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Agronomic performance of maize hybrids under acid and control soil conditions

Liliane N. Tandzi[1,2*], Eddy M. Ngonkeu[2,3], Emmanuel Youmbi[3], Eric Nartey[1], Martin Yeboah[4], Vernon Gracen[5], Jacob Ngeve[2], Hortense A. Mafouasson[1,2]

[1] *Univeristy of Ghana, Department of Agriculture, College of Basic and Applied Sciences, Legon*

[2] *Institute of Agricultural Research for Development, Cameroon*

[3] *Plant Biology department at the University of Yaounde I, Cameroon*

[4] *AVRDC project IITA, Yaounde, Cameroon*

[5] *Cornell University, USA*

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Abstract

Maize (*Zea mays* L.) is a major staple crop in Central Africa and has the potential to mitigate the food insecurity in the sub region. However, maize grain yield is severely constrained by soil acidity. One hundred and twenty one (121) hybrids was evaluated at 12 environments in Bimodal Humid Forest Zone of Cameroon from 2012 to 2014 to estimate the correlation between yield and other yield related traits, heritability, standard heterosis (SH), develop selection indices andidentify high-yielding hybrids. The overall mean yield was 3.3 t/ha in acid soil conditions and 5.3 t/ha in control environments. The mean yield reduction (YR) was 38%. Plant height, ear height, and ears per plant were highly and positively correlated with yield while anthesissilking interval, ear aspect and plant aspect were highly and negatively correlated with yield. Stress tolerance index was highly significantly correlated with yield under acid soil conditions while YR and stress susceptibility index were highly and negatively correlated. The heritability was low for all the traits under stressed environments. The SH of the hybrids ranged from -2% to 53% under acid soil and from -4% to 21% under improved soil with a pH of 5. Fifteen hybrids out yielded the best hybrid check by 10%. These high-yielding hybrids could be released after further testing on-farm.

* **Corresponding Author:** Liliane N. Tandzi ✉ tnliliane@yahoo.fr

Introduction

Maize is the cereal in the humid forest zone (HFZ) of Cameroon. The zone occupies about 16.5 million hectares of humid forest eco-zone (Roboglio*et al*., 2010). The average maize yield is very low and ranges from 0.8 to 1 t/ha (ACDIC, 2010). The acid soils have high Aluminium (Al) content which leads to grain yield losses up to 60%(The *et al*., 2005). Higher yields of maize in the humid forest zone will require the reduction of soil acidity (The *et al*., 2006; Pandey *et al*., 2007) or the development of tolerant hybrids.

Soil amendments have been used to reduce soil acidity. Lime reduces exchangeable Al, making plant nutrients, particularly phosphorus, available (Ngonkeu, 2009) and increases the level of exchangeable cations such as Ca^{2+} and Mg^{2+}(Horst *et al*., 2000). However, the application of lime and mineral fertilizers lead to an increase in cost of maize production (Rojas *et al*., 2001). In addition to the cost of lime, its application may be environmentally threatening and it has only a temporary beneficial effect (The *et al*., 2001). Wood ash at 4 t/ha has also been used and this has significantly increased the yield in acid soils (Mbah*et al*., 2010). This method is however not always sustainable because of the non-availability of ash. Therefore, the use of acid soil-tolerant maize cultivars provides a less expensive and permanent solution, contributing to sustainable crop production on acid soils (Granados *et al*., 1993; Welcker*et al*., 2005).

Several conventional breeding methods have been used to develop acid tolerant germplasm of maize. Several yield-based stress indices have been used to identify stress tolerant genotypes. The stress indices provide a measure of stress based on yield loss under stress conditions in comparison to normal conditions and have been widely used (Talebi*et al*., 2009; Moradi*et al*., 2012; Dewi-Hayati*et al*., 2014). Stress tolerance indices (STI) have been used for comparing genotypic performance across years or environments and identifying genotypes that perform well under both stress and non-stress conditions (Fernandez, 1992).

The most acid-tolerant open-pollinated (OP) variety (ATP-SR-Y) so far released suffers yield reduction due to soil acidity within the ranges of 57 to 60% (Tandzi, 2005; The *et al*., 2006). Maize hybrids are higher yielding and more stress tolerant than populations or OP varieties. The development of high-yielding maize hybrids adapted to soil acidity will improve the sustainability of maize production in the acid prone areas.

The objectives of this study were to:

Identify high-yielding hybrids in acid soil and in control conditions.

Evaluate yield loss, stress susceptibility and stress tolerance indices of the hybrids.

Estimate standard heterosis of hybrids under acid stress and corrected acid stress environments.

Estimate the correlations between agronomic traits, stress susceptibility and tolerance indices in acid soil and control conditions.

Materials and methods

Germplasm

Single crosses

Twenty-five inbred lines from the Institute of Agricultural Research for Development (IRAD), CIMMYT and IITA) were crossed with 4 testers that are parents of superior hybrids (Cam Inb gp1 17, 88069, 9450 and 4001) and 100 single cross hybrids were obtained. Crosses among the four testers were also made and used as hybrid checks. A total of 106 single cross hybrids were evaluated.

Top crosses

Three open-pollinated varieties, two commercial OPVs (ATP SR Y and CMS 8704) and one introduced OPV (C4RR SA4) were also crossed with the four testers and 12 top cross hybrids were obtained.

A total of 118 single cross and top cross hybrids plus the three OPVs used as checks (121 hybrids) were evaluated together under acid soil and control conditions. The list of the parental material used is shown in Table 1. The crosses were done at the breeding field of IRAD Yaounde / Nkolbisson at the beginning of each agricultural campaign from 2011 to 2014.

Experimental sites

Trials were carried out on two sites at the research fields of IRAD, Nkoemvone in Ebolowa, the Southern Region of Cameroon, from 2012 to 2014. Nkoemvone is found on altitude 615 m above the sea level and situated on 12° 24 E, 2° 40 N (The *et al*., 2006). The average temperature is 24° C and the annual rainfall is 1800 mm with bimodal distribution (The *et al*., 2001). The soil is a highly weathered Kandiudox with high Al toxicity (FAO, 1992; The *et al*., 2005) and is highly weathered(Yemefack*et al*., 2005).

Experimental Design

The 121 hybrids were evaluated in a simple lattice design (11 x 11) with two replications in three years. Each site – treatment – year combination was considered as a test environment. The soil treatments were native acid soil and control where 4 t/ha of dolomite was applied. This produced two treatments on each site over three years giving 12 environments (Table 2).

Soil sampling and analysis

Soil was sampled from the field at the beginning of each experimental year for characterization to ascertain the inherent fertility of the soil. This would serve as baseline information to measure the changes in soil characteristics due to the application of treatments. Due to the relative homogeneity of the soils at the experimental site, four composite soil samples were collected from the plough layer (0 - 20 cm) for characterization at IITA soil laboratory following standard procedures.

Land preparation, planting and field management

The experimental sites were cleared from grasses manually and plowed. Each experimental site had two treatments with 2 m alley in between. One treatment was a native acid soil considered as the stress environment and the other was a control where the acidity was corrected with the incorporation of 4t/ha of dolomite lime. The dolomite was incorporated into the soil by plowing.

Each genotype was planted in a 4m long row, with two replications. The distance between the rows was 0.75 m and within row was 0.5 m. Three seeds per hill were hand-sown and later thinned to two plants per hole, which corresponds to an expected plant density of approximately 53,333 plants/ha. Weeds were controlled manually and sometime by the application of herbicides. The field trials received the recommended rate of fertilizer in split application, which was a basal dose of 37 N, 24 P_2O_5 and 14 K_2O kg/ha applied 10 days after sowing and a top dressing with 46 kg N per hectare, applied 30 days after planting (The *et al*., 2005).

Data collection

Data was collected on number of days to anthesis, number of days to silking and anthesis to silking interval (ASI).

Plant height (cm), ear height (cm), moisture content and grain yield were measured on a whole plot basis following standard CIMMYT procedure.Yield was adjusted to 15% moisture using the formula .

GY (t/ha) = [Grain Weight (kg/plot) x 10 x (100-MC) / (100-15) / (Plot Area)]

Where MC = Grain Moisture Content (CIMMYT, 1985).

The plant stand at harvest and the number of ears at harvest were also recorded. At harvest, all ears from each plot were counted and the number of ears per plant (EPP) was calculated using the formula: EPP = EC/PC, Where EC and PC = number of ears and number of plants per row, respectively.

Statistical analysis

The analysis of variance (ANOVA) was performed separately for acid soil and control environments using the PROC GLM in SAS version 9.2. The blocks were nested within replication by environments and replications within environments were treated as random factors and the genotypes as fixed. The statistical model used for the combined analysis is as follows:

$Yijkg = \mu + Ei + Bk(ij) + Gg + EGig + \varepsilon ijkg$..

Where Yijkg is the observed measurement for the gth genotype grown in the environment i, in the block k in replicate j; μ is the; grand mean; Ei is the main effect of environment; Bk (ij) is the effect of block nested within replicate j by environment i; Gg is the effect of the genotype; EGig is the interaction effect between genotype and environment, and εijkg is the error term (Akinwale*et al.*, 2014).

Broad-sense heritability (H^2) was estimated as

$H^2 = \sigma^2_g / (\sigma^2_g + (\sigma^2_{ge} / e) + (\sigma^2_e / re))$

σ^2_g is variance for genotype, σ^2_e is error variance, σ^2_{ge} is variance for genotype x environment interaction, *r* is number of replications, and *e* is number of environments (Fehr, 1991).

Standard heterosis

Standard heterosis, defined as comparison of hybrids to the best performing check, was estimated according to the formula of Singh and Singh, (1994):

Standard heterosis (SH) = (F1 – check) / check x 100.

Stress Susceptibility Index (SSI)

$$SSI = \frac{1 - (Ys)/(Yp)}{SI}$$

Where: SI = Stress Intensity = $1 - \bar{Y}s / \bar{Y}p$,

With $\bar{Y}s$ = mean yield in stress environment,

$\bar{Y}p$ = mean yield in non-stressed environment (Fischer and Maurer, 1978).

Stress tolerance index (STI)

STI = (Ys x Yp) / $(\bar{Y}p)^2$

Where Ys = yield under stress environment;

Yp = yield under control environment;

$(\bar{Y}p)^2$ = mean yield under control environment (Fernandez, 1992).

Yield loss percentage

YLP = (Yp-Ys)/Yp x 100

Where:

Yp = yield of hybrid under non-stressed environment;

Ys = yield of hybrid under stress environments.

Results

Soil characteristics of experimental environments

The acid soil environments were strongly acid with pH in water of 4.3 and a very high Al saturation percentage of 73.2% (Table 3). The ECEC of the soil was also very low with a value of 3.27 cmol/kg. The soil has a low C/N ratio of 10.5. Upon addition of dolomite, the pH increased by almost 0.7 pH units to 5 with an accompanying 54% decrease in Al saturation (33.8%). Liming increased the ECEC to a value of 13.1 cmol/kg.

Table 1. List of inbred lines and OPVs used and their origin.

Genotype name	Origin	Type
ATP S5 31Y-2	IRAD	Line
ATP S6 20Y-1	IRAD	Line
ATP S6 21Y-2	IRAD	Line
ATP S6 31Y-BB	IRAD	Line
ATP S8 26Y-2	IRAD	Line
ATP S8 30Y-3	IRAD	Line
ATP S9 30Y-1	IRAD	Line
ATP S9 36Y-BB	IRAD	Line
ATP-32	IRAD	Line
ATP-50	IRAD	Line
Cml 304	CIMMYT	Line
Cml 357	CIMMYT	Line
Cml 435	CIMMYT	Line
Cml 437	CIMMYT	Line
Cml 439	CIMMYT	Line
Cml 533	CIMMYT	Line
Cml 534	CIMMYT	Line

Cml 535	CIMMYT	Line
Cml 332	CIMMYT	Line
Cml 479	CIMMYT	Line
Cla 183	CIMMYT	Line
Cml 434	CIMMYT	Line
Cla 135	CIMMYT	Line
D300-17	CIMMYT	Line
Cam Inb gp1 17 (F)	IRAD	Line
Testers		
Cam Inb gp1 17	IRAD	Tester
88069	IRAD	Tester
9450	IITA	Tester
4001	IITA	Tester
Checks		
C4RR SA4	CIMMYT	Introduced OPV
CMS 8704	IRAD	Commercial OPV
ATP SR Y	IRAD	Commercial OPV

OPV = open-pollinated variety.

Table 2. Acid soil and control environments.

Environment	Component	
Environment 1	Site 1 * treatment 1 (acid) * year 1 (2012)	Acid soil environments (A)
Environment 2	Site 1 * treatment 1 (acid) * year 2 (2013)	
Environment 3	Site 1 * treatment 1 (acid) * year 3 (2014)	
Environment 4	Site 2 * treatment 1 (acid) * year 1 (2012)	
Environment 5	Site 2 * treatment 1 (acid) * year 2 (2013)	
Environment 6	Site 2 * treatment 1 (acid) * year 3 (2014)	
Environment 7	Site 1 * treatment 2 (control) * year 1 (2012)	Control environments (C)
Environment 8	Site 1 * treatment 2 (control) * year 2 (2013)	
Environment 9	Site 1 * treatment 2 (control) * year 3 (2014)	
Environment 10	Site 2 * treatment 2 (control) * year 1 (2012)	
Environment 11	Site 2 * treatment 2 (control) * year 2 (2013)	
Environment 12	Site 2 * treatment 2 (control) * year 3 (2014)	

Mean square analysis of agronomic traits

The differences among crosses in acid soil environments were highly significant (P<0.001) for yield, plant height, ear height, ear and plant aspect while anthesis-silking interval was significant at P<0.01. Ears per plant were not significant (Table 4). The genotype by environment interaction was significant at P<0.05 for yield and ear aspect. Broad sense heritability varied from 8% for yield to 40% for ear height (Table 4). Anthesis-silking interval had the second lowest heritability of 9% under acid soil environments.In control environments (pH of 5), significantly better performances were recorded among hybrids for anthesis-silking interval, ear height, ears per plant, and ear aspect (P<0.001) and yield and plant aspect were significant at P<0.05 and plant height at P<0.01 (Table 5). The genotype by environment interaction was highly significant (P<0.001) for yield, plant height, ear aspect and plant aspect. Broad sense heritability estimate varied from 20% for yield to 58% for ear height (Table 5). Anthesis-silking interval had the second high heritability (56%).

Mean agronomic performance of hybrids in acid soil environments

The overall mean yield was 3.3 t/ha in acid soil environments, with a minimum yield of 1.4 t/ha (ATP S6 31Y-BB x 88069) and maximum of 6.1 t/ha (Cla 183 x 88069) (Table 6). The mean of plant aspect was 3.2, ear aspect was 2.7, ears per plant was 1.05, ear height was 71.5 cm, plant height was 158.5 cm and anthesis-silking interval was 2.6 (Table 6). Twenty four hybrids were selected based on their high yield in acid soil environments (Table 6). The yield of the selected hybrids ranged from 3.91 t/ha (ATP SR Y x Cam Inb gp1 17) to 6.12 (Cla 183 x 9450). The plant aspects ranged from 2.63 (C4RR SA4 x 88069 and

Cla 183 x 9450) to 3.53 (ATP S8 26Y-3 x Cam Inb gp1 17). The ear aspects varied from 1.92 (Cla 183 x 88069) to 2.82 (C4RR SA4 x 88069). One ear per plant was recorded among these genotypes. Moreover, the ear height of these hybrids ranged from 64.48 cm (ATP S8 26Y-3 x Cam Inb gp1 17) to 101.52 cm (Cla 183 x 9450). The plant height varied from 151.33 cm (ATP S8 26Y-3 x Cam Inb gp1 17) to 198.02 cm (Cla 183 x 9450). The anthesis-silking interval varied from 1.66 (Cml 437 x 9450) to 4.31 (C4RR SA4 x 88069). Among these hybrids, four were top crosses, ATP SR Y x Cam Inb gp1 17 (3.91 t/ha), C4RR SA4 x 88069 (4.06 t/ha), CMS 8704 x 88069 (4.23 t/ha), and C4 RR SA4 x Cam Inb gp1 17 (4.26 t/ha). The best hybrid from crosses between testers was 9450 x Cam Inb gp1 17 which yielded 4.00 t/ha under this environment. The best OPV check was CMS 8704 which yielded 3.17 t/ha under acid soil environments.

Table 3. Chemical properties of soil before and after liming.

	Acid soil	Limed soil
pH H2O	4.3	5.0
Exchangeable Acidity (cmol(+).kg^{-1})	2.4	1.8
ECEC (cmol (+).kg^{-1})	3.3	5.4
Al saturation (%)	73.2	33.8
Mg (cmol (+).kg^{-1})	0.2	1.2
K (cmol (+).kg^{-1})	0.2	0.1
N total (%)	0.1	0.2
C/N	10.5	13.1

N = Nitrogen, Ca = Calcium, Mg = Magnesium, K = Potassium, Na = Sodium, Al = Aluminum, ECEC = Effective Cation Exchangeable Capacity, Al saturation (%) = Aluminum saturation percentage.

Table 4. Mean square for various traits recorded on hybrids evaluated under acid soil conditions in 2012-2014.

Source A	DF	yield	Asi	Pltght	Earght	Epp	Earasp	Plasp
Environment	5	145.9***	264***	47194***	9362.9***	0.5***	55.4***	11.2***
Block(rep*enviro)	156	7***	14***	1284.8***	563.4***	0.05*	0.9***	0.6***
Genotype	120	6.1***	5.6**	1239.5***	569.3***	0.05 NS	0.8***	0.6***
Genotype*environment	600	3.2*	3.8 NS	609 NS	302.9 NS	0.04 NS	0.5**	0.3 NS
Error	570	2.7	4.5	544.5	279	0.04	0.4	0.3
H^2 (%)		8	9	27	40	14	28	17

***P<0.001; **P<0.01; *P<0.05; yield =grain yield; pltasp= plant aspect; earasp=ear aspect; epp= ear per plant; earght = ear height; pltght = plant height; asi =anthesis-silking interval; plstd = plant stand; DF=degrees of freedom; Rep=replication; H^2 (%) = Broad sense heritability in percentage, enviro = environment.

Table 5. Mean squares for various traits recorded on of hybrids grown in the control conditions.

Source	DF	yield	Asi	Pltght	Earght	Epp	Earasp	Plasp
Environment	5	107.5***	389***	18322***	12099***	1.2***	4.3***	15.3***
Block(rep*enviro)	156	6.9***	6.2***	922***	506.8***	0.07***	0.7***	0.5***
Genotype	120	6.1*	4.3***	891**	580.9***	0.07***	0.7***	0.4*
Genotype*environment	600	6.02***	2.7 NS	625.5***	326.5 NS	0.05 NS	0.4***	0.3***
Error	570	4.6	2.8	622.1	292.8	0.05	0.3	0.2
H^2 (%)		20	56	41	58	33	51	34

***P<0.001; **P<0.01; *P<0.05; yield =grain yield; pltasp= plant aspect; earasp=ear aspect; epp= ear per plant; earght = ear height; pltght = plant height; asi =anthesis-silking interval; plstd = plant stand; DF=degrees of freedom; H^2 = broad sense heritability.

Mean agronomic performance of hybrids in control environments

In control environments, the overall mean yield was 5.3 t/ha (Table 7). The minimum yield was 3.50 t/ha (C4 RR SA4 x 9450) and the highest yield was 7.4 t/ha (Table 7). The overall mean was 2.5 for plant aspect, 2.1 for ear aspect, 1.1 for ears per plant, 93.2 for ear height, 194.4 for plant height and 1.9 for anthesis-silking interval.Twenty four hybrids were selected in control environments (Table 7). The yield of selected hybrids ranged from 5.86 t/ha (ATP 32 x 4001) to 7.4 t/ha (CMS 8704 x 9450). The plant aspect ranged from 1.99 (CMS 8704 x 9450) to 2.82 (4001 x 9450) and ear aspect varied from 1.58 (Cml 304 x 9450) to 2.29 (ATP S8 30Y-3 x Cam Inb gp1 17). The ears per plant varied from 0.95 (ATP S9 30Y-1 x 9450) to 1.23 (Cml 535 x Cam Inb gp1 17). Ear height ranged from 82.43 cm (ATP S8 26Y-3 x 8869) to 110.11 cm (Cml 357 x Cam Inb gp1 17) while plant height ranged from 165.53 cm (ATP S8 26Y-3 x 88069) to 213.99 (CMS 8704 x 9450). The anthesis-silking interval varied from 0.64 (ATP SR Y x 4001) to 3.80 (Cml 535 x Cam Inb gp1 17).Among the 24 hybrids selected in control environments, two were top crosses, ATP SR Y x 4001 (7.04 t/ha) and CMS 8704 x 9450 (7.40 t/ha). Another two were hybrids between testers, 4001 x 9450 (6.13 t/ha) which was the best hybrid check across these environments and 4001 x 88069 (6.09 t/ha). The best OPV was CMS 8704, which yielded 5.29 t/ha in this environment.

Table 6. Performance of the 24 highest yielding hybrids in acid soil conditions.

Genotypes	Yield (t/ha)	Pltasp	Earasp	Epp	Earght (cm)	Plthgt (cm)	Asi
Cla 183 x 9450	6.12	2.63	2.02	0.88	101.52	198.02	2.17
ATP S9 36Y-BB x 4001	5.37	3.02	2.77	1.06	76.60	171.20	3.21
Cla 183 x 88069	5.36	2.73	1.92	0.95	79.91	174.65	3.84
Cml 434 x Cam Inb gp1 17	5.11	2.72	2.38	0.99	79.57	176.11	2.97
ATP S5 31Y-2 x 4001	5.07	2.89	2.27	1.15	74.48	159.15	2.88
Cml 437 x Cam Inb gp1 17	4.84	3.11	2.20	0.93	70.68	167.90	3.01
ATP S8 26Y-3 x Cam Inb gp1 17	4.72	3.55	2.67	1.08	64.48	151.33	2.37
Cml 534 x 4001	4.42	3.12	2.37	0.99	78.05	165.09	2.42
Cla 183 x Cam Inb gp1 17	4.42	2.83	2.20	0.98	75.68	177.52	3.11
Cml 439 x 4001	4.39	3.22	2.24	0.93	75.83	155.14	1.69
ATP S5 31Y-2 x 9450	4.34	3.14	2.54	1.04	79.05	169.74	3.07
C4RR SA4 x Cam Inb gp1 17	4.26	3.01	2.75	1.04	75.82	165.57	2.53
ATP S8 30Y-3 x Cam Inb gp1 17	4.25	3.17	2.20	1.01	81.67	168.69	2.91
Cam Inb gp1 17 (F) x 9450	4.23	3.24	2.44	1.12	79.28	163.96	3.54
CMS 8704 x 88069	4.23	3.13	2.47	1.03	73.61	167.22	2.62
Cml 439 x 9450	4.23	3.09	2.52	1.00	66.48	159.15	2.14
ATP S6 31Y-BB x 9450	4.20	3.22	2.44	1.03	83.13	169.42	3.08
ATP S8 30Y-3 x 4001	4.14	3.06	2.41	1.05	73.99	157.52	2.43
Cml 437 x 9450	4.13	3.26	2.57	1.00	73.26	162.82	1.66
C4RR SA4 x 88069	4.06	2.63	2.82	1.26	71.24	159.92	4.31
CLA 135 x 9450	4.05	2.90	2.50	1.02	77.19	169.54	2.42
Cla 183 x 4001	3.97	2.68	2.50	0.96	88.74	171.35	2.62
D300-17 x Cam Inb gp1 17	3.97	2.96	2.56	1.08	73.99	161.13	1.68
ATP SR Y x Cam Inb gp1 17	3.91	3.12	2.75	1.10	75.83	165.67	2.44
Mean	3.3	3.2	2.7	1.05	71.5	158.5	2.6
Minimum	1.4	2.6	1.9	0.9	52	198	-0.9
Maximum	6.1	3.8	3.4	1.3	101.5	135.4	4.6
SED	0.75	0.3	0.1	0.1	8.25	11.5	1.05

Asi = anthesis-silking interval, pltght = plant height, earght = ear height, epp = ear per plant, earasp = ear aspect, pltasp = plant aspect, SED = standard error of difference.

Correlation between yield and other agronomic traits in acid soil and control environments

In acid soil and control soil environments, the correlations between yield and anthesis-silking interval, ear aspect and plant aspect were negative and highly significant ($P<0.001$) while plant height, ear height, and ears per plant were positively and highly significantly correlated with yield (Table 8 and

Table 9).

Grain yield reduction, stress susceptibility index and stress tolerance index of hybrids under acid soil and control environments

The overall mean yield reduction of the hybrids was 38% while stress susceptibility index was 1.0 and stress tolerance index was 17.5 (Table 10). Yield reduction ranged from -10% (Cla 183 x 4001) to 69% (Cml 304 x 4001) (Table 10). The stress susceptibility index ranged from -0.26 (Cla 183 x 4001) to 1.8 (Cml 304 x 4001) and the stress tolerance index varied from 5.9 (ATP S6 31Y-BB x 88069) to 35 (Cla 183 x 9450).The 24 highest yielding hybrids under acid soil expressed yield reduction from -10% (Cla 183 x 4001) to 33% (ATP SR Y x Cam Inb gp1 17) (Table 10). Their stress susceptibility index varied from -0.3 (Cla 183 x 4001) to 1.0 (D300 17 x Cam Inb gp1 17 and Cla 135 x 9450) and the stress tolerance index varied from 18.3 (ATP S8 30Y-3 x 4001) to 36.7 (Cla 183 x 9450). Four hybrids had low yield reduction in both environments. They were Cla 183 x 9450 (-2% of yield reduction), ATP S9 36Y-BB x 4001 (2% yield reduction), Cla 183 x 88069 (7% yield reduction) and ATP S5 31Y-2 x 4001 (0% yield reduction). Their stress susceptibility indices were lower compared to the rest and the stress tolerance indices were acceptable. control condition,yield reduction of the best 24 hybrids ranged from 20% (Cml 434 x Cam Inb gp1 17) to 55% (Cml 332 x Cam Inb gp1 17) while stress susceptibility index varied from 0.5 (Cml 434 x Cam Inb gp1 17) to 1.8 (4001 x 88069) and stress tolerance index varied from 11.9 (4001 x 88069) to 32.4 (Cml 434 x Cam Inb gp1 17) (Table 11). Four hybrids had good yields in both environments and did showed less yield reduction from acid siol to control. They were ATP S6 31Y-BB x 9450 (39% of yield reduction), Cml 434 x Cam Inb gp1 17 (20% of yield reduction), ATP S5 31Y-2 x 9450 (31% of yield reduction) and Cml 439 x 4001 (28% of yield reduction). These hybrids had SSI between 0.5 to 1 and STI ranged from 19.5 to 32.4.

Table 7. Performance of the 24 highest yielding hybrids in control environments.

Genotype	yield (t/ha)	Pltasp	Earasp	Epp	Earght	Plthgt	Asi
CMS 8704 x 9450	7.40	1.99	1.95	1.07	103.96	213.99	1.20
Cml 439 x Cam Inb gp1 17	7.24	2.01	1.60	1.06	89.01	203.31	2.15
ATP SR Y x 4001	7.04	2.35	1.59	1.16	83.07	190.15	0.64
Cml 535 x Cam Inb gp1 17	6.91	2.30	2.16	1.23	88.25	196.53	3.80
ATP S6 31Y-BB x 9450	6.89	2.43	1.94	1.14	105.30	200.18	2.08
Cml 332 x Cam Inb gp1 17	6.60	2.61	2.23	1.16	94.30	203.01	2.60
D300-17 x Cam Inb gp1 17	6.53	2.36	2.02	1.08	105.41	205.09	1.69
Cml 434 x Cam Inb gp1 17	6.35	2.43	1.88	0.97	87.01	192.58	3.35
Cla 135 x 9450	6.31	2.36	2.03	1.09	99.89	206.49	1.05
Cla 135 x 88069	6.29	2.54	1.94	1.03	93.44	196.07	1.32
ATP S5 31Y-2 x 9450	6.29	2.17	1.89	1.32	99.53	211.82	1.30
ATP S8 30Y-3 x Cam Inb gp1 17	6.26	2.53	2.29	1.22	90.51	185.82	1.80
Cml 304 x 9450	6.20	2.33	1.58	1.15	109.35	211.49	1.35
Cml 437 x 88069	6.17	2.36	1.75	1.17	97.96	199.26	2.83
ATP S6 20Y-1 x 9450	6.13	2.54	2.07	1.07	88.92	191.52	2.06
4001 x 9450	6.13	2.82	2.26	1.04	95.48	198.70	2.30
ATP-50 x 9450	6.12	2.45	2.18	1.28	100.90	209.78	1.70
Cml 357 x Cam Inb gp1 17	6.11	2.11	1.67	1.10	110.11	203.89	2.42
4001 x 88069	6.09	2.67	2.10	1.27	95.18	203.05	1.67
Cml 439 x 4001	6.06	2.64	1.83	1.06	89.03	187.49	1.06
ATP S9 30Y-1 x 9450	6.06	2.35	1.97	0.95	87.06	199.72	1.78
ATP S8 26Y-3 x 88069	5.94	2.74	2.25	1.09	82.43	165.53	1.03
Cml 357 x 4001	5.88	2.30	1.76	1.05	93.46	199.38	2.26
ATP-32 x 4001	5.86	2.26	1.99	1.17	87.65	187.47	3.01
Mean	5.3	2.5	2.1	1.1	93.2	194.4	1.9
Minimum	3.50	1.77	1.58	0.95	122.86	222.19	3.80
Maximum	7.40	2.98	3.29	1.36	76.65	165.53	-1.37
SED	1.05	0.3	0.3	0.15	8.4	10.65	0.75

Asi = anthesis-silking interval, pltght = plant height, earght = ear height, epp = ear per plant, earasp = ear aspect, pltasp = plant aspect, SED = standard error of difference.

Table 8. Pearson correlation coefficients among agronomic traits in acid soil environments.

	Asi	Plthght	Earhgt	Epp	Earasp	Pltasp	Yield
asi							
plthght	-0.19***						
earhgt	-0.24***	0.80***					
epp	-0.06*	0.05*	0.05NS				
earasp	-0.19***	-0.17***	-0.12***	-0.03 NS			
pltasp	0.34***	-0.5***	-0.47***	-0.04NS	0.22***		
Yield	-0.13***	0.36***	0.28***	0.09***	-0.47***	-0.4***	

Asi = anthesis-silking interval, pltght = plant height, earght = ear height, epp = ear per plant, earasp = ear aspect, pltasp = plant aspect.

Pearson correlation coefficients of different indices with yield in acid soil and control environments

In acid soil conditions, yield loss and stress susceptibility indices were highly significantly (P<0.001) and negatively correlated with yield (Table 12). Also, stress tolerance index was highly significantly and positively correlated with yield. In control conditions, only stress tolerance index was significantly and positively correlated with yield.

Standard heterosis of the best 24 hybrids in acid soil conditions

The standard heterosis over the best OPV check (CMS 8704, 3.17 t/ha in acid soil environments) and over the best hybrid check (9450 x Cam Inb gp1 17, 4 t/ha in acid soil environments) was estimated for the 24 highest yielding hybrids selected in acid soil environments (Table 13). The standard heterosis ranged from 23% (ATP SR Y x Cam Inb gp1 17) to 93% (Cla 183 x 9450). All the best 24 hybrids out-yielded the best OPV check by more than 20%. Moreover, the standard heterosiscompared to the best hybrid check ranged from -2% (ATP SR Y x Cam Inb gp1 17) to 53% (Cla 183 x 9450). Ten hybrids out-yielded the best hybrid check by at least 10%. They were Cla 183 x 9450 (53%), ATP S9 36Y-BB x 4001 (34%), Cla 183 x 88069 (34%), Cml 434 x Cam Inb gp1 17 (28%), ATP S5 31Y-2 x 4001 (27%), Cml 437 x Cam Inb gp1 17 (21%), ATP S8 26Y-3 x Cam Inb gp1 17 (18%), Cml 534 x 4001 (11%), Cla 183 x Cam Inb gp1 17 (11%), Cml 439 x 4001 (10%). These 10 hybrids had 10% or better performance over all OPV and hybrids checks and represent promising new hybrids for acid soils.

Standard heterosis of the best 24 hybrids in control soil environments

The standard heterosis over the best OPV check (CMS 8704 yielded 5.3 t/ha in control condition) ranged from 11% (Cml 357 x 4001) to 40% (CMS 8704 x 9450) (Table 14). All the top 24 hybrids out-yielded the best OPV check. The standard heterosis over the best hybrid check under improved pH of 5 (4001 x 8869 yielded 6.1 t/ha) ranged from -4% (Cml 357 x 4001) to 21% (CMS 8704 x 9450). Five hybrids out-yielded the best hybrid check by more than 10%. They were ATP S6 31Y-BB x 9450 (13%), Cml 535 x Cam Inb gp1 17 (13%), ATP SR Y x 4001 (15%), Cml 439 x Cam Inb gp1 17 (19%), and CMS 8704 x 9450 (21%). These 5 hybrids were superior to the best hybrids and OPVs available under control conditions. One hybrid ATP S6 31Y-BB x 9450 was better than all checks over both environments.

Table 9. Pearson Correlation Coefficients among agronomic traits in control environments.

	Asi	Plthght	Earhgt	Epp	Earasp	Pltasp	Yield
asi							
plthght	-0.19***						
earhgt	-0.25***	0.80***					
epp	-0.06*	0.05*	0.05 NS				
earasp	-0.19***	-0.17***	-0.12***	-0.03 NS			

pltasp	0.34***	-0.54***	-0.47***	-0.04NS	0.21924	
Yield	-0.13***	0.36***	0.28***	0.09***	-0.47***	-0.40***

Asi = anthesis-silking interval, pltght = plant height, earght = ear height, epp = ear per plant, earasp = ear aspect, pltasp = plant aspect.

Table 10. Yield reduction percentage, stress susceptibility index and stress tolerance index of the 24 highest yielding hybrids selected in acid soil environments.

Genotype	Yield Control	Yield Acid soil	Yield reduction (%)	SSI	STI
Cla 183 x 9450	6.0	6.1	-2	-0.1	36.7
ATP S9 36Y-BB x 4001	5.5	5.4	2	0.1	29.4
Cla 183 x 88069	5.8	5.4	7	0.2	30.9
Cml 434 x Cam Inb gp1 17	6.4	5.1	20	0.5	32.5
ATP S5 31Y-2 x 4001	5.1	5.1	0	0.0	25.8
Cml 437 x Cam Inb gp1 17	5.8	4.8	17	0.5	28.2
ATP S8 26Y-3 x Cam Inb gp1 17	5.3	4.7	11	0.3	25.0
Cml 534 x 4001	4.9	4.4	9	0.2	21.5
Cla 183 x Cam Inb gp1 17	5.5	4.4	20	0.5	24.3
Cml 439 x 4001	6.1	4.4	28	0.7	26.6
ATP S5 31Y-2 x 9450	6.3	4.3	31	0.8	27.3
C4RR SA4 x Cam Inb gp1 17	5.8	4.3	26	0.7	24.7
ATP S8 30Y-3 x Cam Inb gp1 17	6.3	4.3	32	0.9	26.6
Cam Inb gp1 17 (F) x 9450	4.3	4.2	2	0.1	18.4
CMS 8704 x 88069	5.6	4.2	25	0.7	23.9
Cml 439 x 9450	4.7	4.2	9	0.2	19.7
ATP S6 31Y-BB x 9450	6.9	4.2	39	1.0	28.9
ATP S8 30Y-3 x 4001	4.4	4.1	6	0.2	18.3
Cml 437 x 9450	5.4	4.1	23	0.6	22.2
C4RR SA4 x 88069	5.0	4.1	18	0.5	20.1
CLA 135 x 9450	6.3	4.1	36	1.0	25.5
Cla 183 x 4001	3.6	4.0	-10	-0.3	14.4
D300-17 x Cam Inb gp1 17	6.5	4.0	39	1.0	25.9
ATP SR Y x Cam Inb gp1 17	5.8	3.9	33	0.9	22.7
Overall mean	5.3	3.3	38	-0.7	17.5
Minimum	3.5	3.3	-10	-0.3	5.9
Maximum	7.4	6.1	69	1.8	35.0

SSI = stress susceptibility index, STI = stress tolerance index.

Discussion

The significant differences recorded between genotypes and between genotype by environments interactions suggest that all the genotypes were different from each other and responded differently in various environments. Therefore, significant progress could be made by selecting these genotypes in acid soil and control environments. Similar findings were reported by The *et al.*, 2006 and Ifie, 2013.

Table 11. Yield reduction percentage, stress susceptibility index and stress tolerance index of the 24 highest yielding hybrids selected in control soil environments.

Genotype	Yield Control	Yield Acid soil	Yield reduction (%)	SSI	STI
CMS 8704 x 9450	7.4	3.9	47	1.3	28.8
Cml 439 x Cam Inb gp1 17	7.2	3.8	47	1.3	27.6
ATP SR Y x 4001	7.0	3.7	48	1.3	25.8
Cml 535 x Cam Inb gp1 17	6.9	3.5	49	1.3	24.3
ATP S6 31Y-BB x 9450	6.9	4.2	39	1.0	28.9
Cml 332 x Cam Inb gp1 17	6.6	3.0	55	1.4	19.8
D300-17 x Cam Inb gp1 17	6.5	4.0	39	1.0	25.9

Cml 434 x Cam Inb gp1 17	6.4	5.1	20	0.5	32.4
Cla 135 x 9450	6.3	4.1	36	0.9	25.6
Cla 135 x 88069	6.3	3.5	44	1.2	22.2
ATP S5 31Y-2 x 9450	6.3	4.3	31	0.8	27.3
ATP S8 30Y-3 x Cam Inb gp1 17	6.3	4.3	32	0.9	26.6
Cml 304 x 9450	6.2	3.7	41	1.1	22.7
Cml 437 x 88069	6.2	3.4	45	1.2	21.1
ATP S6 20Y-1 x 9450	6.1	3.2	47	1.3	19.8
4001 x 9450	6.1	3.1	49	1.3	19.1
ATP-50 x 9450	6.1	2.8	54	1.4	17.3
Cml 357 x Cam Inb gp1 17	6.1	2.8	54	1.4	17.1
4001 x 88069	6.1	2.0	68	1.8	11.9
Cml 439 x 4001	6.1	4.4	28	0.7	26.6
ATP S9 30Y-1 x 9450	6.1	3.6	40	1.1	21.9
ATP S8 26Y-3 x 88069	5.9	2.9	51	1.3	17.4
Cml 357 x 4001	5.9	3.7	38	1.0	21.6
ATP-32 x 4001	5.9	2.6	56	1.5	15.2
Overall mean	5.3	3.3	38	-0.7	17.5
Minimum	3.5	3.3	-10	-0.3	5.9
Maximum	7.4	6.1	69	1.8	35.0

SSI = stress susceptibility index, STI = stress tolerance index.

Table 12. Correlation coefficients with yield and some indices.

	Yield C	Yield A	Yield loss	SSI	STI
Yield A	0.27 NS				
Yield loss	0.12 NS	-0.92***			
SSI	0.16 NS	-0.90***	0.99***		
STI	0.58**	0.94***	-0.73***	-0.70***	

** = P<0.01, *** = P<0.001, Yield C = yield under control or control environments, Yield A = yield under acid soil environments.

In control environments, the heritability of yield (20%) was 2.5 times greater than the heritability under acid soil conditions (8%). All the traits in acid soil environments had low broad sense heritability estimates compared to control soil conditions. Under stress environments, the heritability was reduced. According to Navas*et al.*(2008), the average heritability of grain yield was 2.2 times greater for the normal fertile soil environments compared with the acid soil environments and the differences in heritability estimates were similar for all the traits. According to Badu-Apraku*et al.*(2013), grain yield is a complex trait controlled by polygenes and has low heritability, especially under stress environments.

Table 13. Standard heterosis of the 24 highest yielding hybrids in acid soil environments.

			Standard heterosis (%)	
			CMS 8704	9450 x Cam Inb gp1 17
Hybrids	yield C	yield A	Acid soil	Acid soil
Cla 183 x 9450	6	6.12	93	53
ATP S9 36Y-BB x 4001	5.48	5.37	70	34
Cla 183 x 88069	5.77	5.36	69	34

Cml 434 x Cam Inb gp1 17	6.35	5.11	61	28
ATP S5 31Y-2 x 4001	5.09	5.07	60	27
Cml 437 x Cam Inb gp1 17	5.83	4.84	53	21
ATP S8 26Y-3 x Cam Inb gp1 17	5.29	4.72	49	18
Cml 534 x 4001	4.86	4.42	39	11
Cla 183 x Cam Inb gp1 17	5.51	4.42	39	11
Cml 439 x 4001	6.06	4.39	39	10
ATP S5 31Y-2 x 9450	6.29	4.34	37	9
C4RR SA4 x Cam Inb gp1 17	5.79	4.26	34	6
ATP S8 30Y-3 x Cam Inb gp1 17	6.26	4.25	34	6
Cam Inb gp1 17 (F) x 9450	4.33	4.23	34	6
CMS 8704 x 88069	5.64	4.23	34	6
Cml 439 x 9450	4.66	4.23	34	6
ATP S6 31Y-BB x 9450	6.89	4.2	32	5
ATP S8 30Y-3 x 4001	4.42	4.14	31	3
Cml 437 x 9450	5.38	4.13	30	3
C4RR SA4 x 88069	4.95	4.06	28	1
CLA 135 x 9450	6.31	4.05	28	1
Cla 183 x 4001	3.62	3.97	25	-1
D300-17 x Cam Inb gp1 17	6.53	3.97	25	-1
ATP SR Y x Cam Inb gp1 17	5.81	3.91	23	-2
Mean	5.3	3.3	4	-18
Checks				
CMS 8704	5.29	3.17	0	-21
Best single hybrid check				
9450 x Cam Inb gp1 17	4.70	4.00	26	0

Yield C = yield under control environments, Yield A = grain yield under acid soil environments.

The overall mean yield of the hybrids on limed soils was 5.3 t/ha and was consistently higher than the overall mean yield of hybrids (3.3 t/ha) on acidic soils. This suggests that Al toxicity significantly reduced grain yield of maize genotypes. Similar results were obtained by Tandzi (2005); The *et al.* (2005); The *et al.* (2006); Navas*et al.* (2008); and Dewi-Hayati*et al.* (2014). A higher yield under limed soils is an indication that liming is effective in improving yield of maize under Al toxicity. However, liming of soil is laborious and expensive. Therefore a more sustainable and cost effective strategy would be the utilization of Al tolerant genotypes. In this study, 24 hybrids selected under acid soil environments and the 24 selected under control conditions out-yielded the best OPV check (CMS 8704 5.29 t/ha under control conditions and 3.17 t/ha under acid soil environments) in each environment.They yielded more 3.5 t/ha under acid soils and 5.8 t/ha under control conditions, compared to the average yield of 1 t/ha reported in Cameroon (ACDIC, 2010).

The best yielding hybrid under acid soil environments was Cla 183 x 9450 (6.12 t/ha). The parents of this hybrid are from CIMMYT and IITA showing the importance of the introduced inbred lines. In control conditions, the highest yielding hybrid was a top cross hybrid, CMS 8704 x 9450 (7.40 t/ha). This hybrid was a cross between a commercial OPV (CMS 8704) and an introduced inbred line from IITA. Crosses between introduced and local varieties could increase the probability of getting high-yielding hybrid combinations. The importance of top crosses is based on the ability to easily produce seeds since one parent is an open-pollinated variety. Interestingly, the top cross hybrid did not rank in the top 24 hybrids under acid soils nor did the hybrid Cla 193 x 9450 rank in the top 24 in control conditions. The best overall hybrid may be ATP S6 31Y-bb x 9450 which made the top 24 under both environments. Yields, plant and ear aspect and anthesis-silking-interval were better under control than in the acid soil environments. Grain yield was positively correlated with plant height, ear height and ears per plant and was negatively correlated with anthesis-silking- interval, plant aspect and ear aspect. The relationship of all these traits with yield was highly significant. Plant height, ear height, ears per plant, anthesis-silking interval, plant aspect and ear aspect could be used to make indirect selections for high yield in stress and non-stress environments. Similar studies have shown that short anthesis-to-silking interval in maize hybrids subsequently led to better pollination (Bolanos and Edmeades, 1996; Arauset *al.*, 2012).

Table 14. Standard heterosis of the 24 highest yielding hybrids in control soil environment.

			Standard heterosis (%)	
			CMS 8704	4001 x 88069
Genotype	yield C	yield A	Control	Control
CMS 8704 x 9450	7.4	3.89	40	21
Cml 439 x Cam Inb gp1 17	7.24	3.81	37	19
ATP SR Y x 4001	7.04	3.67	33	15
Cml 535 x Cam Inb gp1 17	6.91	3.51	31	13
ATP S6 31Y-BB x 9450	6.89	4.2	30	13
Cml 332 x Cam Inb gp1 17	6.6	3	25	8
D300-17 x Cam Inb gp1 17	6.53	3.97	23	7
Cml 434 x Cam Inb gp1 17	6.35	5.11	20	4
CLA 135 x 9450	6.31	4.05	19	3
CLA 135 x 88069	6.29	3.53	19	3
ATP S5 31Y-2 x 9450	6.29	4.34	19	3
ATP S8 30Y-3 x Cam Inb gp1 17	6.26	4.25	18	3
Cml 304 x 9450	6.2	3.66	17	2
Cml 437 x 88069	6.17	3.42	17	1
ATP S6 20Y-1 x 9450	6.13	3.23	16	0
4001 x 9450	6.13	3.11	16	0
ATP-50 x 9450	6.12	2.82	16	0
Cml 357 x Cam Inb gp1 17	6.11	2.8	16	0
4001 x 88069	6.09	1.96	15	0
Cml 439 x 4001	6.06	4.39	15	-1
ATP S9 30Y-1 x 9450	6.06	3.62	15	-1
ATP S8 26Y-3 x 88069	5.94	2.93	12	-3
Cml 357 x 4001	5.88	3.67	11	-4
Overall mean	5.30	3.30	0	-13
Best OPV check				
CMS 8704	5.29	3.17	0	-13
Best hybrid check				
4001 x 88069	6.10	2.00	15	0

Yield C = grain yield in control environments; Yield A = grain yield in acid soil environments.

The percentage of yield reduction is an indication of acid soil effects. Dewi-Hayati*et al.* (2014) reported grain yield reduction in acid soil varied from 2.8 to 71%. In the current study, yield reduction ranged from -10% to 69%. The yield reduction was highest in hybrid Cml 304 x 4001 while the hybrid least affected was Cla 183 x 4001. The percentage yield reduction observed for Cla 183 x 4001 was negative, an indication that yield of the hybrid was higher under acid soils (4.0 t/ha under acid soil and 3.6 t/ha in control environments). This hybrid is not desirable because although it performs well under poor conditions it does not do well under optimal conditions. The hybrid ATP A9 36 Y-BB x 4001 had the lowest yield reduction (2%) under Al toxicity and had grain yield of 5.4 t/ha in acid soil and 5.5 t/ha in control conditions. Cla 183 x 9450 yielded 6.0 t/ha under control conditions and 6.1 t/ha under acid soil. These hybridsare superior overall.

The stress tolerance index ranged from 5.9 (ATP S6 31Y-BB x 88069) to 35 (Cla 183 x 9450). Cla 183 x 9450 performed well under acid soil conditions and control environments and had high stress tolerance index. Cml 304 x 4001 and ATP S6 31Y-BB x 88069 were the most acid soil sensitive hybrids while Cla 183 x 4001 and Cla 183 x 9450 were the most tolerant. Cla 183 x 4001 was not among the 24 highest yielding hybrids selected either in acid soil or in control environments. This shows that the selection of high-yielding hybrids tolerant to Al toxicity should take into account a relatively low yield reduction, a high stress tolerance index and a good stress susceptibility index.

Five hybrids performed well in control conditions but had high yield reduction percentage due to Al toxicity. These were CMS 8704 x 9450 (yield reduction of 47%), Cml 439 x Cam Inb gp1 17 (47%), ATP SR Y x 4001 (48%), Cml 535 x Cam Inb gp1 17 (49%) and ATP S6 31Y-BB x 9450 (39%). Even though these hybrids were high-yielding, they were not tolerant to Al toxicity. These varieties could be advanced and released for environments where acidity is not a constraint for production. Similar results were obtained by The *et al.* (2005) who found that some hybrids had relatively high grain yield on acid soil but were not necessarily tolerant because of the high yield reduction percentage presented due to soil acidity.Yield was negatively correlated with percentage yield reduction (r = -0.92), and stress susceptibility index (r = -0.90) while it was positively correlated with stress tolerance index (+ 0.94) in acid soil environments. This correlation was highly significant suggesting that relatively low yield reduction, low stress susceptibility index and high stress tolerance index could be used to select high-yielding hybrids in acid soil environments. Dewi-Hayati*et al.* (2014) reported similar negative relationship between yield stress indices in acid soil conditions.

In the present study, standard heterosis was used. This does not compare the yield of hybrids to their inbred parents buy compares hybrids to the best checks. Ten hybrids out-yielded the best hybrid check by at least 10% in acid soil conditions. These hybrids were Cla 183 x 9450 (53%), ATP S9 36Y-BB x 4001 (34%), Cla 183 x 88069 (34%), Cml 434 x Cam Inb gp1 17 (28%), ATP S5 31Y-2 x 4001 (27%), Cml 437 x Cam Inb gp1 17 (21%), ATP S8 26Y-3 x Cam Inb gp1 17 (18%), Cml 534 x 4001 (11%), Cla 183 x Cam Inb gp1 17 (11%), Cml 439 x 4001 (10%). In control environments, five hybrids out-yielded the best hybrid check by more than 10% in control environments. They were ATP S6 31Y-BB x 9450 (13%), Cml 535 x Cam Inb gp1 17 (13%), ATP SR Y x 4001 (15%), Cml 439 x Cam Inb gp1 17 (19%), and CMS 8704 x 9450 (21%).These 15 hybrids could be considered for released after multi-locational and on farm trials. Among the 15 best hybrids, two were top crosses and 14 had at least one introduced parents. This means that the introduction of inbred lines was very efficient in the development of high-yielding hybrids in stress and control environments. Cam Inb gp1 17 and 4001 were parents of 6 and 5 hybrids each in the best 15 hybrids selected. Inbred 9450 was a parent in a total of 9 hybrids in the top 24 under control conditions and 6 of the top 24 under acid soils.Cam Inb gp1 17, 4001 and 9450 could be considered as possible testers in future studies.

Conclusion

Variability exists among the inbred lines and OPVs which should allow for progress in selection for acid tolerant genotypes. Fifteen high-yielding hybrids were identified. They were Cla 183 x 9450 (53%), ATP S9 36Y-BB x 4001 (34%), Cla 183 x 88069 (34%), Cml 434 x Cam Inb gp1 17 (28%), ATP S5 31Y-2 x 4001 (27%), Cml 437 x Cam Inb gp1 17 (21%), ATP S8 26Y-3 x Cam Inb gp1 17 (18%), Cml 534 x 4001 (11%), Cla 183 x Cam Inb gp1 17 (11%), Cml 439 x 4001 (10%) identified in acid soil environments and ATP S6 31Y-BB x 9450 (13%), Cml 535 x Cam Inb gp1 17 (13%), ATP SR Y x 4001 (15%), Cml 439 x Cam Inb gp1 17 (19%), and CMS 8704 x 9450 (21%) in control conditions. These high-yielding hybrids could be released for commercial purpose after multi-locational on-farm trials. Cam Inb gp1 17, 4001 and 9450 were the best inbreds in terms of specific combinability in this study some traits such as plant height, ear height, ears per plant, anthesis-silking interval, plant aspect and ear aspect and indices (yield loss percentage, stress tolerance index and stress susceptibility index) were highly correlated with yield. These traits and indices could be used in the indirect selection of high yield in acid soil environments. All the traits in acid soil environments had low broad sense heritability estimates compared to heritability under control soil conditions. Yield reduction due to acid soil was very high for some genotypes.Significant progress could be made by selecting genotypes under acid soil and control environments and by classifying inbred lines into heterotic groups.

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