereby playing an important role in the world's agricultural economy (Kawsar et al., 2011). Globally, maize has a wide acceptance due to its usefulness for both human and animal consumptions (FASDEP, 2002). The crop has been in the diet of Nigerians for centuries (Iken and Amusa, 2004). However, maize yield in Nigeria is still very low compared to developed countries, due to many constraints which include low soil fertility, pests and diseases, drought, weeds, and high cost of inputs, among others (Ngoko et al., 2002; Olaniyan, 2015). Yield loss due to weed competition is one of the most important challenges to crop production all over the world (Hussain et al., 2014). Weeds reduce crop yield by competing for space, light, water, soil nutrients, and other atmospheric resources such as carbon dioxide (Ferrell et al., 2012). The high economic and environmental costs of weed management have led to interest in developing weed suppressive crop varieties (Jannink et al., 1999). Maize varieties that will produce optimum yields in despite weed infestation, must be able to out-compete weeds for moisture, light, space and nutrients. Such maize varieties that are adapted to the rainforest agro-ecology as typified by Ile-Ife, are yet to be identified in Nigeria.

There is little or no information on the genotypic effect of non-parasitic weed stress on maize germplasm, and plant traits conditioning weed stress tolerance in maize are also yet to be identified. In a preliminary study conducted at the Obafemi Awolowo University Teaching and Research Farm (OAU TRF), Ile-Ife, 12 maize varieties (G) were subjected to six treatments (T) which included: (i) no weeding at all; (ii) use of post-emergence herbicide applied once with no subsequent weeding; (iii) complete weed control using pre-emergence herbicides followed by application of post-emergence herbicide during the crop's late vegetative growth stage; (iv) complete weed control using pre-emergence herbicides followed by hand weeding as necessary throughout the growth cycle of the crop; (v) hand weeding till flowering, followed by no weeding for the rest of the season; and (vi) no weeding till flowering, followed by clean weeding till crop maturity (Job, 2015). Higher yields were recorded in treatments iii and iv (about 1.3 t/ha) compared to treatments i and ii (0.3 and 0.4 t/ha, respectively). All the varieties had low yield under non-parasitic weed stress conditions. An earlier study conducted in the same location with 18 Striga tolerant varieties, showed significant differences among weed free, manual, and chemical treatments, as well as significant varietal differences for some agronomic traits (Adesina and Akinwale, 2014). The results of these two studies, although seemingly conflicting in some aspect, suggested the possibility of the existence of genetic variability for weed-stress tolerance in maize germ plasm. Also, the two studies evaluated relatively few varieties in a single experiment. It was, therefore, considered necessary to screen a larger number of varieties from the available maize germ plasm in Nigeria for weed-stress tolerance under the rainforest agro-climatic conditions of SW Nigeria as typified by Ile-Ife in more environments so as to minimize chances of erroneous conclusions due to confounding effects of genotype by environment (G×E), genotype by treatment (G×T), and genotype by environment by treatment (G×E×T) interactions.

Apart from these two studies, a few researchers in other agro-ecologies had carried out some earlier, though less extensive, studies to evaluate the effects of non-parasitic weed stress on maize and other crops. Begna et al. (2001) evaluated the responses of the morphology and yield of three maize hybrids to weed pressure. The study showed that grain yield of two of the hybrids, which were early maturing, was least affected by weed pressure suggesting better tolerance of, and competition with, weeds. Also, in an effort to determine the ability of spring wheat to produce high yield, suppress weeds and withstand mechanical cultivation, Murphy et al. (2008) evaluated 63 landraces and modern cultivars for 5 potential competition traits, including plant height, leaf area index (LAI), juvenile growth habit (JGH), coleoptile length, and 1000 kernel weight (TKW). The study showed that plant height was positively correlated with yield and negatively associated with weed weight. Another similar study conducted on weed tolerance and suppression in wheat by Australian Grain Technologies (AGT) as reported by Haydn et al. (2014) involved a multi-site and multi-year weed competition trial comparing 10 varieties that were widely grown in South Australia, along with promising advanced breeder lines. The trial was conducted at five locations over a period of four years (2010-2013). The relative performance of the varieties for both tolerance and suppression showed a high level of consistency across locations and years. The varieties that performed well were not of any specific maturity, but those that performed poorly all had a vernalization requirement which is associated with poor early vigor.

The specific objectives of this study were to

(i) Determine the genotypic effect of weed infestation on maize;
(ii) Identify plant traits conditioning weed-stress tolerance; and
(iii) Identify weed-stress tolerant maize varieties for further improvement under weed infestation.

Materials and Methods

Land Preparation, Field Layout and Planting

The study was carried out at the OAU TRF, Ile-Ife, in the early and late seasons of 2018. One hundred open-pollinated maize varieties (OPVs) of different maturity groups, obtained from the Maize Improvement Program (MIP) of the International Institute of Tropical Agriculture (IITA), Ibadan were used for the study (Table 1). The study involved three experiments with a total of five plantings which were done from May to September 2018. Each experiment was laid out in a 10 x 10 lattice design with three replications. Land preparation was done by ploughing and harrowing after which the field was mapped for planting using measuring tapes, ropes, and pegs. In all experiments, single-row plots were used.

Extra-early/early varieties	*Intermediate/late varieities*
2011 TZE-W DT STR SYN	AFLATOXIN SYN Y F2
DTE STR-W SYN POP C3	(SYN (dfo/Obatanpa/TZL Comp 3 C3 X C2)
DTE STR-Y SYN POP C3	AFLATOXIN SYN 3 W
TZE-Y POP DT C5 STR C5	TZ COM. 1/ZDP SYN
TZE-W POP DT C5 STR C5	PVA SYN 9
DTE STR-W SYN POP C4	PVA SYN 18 F2
TZE-W POP DT STR C4	F2TWLY131211
TZE-Y POP DT STR C4	DT STR-W SYN 13
EVDT-Y 2000 STR	AFLATOXIN SYN W4
EVDT-W 99 STR	(TZL COMP.1-W C6 X 2/White DT STR SYN) DT C1
TZE-W POP DT STR QPM C0	F2TINLY100123
EVDT-Y 2000 STR QPM	ACR.06 TZL COMP.4 C4
EVDT-W 99 STR QPM	F2SCA1413-12
2012 TZE-W DT C4 STR C5	PVA SYN 8
2015 DTE STR-Y SYN	OBATANPA/IWD C2 SYN
TZE COMP 3 DT C2 F2	PVA SYN HGB C0
TZE-W POP DT C4 STR C5	TZL COMP. 4 C4
TZE-Y POP DT C4 STR C5	STR-SYN-W1
2011 TZE-Y DT STR	F2TWLY100121
2014 TZE-Y DT STR	PVA SYN 3
2014 TZE-W DT STR	DT STR-W SYN 12
TZE-Y POP DT C3 STR C5	PVA SYN 2
TZE-W POP DT C3 STR C5	F2TINLY131228
2010 TZE-W DT STR	DT STR-Y SYN 14
2013 DTE STR-Y SYN	ACR.91 SUW AN-1-SRC1
TZEE-Y POP DT C1 STR C5	PVA SYN 10
TZEE-W POP DT C2 STR C5	F2TINLY13124
2016 TZDEE-W SYN POP DT STR	(TZE COMP. 5 C7/TZE COMP. 3 DT C2) C2
2016 TZEE-W SYN POP DT STR	SAMMAZ 16
2016 TZDEE-Y SYN POP STR	IWD C3 SYN/DT STR SYN-W-1
2016 TZEE-W SYN POP STR QPM	STR-SYN-Y2
2015 TZEE-W HDT STR	Obatanpa/TZL COMP. 4 C3
2013 TZEE-W POP HDT STR	AFLATOXIN SYN Y F2
2012 TZEE-W DT STR C5	F2SCA1413-36
2013 TZEE-Y DT STR	DT STR-W SYN11
2004 TZEE-Y POP STR C4	OBATANPA/TZL COMP. 3
2009 TZEE-W STR	Z. Diplo BC4 C3-W DT C1
2008 TZEE-Y STR	PVA SYN HGA C0
2008 TZEE-W STR	(2 X TZE COMP. 3 DT/WHITE DT STR SYN) C2

2004 TZEE-W POP DT STR C4	SAMMAZ 15
2000 SYN-EE-W STR	PVA SYN 11
2009 TZEE OR1 DT STR QPM	PVA SYN 5
2009 TZEE OR2 STR QPM	ACR.06 TZL COMP. 3 C4
TZEE-Y POP STR C5	PVA SYN 6
TZEE-W POP STR C5	PVA SYN 13
TZEE-W STR 107 BC2	AFLATOXIN SYN 5
TZEE-Y POP STR 106 BC2	TZL COMP. 3 C3 DT
TZEE-W POP STR 108 BC2	AWR-SYN-W
TZEE-W STR 104 BC2	PVA-IDEK SYN 4
TZEE-W POP DT STR X Z107	AWR-SYN-Y

Table 1: Open pollinated maize varieties screened for tolerance to non-parasitic weed stress tolerance in a tropical rainforest agro-ecology.

Field Trials

Experiment 1 - The plantings done on May 11 and June 14 (Environments 1 and 2) had row lengths of 5m each, a total of 100 rows per replication. Before planting, seeds were treated with Apron star, a mixture of insecticide and fungicide containing Thiamethoxam, Metalaxyl-M and Difenoconazole as its active ingredients. This was done to control fungi and soil-borne insects thereby enhancing optimum seed germination and seedling emergence. Three seeds were manually planted per hole at a spacing of 0.5m within rows and 0.75m between rows, and seedlings were thinned to two plants per stand at 2 weeks after planting to give 22 plants per plot. The dimension of the land used in each of the two environments was 15m x 74.25m. Apart from land preparation before planting, weeds were not controlled in the two environments. Land preparation, row spacing, seed treatment before planting, number of plants per stand and number of rows per plot used in Experiment 1 were kept constant for the other two experiments.

Experiment 2 - This experiment, which was planted on August 14 (late season), involved two weed treatments: *Treatment 1*-No weeding at all and *Treatment 2*-Clean weeding. Each row, which was 7m long, was divided into two 3m sub-rows, separated by a 1m alley. The two treatments were planted into the 3m rows, respectively. A 1.5m walkway separated one replication from the other. Clean weeding was achieved through the application of the pre-emergence herbicide (Atrazine) one day after planting at a rate of 5litres/hectare; post-emergence herbicide (Paraforce) a non-selective post-emergence herbicide containing paraquat dichloride as its active ingredient; and supplemental hand weeding as necessary during the growing season.

Experiment 3 - The plantings done on August 29 and September 17 (both late season) involved three weed treatments each: *Treatment 1*: No weeding at all; *Treatment 2*: Clean weeding; *Treatment 3*: Pre-emergence herbicide, followed by no weeding. Each row was 11m long, divided into three 3m sub-rows, separated by 1m alley as done for Experiment 2. The three treatments were planted into the three sub-rows, respectively. Treatments 1 and 2 were handled as done in Experiment 2, while Treatment 3 involved the use of pre-emergence herbicide with no subsequent weeding of any kind till harvest. Overall, Treatments 1, 2, and 3 were evaluated in 5, 3, and 2 environments, respectively. In addition, because the OAU TRF has been prone to fall army worm infestation in recent years, Caterpillar Force, an insecticide containing Emamectin Benzoate (5% Water Dispersible Granules) as its active ingredient, was applied twice at the vegetative stage (about 3 and 5 weeks after planting). The rate of application ranged from 0.9kg to 1.8kg/ha, depending on the degree of severity of infestation in each environment. A basal application of urea fertilizer was done at the rate of about 75 kg/ha at approximately 2 weeks after planting each experiment.

Data Collection

In all experiments and treatments, data were collected on number of leaves (NL) at 40-44 DAP and plant height (PHT) at 31-43 DAP. Plant height was measured in cm as the distance from the base of the plant to the height of the topmost leaf. At flowering, data were collected on days to 50% tasseling, anthesis, and silking, from which the tasseling-anthesis (TAI), tasseling-silking (TSI), and anthesis-silking (ASI) intervals were calculated. At harvest, data were collected on number of stands per plot, number of ears per plot, ear weight per plot, moisture content, and ear aspect (EASP). Ear aspect was rated on a scale of 1 to 5, where 1 = clean, uniform, large and well-filled ears and 5 = ears with undesirable features. After harvest, 5 random ears were selected per plot and data were collected from them on ear length, ear diameter, kernel row number and shelling percentage. The ear length was measured with a meter rule from the base to the tip of the ear; ear diameter was also measured with a meter rule by arranging the 5 ears side-by-side on a plane surface and estimating the mean diameter of the ears. Shelling percentage was calculated as:

$$\frac{\text{kernel weight of 5 ears}}{\text{weight of the 5 ears}} \times 100$$

Grain yield (t/ha) was adjusted to 15% moisture content and converted to tons/ha as follows:

$$\frac{\text{Ear weight per plot}}{\text{Area of plot (m2)}} \times \frac{(100 - \text{Moisture content})}{85} \times \frac{(\text{Shelling \%})}{100} \times \frac{100{,}000}{1000}$$

Where;

1000 kg = 1 ton and 10,000 m = 1 ha (Oluwaranti et al., 2020)

Data Analysis

Analysis of variance (ANOVA) was done on entry means using randomized complete block design for all the measured traits with PROC GLM. The ANOVA models used for the analysis are:

Experiment 1

$Y_{ijkl} = \mu + R_i + E_j + G_k + GE_{jk} + \varepsilon_{ijk}$

Experiments 2 and 3

$Y_{ijkl} = \mu + R_i + E_j + T_k + G_l + GE_{jl} + GT_{kl} + ET_{jk} + GTE_{jkl} + \varepsilon_{ijkl}$

Where Y_{ijkl} is the observed measurement; μ is the grand mean; R_i is the replication effect; E_j is the effect of environment; Tk is the weed treatment effect; G_l is the effect of genotype; GE_{jl} is the genotype by environment interaction effect; GT_{kl} is the genotype by treatment interaction effect; ET_{jk} is the environment by treatment interaction effect; GTE_{jkl} is the genotype by treatment by environment interaction effect and ε_{ijkl} is the residual or error term. PROC VARCOMP was used to obtain the variance components of the traits, for the estimation of broad sense heritability, using Statistical Analysis Systems (SAS) version 9.3. (SAS Institute, 2001). The form of the ANOVA with the expected mean squares used for estimating variance components is presented in Table 2. Theoretically, EMS = mean squares (M) for each source of variation. Therefore, the components of variance were obtained by solving the following equations:

$$\sigma^2_{ge} = \frac{M_2 - M_1}{r} \quad \ldots\ldots 2$$

$$\sigma^2_{g} = \frac{M_3 - M_2}{re} \quad \ldots\ldots 3$$

Sources of variation	***Df***	***Mean squares (MS)***	***Expected mean squares (EMS)***
Environment (E)	e-1		
Replication-in-E	e(r-1)		
Genotype (G)	g-1	M_3	$\sigma^2 + r\sigma^2_{ge} + re\sigma^2_g$
Genotypes x Environment	(e-1) (g-1)	M_2	$\sigma^2 + r\sigma^2_{ge}$
Pooled Error	e(r-1)(g-1)	M_1	σ^2
Total	erg-1		

Table 2: Outline of ANOVA used for the estimation of variance components of measured traits.

Using the variance components, broad sense heritability (H^2_B) on entry mean basis was calculated with the equations:

$$H^2_B = \frac{\sigma 2g}{\sigma^2_{ph}} \quad \ldots\ldots 4$$

and

$$\sigma^2_{ph} = \sigma^2_g + \frac{\sigma^2_{ge}}{e} + \frac{\sigma^2}{re} \quad \ldots\ldots 5$$

(Piepho and Möhring, 2007).

Pearson correlation analysis was carried out on all the measured agronomic traits across the treatments and environments. Mean of each trait was ranked from the best (ranked 1) to the worst (ranked 100) for each variety and the best ten and worst five varieties were identified using rank summation index (RSI).

Results

Environment and variety had highly significant effects on all emergence traits as well as number of leaves at 40-44 DAP and plant height at 31-43 DAP (Table 3). Replication within environment had highly significant effects on emergence traits except ERI as well as PHT at 40-44 DAP and NL at 31-43 DAP; G × E had highly significant effect for ERI only. For all the traits, CV ranged from 12% for ERI to 25% for PHT, and the R^2 from 0.54 for E% and EI to 0.86 for PHT. Environment, replication within environment, and variety also had highly significant effects on the expression of all vegetative vigor and flowering traits (Table 4). Variety x environment interaction was significant or highly significant for plant height (PHT), number of leaves (NL), days to 50% tasseling (TSL) and days to 50% silking (SLK). The CVs for PHT, NL, and TSL were relatively low (<40%) while those for other traits were high, especially the intervals between flowering events, ranging from about 99 to 125% in most cases. The R^2 followed the expected trend, in line with the CVs of the traits (Table 4). In addition, environment and replication within environment had highly significant effects on grain yield and its components; variety and G×E had no significant effect on any of the yield related traits (Table 5). The CVs for these traits were extremely large, ranging from about 144% for grain moisture to 253% for grain yield. Here also, as expected based on the trend of the CV, the R2 values were low, mostly about 0.4 except grain moisture where it was 0.5 (Table 5).

Traits having significant mean squares in the ANOVA showed larger phenotypic than genetic variances, along with moderately large broad sense heritability estimates (Table 6). The two estimates obtained for each of PHT and NL were sufficiently close to assure the breeder of their repeatability under weed stress studies. Flowering traits had moderate broad sense heritability, although values obtained for ASI and TAI were rather low (Table 6). There was significant positive correlation between maize traits under clean weeding and weed stress conditions for early formation of leaves (NL), days to 50% silking, tasseling-silking interval, number of ears per plot, and grain yield (Table 7). Although the correlation coefficients were generally low to moderate, those involving grain yield were striking. Using the five traits that had significant correlation coefficients, the best 10 and worst 5 varieties were selected based on their rank summation index (RSI) under weed stress across three environments (Table 8). Varieties TZEE-W POP STR C5, ACR.06 TZL COMP. 3 C4,

TZEE-W POP STR 108 BC2, EVDT-W 99 STR, SAMMAZ 16, 2016 TZEE-W SYN POP STR QPM, (2 X TZE COMP. 3 DT/WHITE DT STR SYN) C2, EVDT-W 99 STR QPM, 2008 TZEE-Y STR, and EVDT-Y 2000 STR were identified as the best 10 varieties with promising performance potentials under weed stress while F2SCA1413-36, 2015 DTE STR-Y SYN, AFLATOXIN SYN 3 W, TZE-Y POP DT C4 STR C5, and TZE-W POP DT C3 STR C5 were identified as the least weed-stress tolerant.

Source	*DF*	*E%*	*EI*	*ERI*	*PHT*	*NL*
Environment (E)	1	11690.79**	55.54**	410.68**	20.24**	316.83**
‡Rep-in-E	4	1684.31**	8.71**	0.96	0.44**	7.78**
Genotype (G)	99	920.48**	3.39**	1.55**	0.02**	2.47**
G*E	99	139.40	0.99	1.06**	0.01	1.42
Error	396	266.62	1.12	0.57	0.01	1.37
CV,%		22.31	23.48	12.09	25.21	16.67
R^2		0.54	0.54	0.75	0.86	0.57

*, **Significant F-test at 0.05 and 0,01 probability level, respectively.

†DAP = days after planting.

‡Rep=replications; CV=coefficient of variation; R2=coefficient of determination.

E%=emergence percentage; EI=emergence index; ERI=emergence rate index; PHT=plant height; NL=number of leaves.

Table 3: Mean squares of emergence traits, plant height at 31-43 DAP†, and number of leaves at 40-44 DAP of 100 maize varieties evaluated under weed stress conditions during the 2018 cropping seasons at the Teaching and Research Farm of Obafemi Awolowo University, Ile-Ife.

Source	*DF*	*PHT, m*	*NL*	*TSL, days*	*ANTH, days*	*SK, days*	*TAI, days*	*ASI, days*	*TSI, days*
Env (E)	4	12.77**	159.66**	8333.59**	41443.61**	36959.81**	246.21**	58.72**	561.45**
Rep-in-E	10	0.47**	34.15**	3712.42**	15437.36**	6220.75**	129.02**	75.75**	44.32**
Genotype (G)	99	0.08**	9.66**	1004.75**	1237.14**	1176.27**	15.74**	14.50*	9.44**
G*E	396	0.04**	3.65**	393.85*	655.71	634.26*	11.63	11.52	7.57
Error	990	0.031	2.54	326.94	604.6	536.8	10.08	11.07	6.74
CV, %		33.08	21.96	36.97	59.88	52.79	98.86	124.65	116.48
R^2		0.73	0.57	0.52	0.54	0.52	0.46	0.39	0.50

*, **Significant F-test at 0.05 and 0,01 probability level, respectively. E=environment; REP=replications; G=variety; ERR=residual or error; CV=coefficient of variation; R2=coefficient of determination PHT=early plant height; L=number of leaves; TSL=days to 50% tasseling; SK=days to 50% silking; ANTH=days to 50% anthesis; ASI=anthesis-silking interval; TAI =tasseling-anthesis interval; TSI=tasseling-silking interval.

Table 4: Mean squares of the vegetative vigor and flowering traits of 100 maize varieties evaluated under weed stress conditions during the 2018 cropping seasons at the Teaching and Research Farm of Obafemi Awolowo University, Ile-Ife.

Sources	DF	E/PLT	EWT/PLT	MC(%)	ELTH	EDM	KRN	EASP	SHLNG%	YLD
Env (E)	2	163.31**	0.47**	6437.85**	0.11**	0.01**	1292.59**	221.6**	34294.8**	2.86**
Rep-in-E	6	47.94**	0.13**	545.35**	0.02**	0.002**	341.4**	43.46**	10082.4**	1.00**
Genotype (G)	99	3.63	0.01	48.08	0.002	0.0002	30.61	4.16	853.08	0.07
G*E	198	2.58	0.009	35.84	0.001	0.0001	18.2	2.79	726.03	0.08
Error	594	3.49	0.013	46.36	0.002	0.00017	25.18	3.34	845.89	0.10
CV, %		180.13	253.59	143.71	149.86	150.18	149.44	144.84	161.47	254.85

*, **Significant F-test at 0.05 and 0.01 probability level, respectively. Env=environment; Rep=replications; G=variety; CV=coefficient of variation; R2=coefficient of determination; E/PLT=number of ears per plot; EWT/PLT=ear weight per plot; 5EWT=5 ear weight; MC(%)=percentage moisture content; ELTH=ear length; EDM=ear diameter; KRN=kernel row number; EASP=ear aspect; 5KWT=5 kernel weight; SHLNG%=shelling percentage; YLD=yield in tons/ha.

Table 5: Mean squares of yield and its components for 100 maize varieties evaluated under weed stress condition during 2018 cropping seasons at the Teaching and Research Farm of Obafemi Awolowo University, Ile-Ife.

	δ^2	δ^2ge	δ^2g	H^2b
E%	241.1724	0.0000	113.2175	73.8
EI, days	1.0919	0.0000	0.3823	67.75
ERI, days	0.5725	0.1607	0.0829	35.73
PHT (2 Envs), m	0.0107	0.0007	0.0014	41.15
PHT (5 Envs), m	0.0309	0.0039	0.0027	44.90
NL (2 Envs)	1.3743	0.0161	0.1742	42.64
NL (5 Envs)	2.5406	0.3708	0.4008	57.77
TSL, days	326.9400	22.3027	50.9086	59.48
SK, days	536.7963	32.4875	45.1670	44.84
ANTH, days	604.5948	17.0381	48.4522	46.36
ASI, days	11.0702	0.1488	0.2485	20.36
TAI, days	10.0756	0.5165	0.3431	25.32
TSI, days	0.7168	0.0353	0.0776	45.90

δ2, δ2ge, and δ2g are variances due to error, genotype × environment interaction, and genotype, respectively. H2b is broad sense heritability.

Table 6: Components of genetic variance and heritability estimates (on entry mean basis) for traits of 100 maize varieties evaluated under weed stress conditions during 2018 cropping seasons at the Teaching and Research Farm of Obafemi Awolowo University, Ile-Ife.

	Trait under No (zero) weeding				
Trait under clean weeding	***NL1***	***SK 1***	***TSI1***	***E/PLT1***	***YLD1***
NL2	0.482**	0.324**	0.234**	0.126**	0.119**
SK2, days	0.304**	0.217**	0.187**	0.104**	0.081
TSI2, days	-0.007	-0.003	0.064	-0.020	-0.042
E/PLT2	0.326**	0.364**	0.229**	0.379**	0.314**
YLD2, t/ha	0.290**	0.333**	0.188**	0.422**	0.388**

NL1=Number of leaves under zero weeding; SK1=days to 50% silking under zero weeding; TSI1=tasseling-silking interval under zero weeding; E/PLT1=number of ears per plot under zero weeding; YLD1=Yield under zero weeding; NL2=Number of leaves under clean weeding; SK2=days to 50% silking under clean weeding; TSI2=tasseling-silking interval under clean weeding; E/PLT2=number of ears per plot under clean weeding; YLD2=Yield under clean weeding.

Table 7: Pearson correlation analysis under clean weeding and zero weeding conditions of maize evaluated in 3 environments in the cropping seasons of 2018 at the Teaching and Research Farm of Obafemi Awolowo University, Ile-Ife.

Variety Name	***Maturity group***	***NL***	***SK***	***TSI***	***E/PLT***	***YLD***	***RSI***
(2 X TZE COMP. 3 DT/WHITE DT STR SYN) C2	I/L	12	23	41	1	5	82
TZEE-W POP STR C5	EE	1	20	56	15	13	105
ACR.06 TZL COMP. 3 C4	I/L	4	78	10	12	2	106
TZEE-W POP STR 108 BC2	EE	25	44	35	4	6	114
EVDT-W 99 STR	E	9	3	86	15	8	121
SAMMAZ 16	I/L	18	56	29	8	10	121
2016 TZEE-W SYN POP STR QPM	EE	12	21	68	2	21	124
EVDT-W 99 STR QPM	E	25	31	47	3	22	128
2008 TZEE-Y STR	EE	6	25	56	15	27	129
EVDT-Y 2000 STR	E	6	9	93	15	7	130
F2SCA1413-36	I/L	86	60	72	79	87	384
2015 DTE STR-Y SYN	E	78	72	41	97	97	385
AFLATOXIN SYN 3 W	I/L	81	64	60	89	92	386
TZE-Y POP DT C4 STR C5	E	98	96	8	94	96	392
TZE-W POP DT C3 STR C5	E	86	57	60	97	97	397

I/L = Intermediate/Late; EE = Extra-early; E = Early; RSI = Rank Summation Index. Best RSI=5, worst=500.

Table 8: Rank summation index of best 10 and worst 5 varieties based on traits with significant correlation coefficients with grain yield.

Discussion

Highly significant environment and genotype effects for emergence percentage, emergence index and emergence rate index imply that the emergence percentage as well as the rate of emergence differed significantly from variety to variety and from one environment to the other. It was also observed that environmental factors had significant influence on the emergence rate index. The varieties that had the highest emergence rate index in the first environment did not appear to be the best in the second environment. Highly significant genotypic effects observed in some of the traits such as early plant height, number of leaves, days to 50% tasseling, silking and anthesis, anthesis-silking interval, tasseling-anthesis interval, and tasseling-silking interval suggest that there could possibly be genes in some of the evaluated maize varieties that would enhance optimum performance under non-parasitic weed stress. There was a highly significant GxE effect for early plant height, number of leaves, days to 50% tasseling, and days to 50% silking implying that the varieties that had the best performance for any of these traits in one environment were not the top varieties for the traits in another environment. It is important to note that large CV values obtained for most traits measured in this experiment could be attributed largely to experimental errors due to difficulties in data collection on the very weedy experimental plots (as the experiment required). The CVs were much larger for traits measured in later stages of the experiment because by then, the weeds were already well grown and it became increasingly difficult to collect data from plot to plot. The most predominant weed across the five environments was guinea grass (*Panicum maximum*) although there were also few species of broad-leaved weeds. Heritability estimate shows the proportion of the phenotypic variation observed in a trait that is due to genetic factors which can be additive or non-additive. A relatively high broad sense heritability estimated for early plant height, number of leaves, days to 50% tasseling, anthesis, silking, and tasseling-silking interval suggests that these traits could be more heritable than the others under weed stress condition. From the findings of Oliver (1988), Knezevic et al. (1994), Swanton et al. (1999) and Jhala et al. (2014), weeds that emerge at the same time, or within a few days of crop emergence cause higher yield losses than weeds emerging later in the growing season. However, heritable early vegetative vigor traits (such as early plant height and number of leaves), as observed in this study, could enhance the weed suppressive ability (WSA) and/or competitiveness of maize varieties with non-parasitic weeds at such a critical growth stage (Begna et al., 2001; Zystro et al., 2012). Number of leaves, days to 50% flowering (tasseling, silking and anthesis), tasseling-anthesis interval, and number of ears per plot had moderately high broad sense heritability and were more heritable than the other measured traits. Performance of number of leaves, days to 50% silking, tasseling-silking interval, number of ears per plot, and yield under weed stress were significantly correlated with their performance under clean weeding; that is, as the value of any of these traits increases under weed stress, the performance would also increase under non-stress conditions. Consequently, these traits could be used as selection criteria for weed tolerance of maize in the rainforest agro-ecology of Nigeria and similar ecologies. Therefore, it could be inferred that maize varieties that are promising under weed stress would most likely be suitable for cultivation under both stress and non-stress conditions.

Ten of the varieties evaluated in this study were identified as promising weed-stress tolerant germplasm out of which seven were extra-early/early maturing and the others intermediate/late maturing varieties. This corroborates the finding of Begna et al. (2001) who evaluated the responses of the morphology and yield of three maize hybrids to weed pressure and found that the grain yields of two of the hybrids, which were early-maturing, were the least affected by weed pressure suggesting better tolerance or competition with weeds. This could possibly be due to the early seedling vigor of extra-early/early maturing varieties which enhances their competitiveness with weeds. One could expect that the extra-early/early maturing maize varieties would possibly show superior yield performance under weed stress. However, results from similar studies across more environments are urgently needed to corroborate or refute these findings.

Conclusion

This study led to the conclusion that maize germplasm available in Nigeria showed genotypic response to non-parasitic weed stress using traits such as number leaves at about 40-44 DAP, days to 50% silking, tasseling-silking interval, and number of ears/plot. Number of leaves, number of ears per plot, days to 50% silking, and tasseling-silking interval had significant relationships with yield under weed stress and could be used to select for non-parasitic weed stress tolerance. The traits also had relatively higher broad sense heritability estimates. Lastly, ten varieties: TZEE-W POP STR C5, (2 X TZE COMP. 3 DT/WHITE DT STR SYN) C2, ACR.06 TZL COMP. 3 C4, TZEE-W POP STR 108 BC2, EVDT-W 99 STR, SAMMAZ 16, 2016 TZEE-W SYN POP STR QPM, EVDT-W 99 STR QPM, 2008 TZEE-Y STR and EVDT-Y 2000 STR were identified as promising genotypes that can be further improved for non-parasitic weed stress tolerance.

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