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AGRONOMIC PERFORMANCE OF MAIZE HYBRIDS UNDER *Aspergillus flavus* INOCULATION IN CAMEROON

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ABSTRACT

Maize (*Zea mays* L.) is a major staple crop in most of the sub-Sahara Africa (SSA) region, constrained by a multitude of plant diseases, with the ear and kernel rots being the most widespread and difficult to manage on maize. The objective of this study was to access the agronomic performance of F1 maize hybrids exposed to *Aspergillus flavus,* under different agro-ecological conditions, in Cameroon. A total of 120 genotypes of maize, including four commercial hybrids, were evaluated under *A. flavus* infection at two sites; namely Bangangte in the Western Highlands and Mbalmayo, in the Bimodal Humid Forest Zone of Cameroon. The study was conducted during 2020 - 2021 cropping seasons. Results revealed that at Bangangte site, six (89343X88094, 88099X88094, 90204XExp 124, 89246X87036, TZI-5-1171XExp 124 and 90219X1368) out of the top 20 high yielding hybrids, had significantly high (p<0.001 tolerance (0% severity) to *Aspergillus* ear rot infection. At Mbalmayo site, eight (8923X88094, TZI-5-1171XExp124, 89343X88094, 90219X87036, 89243X87036, 87014X88094, TZSTR1150X87036 and 89248X88094) out of the top 20 high yielding hybrids also showed significant high (P<0.001) tolerance (0% severity) to *Aspergillus* ear rot infection. The interaction between hybrids and location was significant (P<0.05) for all measured traits, except ear height, grain texture, ear insect damage and husk cover (P>0.05). The pooled broad sense heritability of hybrids in the two locations varied from 5% for grain texture to 92% for days to 50% physiological maturity. Grain yield was negatively correlated with *Aspergillus* ear rot disease incidence and severity. Hence, promising high yielding maize hybrids with appreciable tolerance to *Aspergillus* ear rot disease could be selected among the tested genotypes.

Key Words: *Aspergillus* ear rot, disease severity, grain yield, *Zea mays*

RÉSUMÉ

Le maïs (*Zea mays* L.) est une culture de base majeure dans la majeure partie de l'Afrique subsaharienne (ASS), une région confrontée à une multitude de maladies des plantes, la pourriture des épis et des grains étant la plus répandue et la plus difficile à gérer sur le maïs. L'objectif de cette étude était d'accéder aux performances agronomiques des hybrides de maïs F1 exposés à *Aspergillus flavus*, dans différentes conditions agro-écologiques, au Cameroun. Au total, 120 génotypes de maïs, dont quatre hybrides commerciaux, ont été évalués sous l' infection causée par A. *flavus* sur deux sites ; à savoir Bangangte dans les hauts plateaux occidentaux et Mbalmayo, dans la zone forestière humide bimodale du Cameroun. L'étude a été menée au cours des saisons agricoles 2020-2021. Les résultats ont révélé que sur le site de Bangangte, six (89343X88094, 88099X88094, 90204XExp 124, 89246X87036, TZI-5-1171XExp 124 and 90219X1368) etaient parmi les 20 hybrides les plus productifs et ils ont également montré une tolérance élevée (P < 0,001) (gravité de 0 %) à l'infection de l'épi causée par *Aspergillus*. Sur le site de Mbalmayo, huit (8923X88094, TZI-5-1171XExp124, 89343X88094, 90219X87036, 89243X87036, 87014X88094, TZSTR1150X87036 et 89248X8809 4) etaient parmi les 20 hybrides, qui avaient les rendements les plus élevés et ils ont également montré une tolérance significativement élevée (P <0,001) (0 % de gravité) à l'infection de l'épi causée par *Aspergillus*. L'interaction entre les hybrides et l'emplacement était significative (P < 0,05) pour tous les caractères mesurés, à l'exception de la hauteur de l'épi, de la texture du grain, des dommages causés par les insectes de l'épi et de la couverture de l'épi (P > 0,05). L'héritabilité sensorielle des hybrides dans les deux sites variait de 5 % pour la texture du grain à 92 % pour les jours et à 50 % pour la maturité physiologique. Le rendement en grain était négativement corrélé à l'incidence et à la gravité de la pourriture de l'épi causée par *Aspergillus*. Par conséquent, des hybrides de maïs prometteurs à haut rendement et avec une tolérance appréciable à la pourriture de l'épi causée par *Aspergillus* a pu être sélectionnée parmi les génotypes testés.

Mots Clés : Pourriture de l'épi causée par *Aspergillus*, gravité de la maladie, rendement en grains, *Zea mays*

INTRODUCTION

Maize (*Zea mays* L.) is an important cereal crop in most of the sub-Sahara Africa (SSA) region. Unfortunately, the crop is stressed by many diseases, with the ear and kernel rots ranked as the most widespread and difficult to manage (Kwemoi, 2010).

The most prominent ear rots of maize are caused by a variety of fungi, the most common of which are *Aspergillus*, *Botrydiploda*, *Diploda*, *Fusarium*, *Gibberella* and *Macropomina* (Chandrashekar, 2000; Kwemoi, 2010). These fungi cause discolouration of grain and accumulation of mycotoxins, the most common being the aflatoxins (Chandrashekar, 2000; Kwemoi, 2010). Aflatoxins being effective carcinogenic toxins, are secondary metabolites produced by several species of *Aspergillus*, especially *A. flavus*.

Aflatoxin poses a serious health hazard in SSA, where maize and its products are the most consumed cereal grain. Apart from the serious public health problems, aflatoxin also poses considerable economic loses in Africa, a continent whose trade balances are based on maize export (Landeira *et al*., 2017).

Several high yielding hybrid materials have been generated by breeding programmes in SSA, with unknown agronomic responses to a surge in *A. flavus* under different agro-ecological zones. The objective of this study, therefore, was to assess the agronomic performance of F1 hybrids exposed to *Aspergillus flavus* under different agro-ecological conditions in Cameroon.

MATERIALS AND METHODS

Study areas. This study was conducted in two sites, namely Bangangte and Mbalmayo in Cameroon. Bangangte is located in the Western Highlands in Cameroon, (latitude 5.14^{0}N and longitude 10.52^{0}E), at the altitude range of 1000 to1350 m above sea level. The maximum and minimum temperatures ranges from 14 to 32 ^{0}C; while mean annual rainfall ranges from 117 to 208 mm. The soils of this region are classified as alluvial and maize is heavily grown and commercially traded in this area.

Mbalmayo is located in the Bimodal Humid Forest Zone of Cameroon. This site is located at latitude 3.30^{O}N and longitude 11.30^{O}E, at the altitude from 335 to 625 m above sea level. The maximum and minimum temperatures range from 30 to 24 ^{O}C; while mean annual rainfall ranges from 240 to 315 mm. The soils of this area are classified as sandy-clay. Maize is equally grown and commercially traded in this area.

Genetic materials. The basic materials for the study comprised of 33 inbred lines (29 lines and 4 testers) as shown in Table 1. The materials were products from the Institute of Agricultural Research for Development (IRAD) in Cameroon; and the International Institute for Tropical Agriculture (IITA) maize breeding programmes. A total of 116 single cross hybrids (Table 1) were generated from the set of parents, following the procedure of line x tester mating design initiated by Kempthorne (1957). In addition to the 116 test cross hybrids, 4 commercial hybrid checks (CHH 101 (87036 X 88069), CLH (103 (87036 X EXP 124, 87036 X 1368) and CHH (105 (87036 X 88094), with unknown *Aspergillus* ear rot resistance; were used.

Pre-study activities. A screening trial was performed at Bangangte and Mbalmayo during the 2020 cropping seasons; consisting of a hybrid trial and an inbred line trial, planted side by side. The hybrid trial consisted of 116 F1 and 4 checks. The hybrids were evaluated during the two cropping seasons, under high *A. flavus* artificial infection. The hybrid trial was laid out in a 12 x 10 alpha lattice design, with two replication.

Inoculum administration. *Aspergillus flavus* was cultured and isolated at the Applied Microbiology Laboratory of IRAD, to obtain adequate number of spores for inoculation. It was grown on Potato-Dextrose Agar (PDA) for 14 days at 28 ^{O}C, with 12 hours of light. The inoculum was prepared from the *A. flavus* isolates. The inoculum was boosted on 100 ml of water, and was incubated at 28 ^{O}C for 3 weeks.

The conidia were washed using 500 ml of sterile distilled water, containing 20 drops of Tween-20 per litre; and filtered through four layers of sterile cheese cloth (Windham and Williams, 2002; Abebe *et al.*, 2006). The concentrations of the conidia were determined using a hemacytometer and adjusted with sterile distilled water (serial dilutions to 9 x 10^7 conidia ml^{-1}). The remunant after inoculation was refrigerated at 4 ^{O}C.

Primary maize ears (upper ears) in each plot were inoculated at 14 days after mid-silk (50% plants in a plot with silks emerged), with conidia using a non-wounding technique (Li, 2004). Husks were slightly opened by hand to expose developing kernels. Exposed kernels were inoculated by delivering 5 mL of conidial suspension with a dropper. Immediately after inoculation, husks were pulled back over the kernels and the cob covered with a polythene bag to create an environment conducive for the fungus (Zuber *et al.*, 1978).

TABLE 1. Maize hybrids used during the study of the agronomic performance of F1 hybrids exposed to *Aspergillus flavus* under different agro-ecological conditions in Cameroon

Entry	Hybrid	Entry	Hybrid	Entry	Hybrid	Entry	Hybrid
1	90219X1368	31	89320X87036	61	TZI-5-1171XExp124	91	89291X88094
2	89320X1368	32	TZI-5-1171X87036	62	89291XExp124	92	87014X88094
3	TZI-5-1171X1368	33	89291X87036	63	87014XExp124	93	90176X88094
4	89291X1368	34	87014X87036	64	90176XExp124	94	90251X88094
5	87014X1368	35	90176X87036	65	90251XExp124	95	89246X88094
6	90176X1368	36	90251X87036	66	89246X Exp124	96	90323X88094
7	90251X1368	37	89246X87036	67	90323X Exp124	97	90267X88094
8	89246X1368	38	90323X87036	68	90267X Exp124	98	89223X88094
9	90323X1368	39	90267X87036	69	89223X Exp124	99	89246X88094
10	90267X1368	40	89223X87036	70	89246X Exp124	100	M131X88094
11	89223X1368	41	89246X87036	71	M131X Exp124	101	89343X88094
12	89246X1368	42	M131X87032	72	89343X Exp124	102	TZSTR1150X88094
13	M131X1368	43	89343X87036	73	TZSTR1150X Exp124	103	88099X88094
14	89343X1368	44	TZSTR1150X87036	74	88099X Exp124	104	90263X88094
15	TZSTR1150X1368	45	88099X87036	75	90263X Exp124	105	89311X88094
16	88099X1368	46	90263X87036	76	89311X Exp124	106	90301X88094
17	90263X1368	47	89311X87036	77	90301X Exp124	107	90188X88094
18	89311X1368	48	90301X87036	78	90188X Exp124	108	90183X88094
19	90301X1368	49	90188X87036	79	90183X Exp124	109	89183X88094
20	90188X1368	50	90183X87036	80	89183X Exp124	110	INEW-SRX88094
21	90183X1368	51	89183X87036	81	INEW-SRX Exp124	111	90204X88094
22	89183X1368	52	INEW-SRX87036	82	90204X Exp124	112	89243X88094
23	INEW-SRX1368	53	90204X87036	83	89243X Exp124	113	89193X88094
24	90204X1368	54	89243X87036	84	89193X Exp124	114	90313X88094
25	89243X1368	55	89193X87036	85	90313X Exp124	115	89365X88094
26	89193X1368	56	90313X87036	86	89365X Exp124	116	90156X88094
27	90313X1368	57	89365X87036	87	90156X Exp124	117	CHH101 (check)
28	89365X1368	58	90156X87036	88	90219X 88094	118	CHH105 (check)
29	90156X1368	59	90219XExp124	89	89320X88094	119	CLH103 (check)
30	90219X87036	60	89320XExp124	90	TZI-5-1171X88094	120	87036X1368 (check)

Data collection. At physiological maturity in all experimental sites, the primary ears in all plots were harvested and rated for the incidence and severity of the ear rots, using the 1 - 7 scoring scale (Reid *et al.*, 1996). By this rating, 1 = sound, unblemished kernels on the ear (0%); 2 = 1 - 3% of kernels on the ear rotten; 3 = 4 - 10% of kernels on the ear rotten; 4 = 11 -25% of kernels on the ear rotten; 5 = 26 - 50% of kernels on the ear rotten; 6 = 51 - 75% of kernels on the ear rotten; and 7 = 76 - 100% of kernels damaged, covered with fungus or discoloured (Reid *et al.*, 1996).

Maize trial descriptions were recorded following CIMMYT (1985) Guide for trial management. Grain yield was recorded at harvest, calculated from the inoculated ears only, and adjusted to the 12.5% moisture using Equation 1:

$$\text{Grain yield} = \frac{(\text{Field ear weight per plot}) \times (100 - \text{MC}) \times 0.8 \times 10{,}000}{1000 \times 100 - 12.5 \times \text{Area harvested per plot}} \ \text{t ha}^{-1} \quad \text{.......... Equation 1}$$

Where:

MC = field moisture content in grains at harvest (%), and 0.8 = shelling coefficient.

Some maize traits previously reported to be associated with either ear rot infection or mycotoxin accumulation (Betran *et al.*, 2002; Rossouw *et al.*, 2002) were also recorded as follows:

(i) Root and stem lodging. This was rated separately on a plot basis, by counting the number of plants that had inclined more than 45^{o} for root lodging, and those whose stalks had broken below the ear, as stem lodging and then multiplied by 100. For the purpose of statistical analysis, these two were combined.

(ii) Ear declination. This was rated on a scale of 1 - 5, where 1 = drooping downwards and 5 = standing upright along the stalk.

(iii) Husk cover. This was measured by sampling five primary ears in each row, which were then rated using the scale of 1 to 5 as proposed by Kossou *et al.* (1993). The rating was done by placing the hand around the husk leaves as they extend beyond the ear tip and making a fist such that the base of the hand rests on the tip of the ear. If the husk leaves are longer than 4 fingers, the rating is 1; but if husk leaves are longer than 3 fingers, the rating is 2. The rating is 3 when husk leaves are longer than 2 fingers; while the rating is 4 when the husk leaves are longer than 1 finger. When the husk leaves are $\leq$ 1 finger, the ear tip is exposed and the rating is 5. The mean was then calculated for each plot.

(iv) Grain type. This was rated on a score scale of 1 - 4, where 1 = flint; 2 = semi flint, more than 50% flint in the kernel row, or slight flint grain; 3 = more than 50% dent in the kernel row or slight dent grain; and 4 = dent.

(v) Ear insect damage. The cobs were rated for insect damage on a scale of 1 - 5, where 1 = clean or no damage and 5 = severe damage with visible holes. The percentage of grains damaged was calculated on plot basis. Insect wounds are closely associated with ear rot infection (Ajanga and Hillocks, 2000) and their damage creates pathways for ear fungal invasion (Munkvold and Desjardins, 1997).

In order to normalise the data for disease severity, ear declination, husk cover, grain type and ear insect damage scores, and angular transformations were carried out and transformed into percentages before analysis.

Data analysis

General analysis of variance for the lattices. These were performed for all the hybrids and checks trait means. Years, replications and incomplete blocks were considered as random effects; while hybrids as fixed effects. Pearson's correlation coefficients were calculated between pairs of mean values of grain yield and other measured traits. All analyses were performed with SAS software (SAS Institute, 2009).

Broad-sense heritability (H^2). The Broad sense heritability was computed using Equation 2:

$$H^2 = \sigma^2 g / (\sigma^2 g + (\sigma^2 ge / e) + (\sigma^2 e / re) \quad \text{.. Equation 2}$$

Where:

$\sigma^2 g$ is variance for genotype, $\sigma^2 e$ is error variance, $\sigma^2 ge$ is variance for genotype x environment interaction, *r* is number of replications, and *e* is number of environments (Fehr, 1999).

Standard heterosis. Standard heterosis, defined as comparison of hybrids to the best performing check, was estimated according to Equation 3 (Singh and Singh, 1994):

$$\text{Standard heterosis (SH)} = (\text{F1} - \text{check}) / \text{check} \times 100 \quad \text{.. Equation 3}$$

RESULTS

Agronomic performance. The hybrids were very highly significant (P<0.001) for *Aspergillus* ear rot disease incidence, ear insect damage and plant vigour (Table 2). The differences among hybrids were highly significant (P<0.01) for days to 75% physiological maturity, plant height, days to 50% anthesis, anthesis-silking interval and *Aspergillus* ear rot disease severity (Table 2). On the other hand, there were significant differences (P<0.05) for grain yield, days to 50% silking, lodging and ear aspect (Table 2). However, no significant differences (P>0.05) were recorded for ear height, grain texture, ear declination and husk cover (Table 2).

At Bangangte trial site, the broad sense heritability of hybrids was 2% for lodging and 58% for days to mid silking. Ear height recorded the second lowest heritability of 11% (Table 2).

Mean squares for grain yield and other agronomic traits at Mbalmayo trial site. At Mbalmayo trial site, the hybrids were very highly significant (P<0.001) for days to 50% anthesis, days to 50% silking, *Aspergillus* ear rot disease incidence and severity, ear insect damage, ear declination, husk cover and ear aspect (Table 3). However, the hybrids were highly significant (P<0.01) for grain yield, days to 75% physiological maturity and plant height (Table 3). Hybrids were barely significant (P<0.05) for ear height, anthesis-silking interval and plant vigour (Table 3). On the other hand, there was no significant hybrid effects (P>0.05) for lodging and grain texture (Table 3).

The broad sense heritability of hybrids evaluated at Mbalmayo was 11% for ear height and 99% for *Aspergillus* ear rot disease incidence. Ear height recorded the second lowest heritability of 12% (Table 3).

Mean squares for grain yield and other agronomic traits across both trial sites. The hybrids were very highly significant (P<0.001) for anthesis-silking interval, *Aspergillus* ear rot disease severity, ear insect damage, ear declination, husk cover and ear aspect; highly significant (P<0.01) for grain yield, days to 75% physiological maturity, *Aspergillus* ear rot disease incidence and plant

TABLE 2. Mean squares for grain yield and other agronomic traits at Bangangte trial site

SOV	DF	GYD (t ha^{-1})	MAT (days)	EH (cm)	PH (cm)	AD (days)	SD (days)	ASI (days)	LOD (%)
REP	1	1.35	0	260.02	0.73	0.03	0.04	0	5.59
BLOCK(REP)	18	6.8	24.57	334.31	999.89*	46.76***	45.47***	1.76	663.16***
HYBRIDS	119	5.68*	11.51**	256.39	670.18**	5.98**	5.77*	1.41**	253.84*
ERROR	101	4.24	11.73	224.1	542.91	655.4	600.58	1.19	235.51
R-Square		0.7	0.64	0.61	0.63	0.76	0.77	0.63	0.64
CV (%)		28.69	2.76	12.28	10.01	3.8	3.8	38.76	99.94
H^2 (%)	41	23	11	19	57	58	21	2	

Disease related traits

SOV	DF	[a]INC (%)	[a]SEV (%)	[a]TEX (%)	[a]INSECT (%)	[a]EARDEC (%)	[a]HUSK (%)	[a]EARASP (%)	[a]PLTVIG (%)
REP	1	47.62	613.4***	0.01	171.6**	0.29	0.29	0.08	0.02
BLOCK(REP)	18	319.56	49.31*	26.77***	33.87*	106.93***	106.93***	29.65***	65.15***
HYBRIDS	119	374.46***	46.78**	8.48	36.61***	35.57	35.57	8.12*	15.44***
ERROR	101	421.31	28.65	6.95	19.5	30.45	30.45	9.35	22.12
R-Square		0.7	0.75	0.72	0.74	0.68	0.68	0.61	0.56
CV (%)		76.02	59.33	31.99	62.31	111.91	111.91	49.67	45.49
H^2		41	55	47	51	35	35	13	8

*, ** and *** = Mean squares significant at pÂ0.05, P<0.01 and P<0.001 probability levels, respectively. GYD = grain yield, MAT = days from planting to 75% physiological maturity, EH = ear height, PH = plant height, AD = days from planting to 50% anthesis, SD = days from planting to 50% silking, ASI = anthesis silking interval, LOD = lodging, INC = disease incidence, SEV= disease severity, TEX = grain texture, INSECT = insect damage, EARDEC = ear declination, HUSK = husk cover, EARASP = ear aspect, PLTVIG = plant vigour and H^2 = broad sense heritability.

[a] Angular transformation of visually scored data (1-7 score) was performed and converted to percentage to normalize the data before analysis

TABLE 3. Mean squares for grain yield and other agronomic traits at Mbalmayo trial site

SOV	DF	GYD ($t\ ha^{-1}$)	MAT (days)	EH (cm)	PH (cm)	AD (days)	SD (days)	ASI (days)	LOD (%)
REP	1	17.48**	0.23	151.6	2968.31*	0.05	0.7	0.99	633.51
BLOCK(REP)	18	3.44	38.33***	283.53	912.25*	7.2***	10.37***	1.05	486.02*
HYBRIDS	119	4.3**	7.52**	272.49*	578.01**	3.69***	5.48***	1.2*	237.93
ERROR	101	2.78	825.84	299.62	534.05	1.64	2.66	0.94	284.43
R-Square		0.7	0.69	0.55	0.62	0.79	0.78	0.65	0.61
CV (%)		20.58	2.64	13.55	9.16	2.51	2.69	39.06	127.36
H^2 (%)	40	39	11	15	64	60	27	12	

Disease related traits

SOV	DF	[a]INC (%)	[a]SEV (%)	[a]TEX (%)	[a]INSECT (%)	[a]EARDEC (%)	[a]HUSK (%)	[a]EARASP (%)	[a]PLTVIG (%)
REP	1	1.14	46.04	83.44**	1.39	6.01	2.32	0.04	377.13***
BLOCK(REP)	18	478.92	39.18	23.21	28.7	27.27	0.95	0.19	33.84*
HYBRIDS	119	1042.3***	68.97***	9.12	59.62***	82.51***	20.07***	18.25***	20.93*
ERROR	101	413.14	29.3	12.84	22.29	24.06	0.99	0.34	17.46
R-Square		0.77	0.77	0.54	0.78	0.82	0.96	0.99	0.67
CV (%)		67.21	67.21	37.42	55.55	58.27	68.76	5.42	46.95
H^2		99	59	15	62	71	95	98	33

*, ** and *** = Mean squares significant at $P<0.05$, $P<0.01$ and $P<0.001$ probability levels respectively. GYD = grain yield, MAT = days from planting to 75% physiological maturity, EH = ear height, PH = plant height, AD = days from planting to 50% anthesis, SD = days from planting to 50% silking, ASI = anthesis silking interval, LOD = lodging, INC = disease incidence, SEV = disease severity, TEX = grain texture, INSECT = insect damage, EARDEC = ear declination, HUSK = husk cover, EARASP = ear aspect, PLTVIG= plant vigour and H^2 = broad sense heritability

[a] Angular transformation of visually scored data (1-7 score) was performed and converted to percentage to normalize the data before analysis

vigour (Table 4). There were barely significantly different (P<0.05) for ear height, days to 50% anthesis, days to 50% silking and grain texture (Table 4). No significant (P>0.05) hybrid effect was recorded for lodging (Table 4).

The interaction between hybrids and location was very highly significant (P<0.001) for ear declination (Table 4); but highly significant (P<0.01) for grain yield, days to 75% physiological maturity, *Aspergillus* ear rot disease incidence and ear aspect (Table 4). The interaction between hybrids and location was significant (P<0.05) for plant height, days to 50% anthesis, days to 50% silking, anthesis silking interval, lodging, *Aspergillus* ear rot disease severity and plant vigour. The interaction between hybrids and location was not significant (P>0.05) for the rest of the measured parameters (Table 4). The broad sense heritability of hybrids across the two locations varied from 5% for grain texture to 92% for days to 50% physiological maturity. Plant vigour recorded the second lowest heritability of 6%.

Agronomic and disease related traits of hybrids at Bangangte trial site. Significant differences existed among test crosses for most of the measured traits (Table 5). The highest grain yield was 11.8 t ha^{-1}, recorded by hybrid TZSTR1150X87036; while the lowest grain yield of 3.4 t ha^{-1} was by the hybrid 87014 X Exp 124 (Table 5).

Grain yield of the selected hybrids ranged from 9.3 for hybrids 89248X8036, 90267X87036, 89291XExp 124 and 90219X1368, to 11.8 t ha^{-1} for genotype TZSTR1150X87036 (Table 5), The *Aspergillus* ear rot disease incidence varied from 0.0% for genotype CHH105 to 60.4% for genotype 89193X87036. The *Aspergillus* ear rot disease severity varied from 0 to 14.4% (Table 5). Three hybrids, TZSTR1150X87036, 89343X87036 and 89243x87036, yielded significantly higher grain yields than the best hybrid check.

Agronomic and disease related traits of hybrids at Mbalmayo trial site. Significant differences existed among the test crosses for most of the measured traits (Table 3). The lowest grain yield of the selected hybrids was 9.6 t ha^{-1} for hybrid 89291 XExp 124, and lowest, 12.9 t ha^{-1}, for the hybrid 90267 X 88094 (Table 6). The *Aspergillus* ear rot disease incidence varied from 0 to 53.1% (Table 6). The severity of the disease varied from 0 to 14.9% for the hybrid 89193X87036. The highest yielding hybrid check was CLH103, which yielded 11.6 t ha^{-1}. Three hybrids (90267X88094, 8923X88094 and 90219X88094) yielded above the best hybrid check (Table 6).

Agronomic and disease related traits of pooled top twenty hybrids across both trial sites. Across the two study sites, significant differences existed among the test crosses for most of the measured traits (Table 4). The highest grain yield of 11.7 t ha^{-1} was recorded by the hybrid 8923 X 88094; while the lowest of 9.1 t ha^{-1} was recorded by the hybrids 8923 X87036 and 89320 X Exp 124 (Table 7). The highest yielding hybrid check was CHH101, which yielded 10.1 t ha^{-1}. Nine hybrids significantly yielded above the best hybrid check (Table 7).

Aspergillus ear rot disease incidence varied from 0.5% for the hybrid TZI0501171XExp 124) to 57.7% for the hybrid 89193X87036 (Table 7). *Aspergillus* ear rot disease severity varied from 0% for the hybrids 89343X88094, TZI-501171XExp 124, 90219X 87036, 87036X1368, to 14.7% for the genotype 89193x87036 (Table 7).

Correlations between yield and disease related traits. There were no significant correlations among the measured traits for the two sites; therefore, pooled data were used to compute the correlations between the traits. The correlation between *Aspergillus* ear rot disease incidence and severity for ear insect damage, ear declination, husk cover, grain

TABLE 4. Pooled mean squares for grain yield and other agronomic traits across Bangangte and Mbalmayo trial sites

SOV	DF	GYD (t ha^{-1})	MAT (days)	EH (cm)	PH (cm)	AD (days)	SD (days)	ASI (days)	LOD (%)
LOCATION	1	101.84***	308.48***	4036.8***	45008.13***	9478.52***	1584.13***	13.33***	530.25
REP	1	13.81*	0.74	380.76	1479.25	0.08	0.23	0.5	250.16
BLOCK (REP)	37	5.73*	36**	408.8*	669.25	28.63***	27.99***	1.38	675.56***
HYBRIDS	119	8.76**	12.69**	345.49*	892.47**	7.9*	8.09*	1.85***	327.71
LOC*HYB	101	1.93**	10.2**	144.57	248.51*	4.07*	5.09*	0.84*	198.53*
ERROR 220	3.53	11.18	255.7	59.76	5.66	6.1	1.09	275.9	
R-Square		0.68	0.93	0.56	0.6	0.9	0.75	0.61	0.57
CV (%)		24.62	2.88	12.81	10.1	3.81	3.96	39.43	116.21
H^2		45	92	8	23	88	61	24	10

Disease related traits

SOV	DF (%)	INC (%)	SEV (%)	TEX (%)	INSECT (%)	EARDEC (%)	HUSK (%)	EARASP (%)	PLTVIG
LOCATION	1	1261.66	28.94	213.83***	251.52***	1459.06**	1453.18**	643.96***	248.89***
REP	1	19.4	509.33***	39.83	95.11*	4.59	0.47	643.51***	191.02***
BLOCK (REP)	37	482.07	46.85	23.79**	30.93	74.04***	59.02***	36.21***	47.72**
HYBRIDS	119	1615.49**	117.55***	9.73*	89.05***	63.54***	111.37***	14.49***	21.05**
LOC*HYBS	101	73.97**	7.63*	8.33	9.43	56.6***	15.82	16.2**	16.28*
ERROR	220	406.92	30.74	11.31	21.96	29.62	18.17	2.3	21.45
R-Square		0.73	0.7	0.55	0.73	0.74	0.71	0.93	0.56
CV (%)		70.48	59.7	37.74	60	81.55	133.6	20.72	22.78
H^2		56	55	5	57	58	52	91	6

*, ** and *** = Mean squares significant at P<0.05, P<0.01 and P<0.001 probability levels, respectively. GYD = grain yield, MAT = days from planting to 75% physiological maturity, EH = ear height, PH = plant height, AD = days from planting to 50% anthesis, SD = days from planting to 50% silking, ASI = anthesis silking interval, LOD = lodging, INC = disease incidence, SEV = disease severity, TEX = grain texture, INSECT = insect damage, EARDEC = ear declination, HUSK = husk cover, EARASP = ear aspect, PLTVIG = plant vigour and H^2 = broad sense heritability

[a] Angular transformation of visually scored data (1-7 score) was performed and converted to percentage to normalize the data before analysis

TABLE 5. Performance of top 20 yielding maize hybrids and checks at Bangangte trial site

Hybrids	AD	SD	ASI	PH	EH	MAT	INC	SEV	EARASP	PLTVIG	HUSK	LODG	EARDEC	INSECT	TEX	GYD
TZSTR1150X87036	69	66.5	2.5	212.5	125	121.5	17	5.9	8	17	6.3	7	6.3	0	10.2	11.8
89343X88094	70	68	2	232.5	113.5	125	3.7	0	1.1	6.2	4.2	27.1	4.2	0	8.8	11.6
89243X87036	69.5	67	2.5	230	121.5	126	2.8	2.4	5.7	7.6	10.4	7	10.4	0	7.6	11
89 23X88094	68	67	1	230	145	121.5	11.8	2.4	4.6	8.8	4.2	16.5	4.2	3.9	9	10.7
88099X88094	68	64.5	3.5	222.5	112.5	125	4.5	0	3.4	9	10.4	3.6	10.4	3.9	7.6	10.6
90204XExp 124	68.5	65.5	3	170	110	124.5	14.2	0	10.2	9	6.3	14.8	6.3	2.7	7.6	10.5
90183XExp 124	71	69	2	193.5	100	127.5	5.3	5.2	5.7	9	10.4	23.8	10.4	7.6	7.6	10.2
89246X87036	68.5	65.5	2.5	225	138.5	124.5	8.5	0	6.8	6.2	4.2	7.5	4.2	3.9	6.2	10.1
90267X88094	69.5	66.5	3	212.5	125	125.5	25.1	10.3	5.7	9	10.4	12.3	10.4	13.7	8.8	9.9
89311X1368	70	67.5	2.5	192.5	127	124	5	4.4	8	9	8.3	19.7	8.3	3.9	7.6	9.8
TZI-5-1171XExp 124	68	63	2	227.5	135	126.5	1	0	5.7	8.8	10.4	0	10.4	0	10.2	9.7
90301XExp 124	71	67.5	3.5	255	121	126.5	5.4	7.9	5.7	7.6	4.2	33.5	4.2	3.9	6.2	9.7
89320XExp 124	67.5	64.5	3	245	125	120	1.8	2.4	6.8	11.3	6.3	11	6.3	0	7.6	9.6
89243XExp 124	67	63	4	240	120.5	127	21.5	13.6	4.6	10.2	10.4	18.5	10.4	7.6	7.6	9.6
IN EW-SRX1368	68.5	64.5	4	222.5	106.5	125.5	21	8.1	3.4	15.6	10.4	32.7	10.4	2.7	9	9.6
89193X87036	65	64	1	261.5	123.5	123.5	60.4	14.4	4.6	17	0	17.5	0	9.7	10.2	9.4
89248X87036	68	65.5	2.5	237.5	120	121.5	47	13.4	6.8	12.5	0	27	0	19.2	9	9.3
90267X87036	67.5	65	2.5	195	105	124.5	27.8	11.8	5.7	10.2	4.2	4.5	4.2	7.8	9	9.3
89291XExp 124	69.5	66.5	4	235.5	138	120.5	32.3	12.5	6.8	8.8	4.2	26.7	4.2	13.7	9	9.3
90219X1368	68	65	3	215	127.5	128	4	0	3.4	10.2	8.3	40	8.3	2.7	8.8	9.3
Hybrid checks																
CHH105	68	64	4	236	127.5	127.5	0	0	3.4	9	6.3	12.5	6.3	3.9	9	10.4
CLH103	68.5	64.5	4	243.5	123.5	126	22.8	11	9.1	12.5	4.2	6	4.2	8.8	6.2	5.9
87036X1368	65	62	3	241.5	110	125.5	1.5	0	6.8	6.2	4.2	61.2	4.2	4.9	7.6	8.4
CHH101	64.5	63	1.5	240.5	114.5	124.5	4.7	3.5	4.6	17	0	18	0	0	8.8	10.8
Mean	67	64.2	2.8	232.8	122	124.1	27	9	6.2	10.3	4.9	15.3	4.9	7.1	8.2	7.1
Maximum	71	69	5	270	160	128.5	75.7	25	11.4	17	16.7	61.2	16.7	19.2	17	11.8
Minimum	58.5	56	1	170	92.5	115.5	0	0	1.1	0.2	0	0	0	0	3.1	3.4
CV (%)	3.8	3.8	38.8	10	12.3	2.8	76	59.3	49.7	45.5	111.9	99.9	111.9	62.3	32	28.7

GYD = grain yield ($t\ ha^{-1}$), MAT = days from planting to 75% physiological maturity, EH = ear height (cm), PH = plant height (cm), AD = days from planting to 50% anthesis, SD = days from planting to 50% silking, ASI = anthesis silking interval (days), LOD = lodging (%), INC = disease incidence (%), SEV = disease severity (%), TEX = grain texture (%), INSECT = insect damage (%), EARDEC = ear declination (%), HUSK = husk cover (%), EARASP = ear aspect (%), PLTVIG = plant vigour (%) [a] Angular transformation of visually scored data (1-7 score) was performed and converted to percentage to normalize the data before analysis

TABLE 6. Performance of top 20 yielding maize hybrids and checks at Mbalmayo trial site

Hybrids	AD	SD	ASI	PH	EH	MAT	INC	SEV	EARASP	PLTVIG	HUSK	LODG	EARDEC	INSECT	TEX	GYD
90267X88094	61	64	3	235	135	112	44	11.7	6.2	7.6	7.6	2.8	7	16.7	10.7	12.9
89 23X88094	57.5	60	2.5	250	145	109	0	0	6.2	15.1	0	0	0	0	7.4	12.8
90219X88094	58	60.5	2.5	240	120	104	39.2	12.5	6.2	12.5	0	20.4	6.3	8.3	9.1	11.9
90204XExp 124	60	62	2	190	120	111.5	8	4.4	13.6	10.2	0	8.8	4.2	2.9	9.1	10.9
TZI-5-1171XExp 124	57.5	58.5	1	270	125	109	0	0	11.4	11.1	0	0	0	0	10.7	10.7
90301XExp 124	60.5	63.5	3	270	140	107.5	6.6	5.9	11.4	5.7	0	27.4	2.9	2.9	9.1	10.7
90183XExp 124	59.5	61.5	2	245	110	106	13.6	6.8	9	9	0	13.9	5.2	9.4	9.1	10.7
89193X87036	57	60	3	295	110	105	55	14.9	11.4	7.6	0	11.3	25	12.5	5.5	10.4
89343X88094	58	60	2	255	120	107	0	0	6.2	6.2	0	2.8	0	2.9	9.1	10.4
90219X87036	58.5	62	3.5	215	125	107.5	0	0	11.4	10.2	0	14.3	0	0	7.4	10.3
89311XExp 124	57.5	60.5	3	290	135	105.5	40.2	12.5	11.4	3.1	0	8.4	8.3	15.4	10.7	10
90188X1368	59	62.5	3.5	240	120	105.5	1.5	2.4	6.2	12.5	0	2.8	0	2.9	10.9	10
89243X87036	56.5	58.5	2	260	130	110	0	0	6.2	4.5	0	0	0	0	10.9	9.9
87014X88094	58	59.5	1.5	250	125	110.5	0	0	9	7.6	0	24.5	0	0	12.5	9.9
IN EW-SRX1368	58	61	3	255	130	109	17	6.6	9	4.5	7.6	12.9	5.2	0	12.5	9.8
89291XExp 124	59	63.5	4.5	285	115	112	53.1	12.5	9	4.5	0	32.6	12.5	15.4	10.9	9.6
90219X1368	57	59.5	2.5	265	140	109	0.5	2.4	9	10.2	0	18.8	0	4.2	7.4	9.6
TZSTR1150X87036	57.5	59	1.5	220	135	108.5	0	0	9	12.5	0	10.9	0	0	5.5	9.5
89248X88094	59	61.5	2.5	275	140	111.5	0	0	9	4.5	0	2.8	0	0	7.5	9.5
89320X1368	57	59.5	2.5	260	125	107	6	5.9	9	4.5	0	55	4.2	2.9	10.9	9.5
Hybrid checks																
CHH105	59.5	63	3.5	275	135	109.5	12.5	3.5	6.2	10.2	0	6.3	4.2	4.2	9.1	7.8
CLH103	57	59	2	265	130	107.5	20.2	8.7	13.6	8.8	0	28.6	8.3	9.4	9.1	11.6
87036X1368	57.5	59	1.5	255	120	109	0	0	11.4	10.2	0	43.8	0	5.2	12.5	7.5
CHH101	58.5	60	1.5	265	135	110.5	3	2.4	6.2	13.6	0	0	5.8	0	7.4	9.4
Mean	58.1	60.6	2.5	252.2	127.8	108.1	30.2	9.5	10.8	8.9	4.9	13.2	8.4	8.5	9.9	8.1
Maximum	62	65	5	295	160	112.5	82.2	22.6	25	21.9	16.7	59.9	5.3	25	14.3	12.9
Minimum	54.5	57	1	190	100	102.5	0	0	0	3.1	0	0	0	0	3.7	3.8
CV(%)	2.5	2.7	39.1	9.2	13.6	2.6	67.2	56.8	5.4	47	68.8	127.4	58.3	55.6	37.4	20.6

GYD = grain yield (t ha^{-1}), MAT = days from planting to 75% physiological maturity, EH = ear height (cm), PH = plant height (cm), AD = days from planting to 50% anthesis, SD = days from planting to 50% silking, ASI = anthesis silking interval (days), LOD = lodging (%), INC= disease incidence (%), SEV = disease severity (%), TEX = grain texture (%), INSECT = insect damage (%), EARDEC = ear declination (%), HUSK = husk cover (%), EARASP= ear aspect (%), PLTVIG = plant vigour (%)

TABLE 7. Performance of top pooled 20 yielding maize hybrids and checks across Bangangte and Mbalmayo trial sites

Hybrids	AD	SD	ASI	PH	EH	MAT	INC	SEV	EARASP	PLTVIG	HUSK	LODG	EARDEC	INSECT	TEX	GYD
89 23X88094	62.8	63.5	1.8	240	145	115.3	5.9	1.2	5.5	11.9	2.1	8.3	2.1	2	8.2	11.7
90267X88094	65.3	65.3	3	223.8	130	118.8	34.6	11	6.7	8.3	9	7.6	8.7	15.2	9.8	11.4
89343X88094	64	64	2	243.8	116.8	116	1.9	0	2.1	6.2	2.1	14.9	2.1	1.4	9	11
90204XExp 124	64.3	63.8	2.5	180	115	118	11.1	2.2	11.4	9.6	3.1	11.8	5.2	2.8	8.4	10.7
TZSTR1150X87036	63.3	62.8	2	216.3	130	115	8.5	2.9	8.5	14.7	3.1	8.9	3.1	0	7.8	10.6
89243X87036	63	62.8	2.3	245	125.8	118	1.4	1.2	6.7	6	5.2	3.5	5.2	0	9.2	10.5
90183XExp 124	65.3	65.3	2	219.3	105	116.8	9.4	6	7.4	9	5.2	18.9	7.8	8.5	8.4	10.4
TZI-5-1171XExp 124	62.8	60.8	1.5	248.8	130	117.8	0.5	0	6.8	9.9	5.2	0	5.2	0	10.5	10.2
90301XExp 124	65.8	65.5	3.3	262.5	130.5	117	6	6.9	8	6.6	2.1	30.4	3.5	3.4	7.7	10.2
90219X88094	63.3	63.8	2	236	116.3	115	35.3	11.3	6.7	11.3	3.1	25.6	6.3	8	8.4	10.1
88099X88094	63	62	2.5	236.3	118.8	117.5	3.3	1.2	4.5	9.6	5.2	20	5.2	4	8.4	10
89193X87036	61	62	2	278.3	116.8	114.3	57.7	14.7	5.7	12.3	0	14.4	12.5	11.1	7.8	9.9
IN EW-SRX1368	63.3	62.8	3.5	238.8	118.3	117.3	19	7.4	5.1	10	9	22.8	7.8	1.4	10.7	9.7
89246X87036	62.5	62	2.3	240	131.8	116.8	4.7	1.2	7.4	8.6	2.1	10	2.1	3.4	6.8	9.6
90219X87036	63	62.5	4	202.5	126.8	117.3	0.6	0	8	10.2	2.1	22	2.1	0	6.8	9.5
89291XExp 124	64.3	65	4.3	260.3	126.5	116.3	42.7	12.5	7.9	6.6	2.1	29.6	8.3	14.5	9.9	9.5
90219X1368	62.5	62.3	2.8	240	133.8	118.5	2.2	1.2	4.5	10.2	4.2	29.4	4.2	3.4	8.1	9.5
89311X1368	63.5	63.5	2.8	201.3	136	117	5.5	5.6	9.1	6.7	4.2	11.3	4.2	4	10	9.4
89 23X87036	62.3	62	3.3	255	128	116.3	5.8	3.7	5.1	11.3	2.1	17.8	2.1	3.9	10.8	9.1
89320XExp 124	62.5	62.8	3.3	255	115	114	0.9	1.2	8.5	9.1	3.1	20.9	3.1	0	9.2	9.1
Hybrid checks																
CHH105	63.8	63.5	3.8	255.5	131.3	118.5	6.3	1.8	4.4	9.6	3.1	9.4	5.2	4	9.1	9.1
CLH103	62.8	61.8	3	254.3	126.8	116.8	21.5	9.9	10.2	10.6	2.1	17.3	6.3	9.1	7.7	8.8
87036X1368	61.3	60.5	2.3	248.3	115	117.3	0.8	0	8	8.2	2.1	52.5	2.1	5.1	10	8
CHH 101	61.5	61.5	1.5	252.8	124.8	117.5	3.9	3	5.5	15.3	0	9	2.9	0	8.1	10.1
Mean	62.5	62.4	2.7	242.5	124.9	116.1	28.6	9.3	7.3	9.6	3.2	14.3	6.7	7.8	8.9	7.6
Maximum	66	65.8	5	278.3	160	119.5	75.1	22.6	13.1	17.9	14.7	52.5	15.6	19.7	13.9	11.7
Minimum	56.8	56.5	1	180	104.5	111.8	0	0	2.1	3.1	0	0	0	0	4.9	3.7
CV(%)	3.8	4	39.4	10.1	12.8	2.9	70.5	59.7	20.7	48.2	133.6	116.2	81.6	60	37.7	24.6

GYD = grain yield (t ha^{-1}), MAT = days from planting to 75% physiological maturity, EH = ear height (cm), PH = plant height (cm), AD = days from planting to 50% anthesis, SD = days from planting to 50% silking, ASI = anthesis silking interval (days), LOD = lodging (%), INC = disease incidence (%), SEV = disease severity (%), TEX= grain texture (%), INSECT = insect damage (%), EARDEC = ear declination (%), HUSK = husk cover (%), EARASP = ear aspect (%), PLTVIG = plant vigour (%)

[a] Angular transformation of visually scored data (1-7 score) was performed and converted to percentage to normalize the data before analysis

texture and grain yield an and other agronomic traits are shown in Table 8.

There were very strong (P<0.001) and positive correlations between days to 50% anthesis and days to 50% silking, days to 75% physiological maturity and days to 50% anthesis, *Aspergillus* ear rot disease incidence and severity (Table 8). There were also strong correlations (P<0.01) between ear insect damage and *Aspergillus* ear rot disease incidence and severity, and ear insect damage.

The correlation between *Aspergillus* ear rot disease incidence and severity was very highly significant (P<0.001) and positive (Table 8). Furthermore, correlations between *Aspergillus* ear rot disease incidence, ear declination and ear insect damage were positively and very highly significant (Table 8). On the other hand, the correlation between *Aspergillus* ear rot disease incidence and ear aspect was positive, but barely significant (P<0.05).

The correlations between *Aspergillus* ear rot disease severity with ear declination and ear insect damage were positive and very highly significant (P<0.001). The correlation between *Aspergillus* ear rot disease severity and ear aspect were also positive and significant. In contrast, the correlations between *Aspergillus* ear rot disease severity and husk cover or lodging were negative and not significant (P>0.05).

Pooled standard heterosis of the best 20 hybrids and checks across both trial sites. There were no significant differences (P>0.05) among the measured traits in standard heterosis for the two sites; therefore, pooled data were used to compute the standard heterosis. The standard heterosis over the hybrid checks was best for the 20 high yielding hybrids under disease exposure (Table 9). The standard heterosis ranged from -9.9% for genotype 8923X87036 and 89320XExp 124, to 46.3% for hybrid 8923X88094. The standard heterosis over the best hybrid check (CHH101) ranged from -9.9 to 15.8% (Table 9). Nine hybrids significantly out-yielded the best hybrid check by at least 1% (Table 9).

DISCUSSION

Agronomic performance. The significant differences recorded among hybrids for grain yield and agronomic related traits under exposure to the ear rot disease at each study site (Tables 2 - 4), suggest that high yielding hybrids with satisfactory resistance to ear rot disease can be selected from this cohort of maize hybrids for ear rot resistance breeding in Cameroon. The best yields produced by genotype TZSTR1150X87036 and 90267X88094 for Bangangte and Mbalmayo, respectively, under the circumstances imply that these genotypes can be selected as sources of resistance in each of the study sites. On the other hand, the poorest yields generated by some genotypes (Tables 5-6), suggest that these genotypes cannot be used as breeding materials in the study sites.

The significant difference for hybrid x location interaction on grain yield (Table 4), implies that the disease affected sites differently; a fact that may be attributed to the diverse agro-climatic condition of different soil types, fertility levels and moisture levels; temperatures, and management practices. This also means that different sites must be targeted with different disease management technologies for optimal performance of different genotypes. A similar report was given by Adebayo and Menkir (2014) in Nigeria.

At Bangangte, nine hybrids with yields ranging from 10.2 to 11.7 t ha^{-1}, significantly out- yielded the best hybrid check (CHH 101); the latter with a yield of 10.1 t ha^{-1} (Table 5). These hybrids could be further tested in multi-environmental trials with the aim of selecting high yielding ear rot tolerant materials in Cameroon. At Mbalmayo, three hybrids with yields ranging from 11.9 to 12.9 t ha^{-1} significantly out-yielded the best hybrid check (CLH 103); the latter with a yield of 11.6

TABLE 8. Pooled Pearson correlation coefficients among agronomic and disease related traits of maize hybrids across Bangangte and Mbalmayo trial sites

	AD	SD	ASI	PH	EH	MAT	INC	[a]SEV	[a]EarAsp	[a]PLTVIG	[a]HUSK	LODG	[a]Eardec	[a]Insect	[a]TEX	GYD
AD																
SD	0.84***															
ASI	0.16***	0.17***														
PH	-0.34***	-0.22***	-0.19***													
EH	-0.13**	-0.06	-0.02	0.07												
MAT	0.83***	0.56***	0.13**	-0.35***	-0.18***											
INC	-0.12**	-0.11**	0.08	0.06	0.07	-0.09*										
SEV	-0.10*	-0.12**	0.04	0.07	0.08	-0.08	0.85***									
EarAsp	-0.24***	-0.14**	-0.05	0.03	0.11**	-0.29***	0.10*	0.09*								
PLTVIG	0.10*	0.06	0.05	-0.16***	0.02	0.12**	0.05	0.06	0.04							
HUSK	0.37***	0.30***	0.03	-0.15***	-0.07**	0.35***	0.02	-0.01	-0.17***	-0.01						
LODG	0.06	0.03	0.05	-0.03	-0.12	0.06	-0.02	-0.02	0.01	0.01	-0.04					
Eardec	-0.16***	-0.06	0.01	0.07	0.03	-0.21***	0.48***	0.41***	0.14	-0.05	0.44***	0.01				
Insect	-0.09	-0.02	0.01	0.02	0.03	-0.13**	0.67***	0.61***	0.11*	-0.01	0.01	0.01	0.42***			
TEX	-0.16***	-0.11*	0.09	-0.02	-0.01	-0.19***	0.04	0.03	0.16***	0.17***	-0.15***	0.12	0.01	0.09		
GYD	-0.13**	-0.06	-0.15***	0.08	0.01	-0.16***	-0.23***	-0.26***	-0.05	-0.23***	-0.02	-0.05	-0.01	-0.22***	0.02	

The correlations are estimated by Pairwise method. *, ** and *** = Correlation coefficients significant at $P<0.05$, $P<0.01$ and $P<0.001$ probability levels, respectively. GYD = grain yield (t ha^{-1}), MAT = days from planting to 75% physiological maturity, EH = ear height (cm), PH = plant height (cm), AD = days from planting to 50% anthesis, SD = days from planting to 50% silking, ASI = anthesis silking interval (days), LOD = lodging (%), INC = disease incidence (%), SEV = disease severity (%), TEX = grain texture (%), INSECT = insect damage (%), EARDEC = ear declination (%), HUSK = husk cover (%), EARASP= ear aspect (%), PLTVIG = plant vigour (%)

[a] Angular transformation of visually scored data (1-7 score) was performed and converted to percentage to normalize the data before analysis

TABLE 9. Pooled standard heterosis for grain yield of the top 20 maize hybrids across Bangangte and Mbalmayo trial sites

Hybrids	Standard heterosis (%)				
	GYD (t ha^{-1})	CHH101	87036X1368	CLH103	CHH105
89 23X88094	11.7	15.8	46.3	33.0	28.6
90267X88094	11.4	12.9	42.5	29.5	25.3
89343X88094	11	8.9	37.5	25.0	20.9
90204XExp 124	10.7	5.9	33.8	21.6	17.6
TZSTR1150X87036	10.6	5.0	32.5	20.5	16.5
89243X87036	10.5	4.0	31.3	19.3	15.4
90183XExp 124	10.4	3.0	30.0	18.2	14.3
TZI-5-1171XExp 124	10.2	1.0	27.5	15.9	12.1
90301XExp 124	10.2	1.0	27.5	15.9	12.1
90219X88094	10.1	0.0	26.3	14.8	11.0
88099X88094	10	-1.0	25.0	13.6	9.9
89193X87036	9.9	-2.0	23.8	12.5	8.8
IN EW-SRX1368	9.7	-4.0	21.3	10.2	6.6
89246X87036	9.6	-5.0	20.0	9.1	5.5
90219X87036	9.5	-5.9	18.8	8.0	4.4
89291XExp 124	9.5	-5.9	18.8	8.0	4.4
90219X1368	9.5	-5.9	18.8	8.0	4.4
89311X1368	9.4	-6.9	17.5	6.8	3.3
89 23X87036	9.1	-9.9	13.8	3.4	0.0
89320XExp 124	9.1	-9.9	13.8	3.4	0.0
Mean	7.6	-24.3	-4.5	-13.1	-16
Hybrid checks					
CHH105	9.1	-9.9	13.8	3.4	0.0
CLH103	8.8	-12.9	10.0	0.0	-3.3
87036X136899	8	-20.8	0.0	-9.1	-12.1
CHH101	10.1	0.0	26.3	14.8	11.0

t ha^{-1} (Table 6). Crosses between some lines such as 8923, TZI0501171, 89343, 90219, 89243, 87014, TZSTR1150 89248, 1368, 87036 88094 and Exp 124) can be used to increase the probability of obtaining high yielding hybrid combinations suitable under prevalent disease conditions in Cameroon.

The highest yielding hybrids in this study (Tables 5-7) also exhibited favourable levels of resistance to ear rot disease (Tables 5-7). Genotypes 8923X88094, TZI-5-1171XExp 124, 89343x88094, 90219X87036, 89243X87036 and 87014X87036 had the highest potential as sources of resistance to the maize ear rot disease. Hence, further evaluations need to be done to ascertain more tolerant hybrids that will be registered in the National Catalogue for Plant Varieties. These findings conform to those of Adebayo and Menkir (2014) who worked in Nigeria and concluded that higher yielding maize hybrids were resistant to foliar diseases including maize streak virus, common rust, blight and curvularia.

The short anthesis - silking interval observed in this study (Tables 5-7), could be used to make indirect selections for high yields in various environments. This is in line with findings of earlier works that revealed that short anthesis – silking intervals in maize hybrids subsequently leads to better pollination that enhances yield (Araus *et al*., 2012; Tandzi *et al.,* 2015). Short anthesis-silking interval helps in proper synchronisation of pollen shed and silk emergence in maize for proper pollination and fertilisation to occur (Tandzi *et al*., 2015).

The various tested genotypes, which showed favourable and significant responses to some disease related secondary traits like grain texture, ear insect damage and ear declination (Tables 5-7) could also be used to make indirect selection for ear rot disease resistance in the regions represented by the study sites. Previous works have also showed that genotypes with increased ear declination or dropped ears appear to be resistant to the maize ear rot disease (Russin *et al*., 1997; Rossouw *et al*., 2002). Ako *et al*. (2003) reported that ear rot infected maize had higher insect damage than normal ears.

Broad sense heritability. The heritability of grain texture (5%), plant vigour (6%) and ear height (8%) were the lowest among the parameters measured. High broad sense heritability is an indication of the possibility of effective selection for genetic improvement based on traits. The high heritability for grain yield (45%), days to 50% silking (61%) and days to 50% anthesis (88%) were similar to those of earlier work Bello *et al*. (2012), who demonstrated high heritability of grain yield and its component characters in maize. Wannows *et al*. (2010) concluded that characters with high heritability can easily be fixed with simple selection, resulting to rapid breeding progress. So, outstanding genotypes for maize grain yield and ear rot tolerance should be tested at multilocations to access their performance in several regions of Cameroon.

Standard heterosis. The observed range of heterosis of -9.9% (for CHH101) to 46.3% (for 87036X1368) over the hybrid checks for grain yield, across the sites (Table 7), could be attributed to the fact that deleterious recessive genes of one parent were concealed by the dorminant genes of the other parent (Gurung (2006)). Gurung (2006) reported -22 to 63% similar hetrosis for grain yield in maize populations exposed to high levels of the disease. Jiban *et al*. (2018) reported -0.3 to 73.4% standard heterosis in coordinated varietal trial- hybrid, diallel cross and test cross of Napalese maize hybrids.

In the present study, the cross between 8923 and 88094 exhibited maximum standard heterosis (15.8%) for grain yield over the best hybrid check (CHH101); and exhibited a standard heterosis of 46.3% over the least performing check (87036X1368). Out of the 116 single cross hybrids evaluated across the two locations, 106 showed negative standard heterosis over the best check (CHH101) for grain yield; while 10 crosses (M131X88094, M131XExp 124, TZI-5-1171X1368, TZI-5-1171X87036, TZI-5-1171X88094, TZI-5-1171XExp 124, TZSTR1150X1368, TZSTR1150X87036, TZSTR1150X88094 and TZSTR1150XExp 124) exhibited positive standard heterosis for grain yield (Table 7). Our findings are in line with many previous studies (Ziggiju *et al*. 2017; Abebe *et al*., 2020), who reported positive and negative significant standard heterosis for grain yield in maize hybrids. The high level of heterosis observed in the present study could be attributed to the involvement of more distant related inbred lines (Ziggiju *et al*. 2017; Abebe *et al*., 2020). Fato (2010) and Hallauer and Miranda (1988) suggested that full exploitation of heterosis requires crossing of distantly related materials. This heterotic vigour in the F1 hybrids can be exploited in the development of new ear rot tolerant varieties in Cameroon.

Parametric correlations. Grain yield positively correlated with plant height, ear height and grain texture; but negatively correlated with the rest of the test parameters (Table 8). The negative correlation of grain yield and days to 50% anthesis, days to 50% silking, anthesis-silking interval, days to 75% physiological maturity, ear rot disease incidence, ear rot disease severity, ear aspect, plant vigour, husk cover, lodging, ear declination and ear insect damage, show that grain yield could greatly be reduced with increase in the magnitudes of the measured traits. A similar demonstration was shown by Adebayo and Menkir (2014) in Nigeria who revealed negative correlations of grain yield with plant aspect, ear aspect, streak, rust, blight and curvularia.

The relationship between grain yield and anthesis-silking interval, days to 75% physiological maturity, ear rot disease incidence, ear rot disease severity, plant vigour and ear insect damage were very highly significant ($P<0.001$). These relationships reveal the diversity in the genetic materials used in the study and hence, the possibility of achieving ear rot tolerant maize varieties

The significant relationships between grain yield with either of the following anthesis-silking interval, days to 75% physiological maturity, ear rot disease incidence, ear rot disease severity, plant vigour and ear insect damage was very highly significant (Table 8.). This shows the diversity of potential high yielding and tolerant varieties.

Plant height, ear height anthesis-silking interval, plant vigour, ear rot disease incidence and ear rot disease severity could thus be exploited to make indirect selections for high yield in disease stress conditions. Similar studies have revealed that short anthesis-silking interval in maize hybrids subsequently led to better pollination (Araus *et al.*, 2012; Tandzi *et al.*, 2015).

The correlation coefficients between four agronomic traits: lodging, ear declination, husk cover and ear insect damage with ear rot disease incidence, ear rot disease severity and grain yield, showed moderate to high correlations in the maize hybrids. Similar results from earlier studies have been reported (Robertson-Hoyt *et al.*, 2007; Mukanga, 2009). Generally, the correlations were reliable in indicating whether the relationship between two traits was positive or negative. The negative correlation of lodging with grain yield is a clear indication that selection for resistance for lodging could increase grain yield

The relationship between ear insect damage and grain yield was positive and very highly significant with incidence and severity of *Aspergillus* ear rot (Table 8). This is an indication that selection for ear insect damage reduction would result in reduced incidence and severity of *Aspergillus* ear rot. The negative correlation between grain yield and *Aspergillus* ear rot disease incidence and severity suggests that grain yield is enhanced by tolerant genotypes to the ear rot infection. Adebayo and Menkir (2014) recorded higher maize yields with reduced ear rot infection. A strong relationship between ear insect damage and ear rot severity has also been reported by other researchers (Cardwell *et al.*, 2000; Mukanga, 2009).

CONCLUSION

There is generally a strong hybrid response to *Aspergillus* ear rot in the maize hybrids at the two sites, Bangangte and Mbalmayo both in Cameroon. This provides an opportunity for enhancing the selection for ear rot resistant high yielding maize hybrids in Cameroon. Disease related secondary traits like grain texture, ear insect damage and ear declination could also be used to make indirect selection for ear rot disease resistance in various environments. Some genotypes exhibited increased ear declination or dropped ears and could be used as gene pools for resistance to the maize ear rot disease. The negative correlation of lodging with grain yield is a clear indication that selection for resistance for lodging could increase grain yield. The relationship between ear insect damage and grain yield was negative and very highly significant, but strongly positive and very highly significant with incidence and severity of *Aspergillus* ear rot, indicating that selection for ear insect damage reduction would result in reduced incidence and severity of *Aspergillus* ear rot. The relationship between ear insect damage and grain yield was negative and very highly significant but strongly positive and very highly significant with incidence and severity of *Aspergillus* ear rot; suggesting that selection for ear insect damage reduction would result in reduced incidence and severity of *Aspergillus* ear rot.

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REFERENCES

Abebe Abenezer, Legesse Wolde and Wosene Gebreselassie, 2020. Standard heterosis and trait association of maize inbred lines using line x tester mating design in Ethiopia. *African Journal of Plant Science* 14(4):192-204. doi:10.5897/AJPS2019.1839.

Abebe, M., Brown, L.R., Ranajit, B. and Cleveland, E.T. 2006. A USA-Africa collaboration strategy for identifying, characterizing and developing maize germplasm with resistance to aflatoxin contamination. *Mycopathologia* 162:225-232.

Adebayo, M.A. and Menkir, A. 2014. Agronomic performance of elite drought tolerant maize (*Zea mays* L.) hybrids under natural disease inoculation in the rainforest of Nigeria. *International Journal of Applied Agricultural and Apicultural Research* 10 (1 and 2):154-162.

Ajanga, S. and Hillocks, R.J. 2000. Maize cob rot in Kenya and its association with stalk borer damage. *Crop Protection* 19:297-300.

Ako, M., Schulthess, F., Gumedzoe, M.Y.D. and Cardwell, K.F. 2003. The effect of *Fusarium verticillioides* on oviposition behaviour and bionomics of Lepidopteron and coleopteran pests attacking the stem and cobs of maize in West Africa. *Entomologia Experimentalis et Applicata* 106:201-210.

Araus, L.J, Serret, D.M. and Edmeades, O.G. 2012. Phenotyping maize for adaptation to drought. *Frontier in Physiology* 3(305):20.

Bello, O.B., Ige, S.A., Azeez, M.A., Afolabi, M.S., Abdulmliq, S.Y. and Mohamood, J. 2012. Heritability and genetic advance for grain yield and its component characteristics in maize (*Zea mays* L.). *International Journal of Plant Research* 2(5):138-145. doi::10.5923/j.plant.20120205.01.

Betrán, F.J., Isakeit, T. and Odvody, G. 2002. Aflatoxin accumulation of white and yellow maize inbreds in diallel crosses. *Crop Science* 42:1894-1901.

Cardwell, K.F., Kling, J.G., Maziya-Dixon, B. and Bosque-Pérez, N. A. 2000. Interactions between *Fusarium verticillioides, Aspergillus flavus*, and insect infestation in four maize genotypes in lowland Africa. *Phytopathology* 90:276-284.

Chandrashekar, A., Shewry, P.R. and Bandyopadhyay, R. 2000. Some solutions to the problem of grain mold in sorghum: A review. pp. 124-168.

CIMMYT. 1985. Managing Trials and Reporting Data for CIMMYT's International Maize Testing Program, Mexico, D.F. 21pp.

Fato, P. 2010. Investigation of heterotic patterns and Genetic Analysis of Downy Mildew Resistance in Mozambican lowland maize (*Zea Mays* L.) germplasm. PhD.

Dissertation Presented University of Kwazulu-Natal, South Africa. 146pp.

Fehr, W.R. 1999. Principles of cultivar development: Development of hybrid cultivars. Macmillan Publishing Company, New York, USA. 539pp.

Gurung, D.B. 2006. Genetic diversity, heterosis and combining ability within Nepalese maize varieties. Ph. D. thesis, Central Luzon State University, Science of Munoz, Nueva Ecija, Philippines. 171pp.

Hallauer, A.R. and Miranda, J.B. 1988. Quantitative Genetics in Maize Breeding, 2nd edn. Iowa State University Press, Iowa Ames, USA. 468pp.

Jiban Shrestha, Dil Bahadur Gurung and Tirtha Raj Rijal. 2018. Standard heterosis for grain yield in maize hybrids. *Farming and Management* 3(1):30-36. doi: 10.31830/ 2456-8724. 2018.0001.6.

Kempthorne, O. 1957. An Introduction to Genetic Statistics, New York, John Willey and sons, Inc., USA. 545pp.

Kossou, D.K., Mareck, J.H. and Bosque-Perez, N.A. 1993. Comparison of improved and local maize varieties in the Republic of Benin with emphasis on susceptibility to *Sitophilus zeamais* Motschulsky. *Journal of Stored Product Research* 29:333-343.

Kwemoi, D.B. 2010. Characterization of diverse set of maize germplasm for resistance to infection by *Aspergillus flavus*. Master's thesis dissertation, Makerere University, Kampala, Uganda.88pp.

Landeira, C., Frazzoli, C., Orisakwe, O.E. 2017. Engaging one health for non-communicable diseases in Africa. Perspective for mycotoxins. *Front Public Health*5: 266.

Li, R. 2004. A genetic study of resistance to kernel infection by *Aspergillus flavus* in maize. Louisiana State University and Mechanical Collage, PhD. Dissertation, USA. 64pp.

Mukanga, M. 2009. Genetic improvement of Zambian maize (*Zea mays* L.) populations for resistance to ear rot and a survey of associated Mycotoxins. PhD. Thesis, African Centre for Crop Improvement, University of KwaZulu-Natal, South Africa. 205pp.

Munkvold, G.P. and Desjardins, A.E. 1997. Fumonisins in maize: Can we reduce their occurrence? *Plant Disease* 81:556-565.

Reid, L.M., Hamilton, R.I. and Mather, D.E. 1996. Distribution of deoxynivalenol in *Fusarium graminearum* infected maize ears. *Phytopathology* 86:110- 114.

Robertson-Hoyt, L. A., Betrán, J., G. A. Payne, J., White, D.G., Isakeit, T., Maragos, C.M., Molnár, T.L. and Holland, J.B. 2007. Relationships among resistances to *Fusarium* and *Aspergillus* ear rots and contamination by fumonisin and aflatoxin in maize. *Hytopathology* 97:311-317.

Rossouw, J.D., Van Rensburg, J. B. J. and Van Deventer, C. S. 2002. Breeding for resistance to ear rot of maize caused by *Stenocarpella maydis* (Berk) Sutton. Evaluation of selection criteria. *South African Journal of Plant and Soil* 19:182-187.

Russin, J.S., Guo, Z.B., Tubajika, K.M. Brown, R.L. Cleveland, T. E. and Widstrom, N.W. 1997. Comparison of kernel wax from corn genotypes resistant or susceptible to *Aspergillus flavus*. *Phytopathology* 87:529-533.

SAS Institute. 2009. SAS Proprietary Software Release 9.2. SAS Institute, Inc., Cary, NC., USA.

Singh, R.K. and Singh, P.K. 1994. A manual on genetics and plant breeding. Experimental techniques, Kalyani Publs. Ludiana, New Delhi, India. pp. 99-107.

Tandzi, L.N., Ngonkeu, E.M., Youmbi, E., Nartey, E., Yeboah, M., Gracen, V., Ngeve, J. and Mafouasson, H.A. 2015. Agronomic performance of maize hybrids under acid and control soil conditions. *International Journal of Agronomy and Agricultural Research* 69(4):275-291.

Wannows, A.A., Azam, H.K. and Al-Ahmad, S.A. 2010. Genetic variance, heritability, correlation and path coefficient analysis in yellow maize crosses (*Zea mays* L.). *Agriculture and Biology Journal of North America* 1(4):630-637.

Windham, G.L. and Williams, W.P. 2002. Evaluation of corn inbreds and advanced breeding lines for resistance to aflatoxin contamination in the field. *Plant Diseases* 86:232-234.

Ziggiju, M, Habtamu, Z. and Legesse, W. 2017. Ethiopian standard heterosis of pipeline maize (*Zea Mays* L.) hybrids for grain yield and yield related traits. *International Journal of Plant Breeding and Genetics* 4(1):249-255.

Zuber, M.S., Calvert, O.H., Kwolek, W.F., Lillehoj, E.B. and Kang, M.S. 1978. Aflatoxin BI production in an eight-line diallel of *Zea mays* infected with *Aspergillus flavus*. *Phytopathology* 68:1346-1349.