African Crop Science Journal, Vol. 30, No. 1, pp. 101 - 114
Printed in Uganda.
ISSN 1021-9730/2022 $4.00

DOI: https://dx.doi.org/10.4314/acsj.v30i1.8

FIELD PERFORMANCE OF *Shrunken-2* MAIZE HYBRIDS AND ITS RELATIONSHIP WITH GENETIC DISTANCE OF THEIR INBRED PARENTS

O.O. OLADEJO, V.O. ADETIMIRIN[1] and J.E. IBOYI[2]

Pan African University Life and Earth Sciences Institute, University of Ibadan, Ibadan 200284, Nigeria
[1]Plant Breeding Laboratory, Department of Crop and Horticultural Sciences, University of Ibadan, Ibadan 200284, Nigeria
[2]Department of Agronomy, University of Florida, West Florida Research and Education Center, Jay, FL 32565, USA
Corresponding author: omobolanle.oladejo@uniosun.edu.ng

(*Received 13 January 2022; accepted 27 February 2022*)

ABSTRACT

Maize (*Zea mays* L.) is an important crop in West and Central Africa, where flint and dent types are the widely cultivated and used as food, feed and raw materials in industries. Sweet maize, the generic term used for maize types with elevated levels of sugar in their kernels, is increasingly popular in Nigeria and other countries of West Africa. This study evaluated the field performance of some super-sweet *shrunken-2* (*sh-2*) maize hybrids and determined its relationship with SSR-based genetic distance of their inbred parents. A total of 21 *shrunken-2* maize hybrids and seven *shrunken-2* maize hybrid checks were evaluated. Analysis of variance was carried out on data collected and correlation analysis between the genetic distance of parental lines and agronomic traits of their hybrids. There were significant differences ($P < 0.01$) among the hybrids for all agronomic traits studied. Field emergence ranged from 28.2 to 97.4%; while fresh cob weight and husk cover (1-9) ranged from 0.05 to 0.17 and 2.7 to 6.7 g plant^{-1}, respectively. Among the hybrids, UI1 x UI75 was the most promising, combining high emergence with high fresh cob yield, good husk cover, resistance to endemic foliar diseases, good plant aspect and moderate ear aspect. Genetic distance between parental inbred lines was not useful for predicting hybrid performance among the sets of *shrunken-2* inbred lines considered. The parental lines, however, have potential for use in *shrunken-2* maize breeding programmes.

Key Words: Cob yield, genetic distance, *Shrunken-2* maize

RÉSUMÉ

Le maïs (*Zea mays* L.) est une culture importante en Afrique de l'Ouest et du Centre, où les types de silex et denté sont largement cultivés et utilisés comme aliments, aliments pour animaux et matières premières dans les industries. Le maïs doux, le terme générique utilisé pour les types de maïs avec des niveaux élevés de sucre dans leurs grains, est de plus en plus populaire au Nigeria et dans d'autres pays d'Afrique de l'Ouest. Cette étude a évalué la performance au champ de certains hybrides de maïs super-doux *shrunken-2* (*sh-2*) et a déterminé sa relation avec la distance génétique basée sur le SSR de leurs parents consanguins. Au total, 21 hybrides de maïs *shrunken-2* et sept témoins hybrides de maïs *shrunken-2* ont été évalués. Une analyse de variance a été effectuée sur les données recueillies et une analyse de corrélation entre la distance génétique des lignées parentales et les caractères agronomiques de leurs hybrides. Il y avait des différences significatives (P < 0,01) entre les hybrides pour tous les caractères agronomiques étudiés. L'émergence au champ variait de 28,2 à 97,4 %; tandis que le poids de l'épi frais et la couverture de l'enveloppe (1-9) variaient de 0,05 à 0,17 et de 2,7 à 6,7 g plante^{-1}, respectivement. Parmi les hybrides, UI1 x UI75 était le plus prometteur, combinant une émergence élevée avec un rendement élevé en épis frais, une bonne couverture de brou, une résistance aux maladies foliaires endémiques, un bon aspect de la plante et un aspect modéré de l'épi. La distance génétique entre les lignées consanguines parentales n'était pas utile pour prédire les performances hybrides parmi les ensembles de lignées consanguines *shrunken-2* considérées. Les lignées parentales, cependant, ont un potentiel d'utilisation dans les programmes de sélection de maïs *Shrunken-2*.

Mots Clés : Rendement en épis, distance génétique, maïs *shrunken-2*

INTRODUCTION

Maize (*Zea mays* L.) is an important crop in West and Central Africa, where flint and dent types are the widely cultivated and used as food, feed and raw materials in industries. Sweet maize, the generic term used for maize types with elevated levels of sugar in their kernels, is becoming increasingly popular in Nigeria and other countries of West Africa. The sweetness in these maize types is conditioned by several recessive genes viz. *amylose extender* (*ae*), *sugary enhancer* (*se*), *sugary* (*su*),*brittle-1* (*bt-1*), *brittle-2* (*bt-2*), *shrunken-1* (*sh-1*) and *shrunken-2* (*sh-2*). These genes promote changes in carbohydrate composition in the endosperm and cause differences in the starch-sugar proportions in the kernels (Tracy, 2001). Among sweet maize mutants, the *sh-2* gene results in the highest level of sweetness. The *sh-2* mutant at the immature milky stage (20 days after pollination) contains 29.9% sucrose, compared to 10.2% in su1 and 3.5% in field corn (Creech, 1965). The sweetness conditioned by *sh-2* mutant is retained for longer after harvest compared to other sweet maize mutants (Wilson *et al.*, 1993; Yousef and Juvik, 2002), giving it greater processing and shipment flexibility to distant markets, with minimal loss in eating quality. These attributes make *sh-2*maize the ideal sweet maize type for Nigeria and other countries of West Africa where refrigerated haulage infrastructure is rarely available or expensive to procure (Adetimirin *et al.*, 2006). The kernels of *sh-2* maize are also a good source of tocopherols, carotenoids, vitamin A, and vitamin C (Juvik, 2009; Yunita, 2017), underscoring its potential for improving the nutrition of people of West Africa, a region which has one of the lowest nutrition rankings among all regions of the world (UNDESA, 2020).

In contrast to flint and dent maize that have a genetic crop improvement history of about seven decades in Nigeria (Fajemisin, 2014), sweet maize breeding was initiated by the Department of Agronomy, University of Ibadan in 2000, with the introduction of a broad-base *shrunken-2* maize population from South Korea. The goal of the introduction was to provide a rich germplasm for the development of *sh-2* maize hybrids for Nigeria and the rest of West Africa. Prior to the introduction, there was no record of an active sweet maize breeding programme in West Africa. Consequently, all sweet maize cultivation to date has been based on imported seeds. The introduced *sh-2* maize population was adapted to tropical environmental conditions by four cycles of mass selection (Adetimirin, 2008).

Although open-pollinated varieties of maize are widely cultivated in Nigeria, a combination of factors provide hybrids a unique niche in the production of sweet maize. These factors include the uniformity of hybrids for important agronomic traits including time taken to maturity that makes possible one-time mechanical harvesting, their higher yield and the prime price of fresh sweet maize that over compensates for the high cost of the seeds.

Information on germplasm diversity and relationships among plant materials is of great importance in maize hybrid development (Choukan and Warburton, 2005; Vanèetoviæ *et al.*, 2015). The superiority of hybrids over their parents, referred to as hybrid vigour or heterosis, is often manifested when the parental inbred lines show dissimilarity. Such dissimilarities are not only in terms of easily observed field traits but may be on the basis of their genetic material, which unlike important agronomic traits, are not influenced by environments (Legesse *et al.*, 2007). Molecular markers can facilitate the process of hybrid development. Simple sequence repeat (SSR) markers, a type of DNA markers, are useful in revealing the dissimilarity among inbred lines, thus providing a basis for the exploitation of heterosis among them. In addition to their freedom from interaction with the environment, the use of molecular markers has proven to be valuable for diversity analysis because they are fast, efficient and detect large numbers of differences (Melchinger, 1999; Legesse *et al.*, 2007). A measure of dissimilarity is the genetic distance values between pairs of inbred lines. Information on genetic distance can be useful in guiding the selection of parents for the development of superior hybrids, especially in situations where testers for the determining heterotic groups are not available as is the case with the lines developed from the tropical-adapted *sh-2* maize population. It can also guide the selection of testers and the classification of inbred lines into heterotic groups. Two inbred lines (UI 48 and UI 35) developed from the tropicalised *sh-2* maize population, whose F_1 hybrid was found to show heterosis with a fresh cob yield > 10 t ha^{-1} (Akintunde, 2017) had a genetic distance of 0.52. These results suggest that greater genetic distance may be associated with heterosis among the lines developed from the *sh-2* population.

The objective of this study was to evaluate the field performance of hybrids formed from some inbred lines extracted from the tropical-adapted *shrunken-2* maize population, and determine the relationship between fresh yield and other agronomic traits of the hybrids on one hand and the SSR-based genetic distance between their parental lines.

MATERIALS AND METHODS

A field study was carried out at the Teaching and Research Farm of the University of Ibadan (7^{O}26'N, 3^{O}54'E), Ibadan, Nigeria; while the laboratory study was carried out in the Biotechnology Laboratory of the Department of Crop and Horticultural Sciences, University of Ibadan.

Field experiment. Eight *sh-2* inbred lines at S_8 stage of inbreeding (UI 1, UI 7, U1 10, UI 58, UI 61, UI 64, UI 75 and UI 77),with good agronomic traits and seed vigour were selected for the study. The lines were crossed in a diallel during the dry season (January - April) of 2020 under irrigation. Of the 28 crosses (without reciprocals) expected, adequate seeds were produced for 21 single crosses and evaluated between May and August, 2020. Plots consisted of single rows, each 3 m long and spaced 0.75 m apart. One seed was sown per hill, with hill spacing of 0.25 m. Fertiliser (NPK 15-15-15) was applied at the rate of 30 kg N per hect are at two weeks after planting (WAP) and an additional 30 kg N of urea was applied at 6 WAP. An insecticide containing Emamectin Benzoate (5% WDG) was sprayed to control fall armyworm (*Spodoptera frugiperda*).

Emergence was recorded at 10 days after planting. Seedling vigour was scored on plot basis at 4 WAP on a scale of 1 to 9, where 1 = very tall seedlings, very large and green leaf blade, indicating excellent vigour; and 9 = very short seedlings with very small yellow leaf blades, which indicate very poor vigour (Cisse and Ejeta, 2003; Adetimrin *et al.*, 2006; Adetimrin, 2007). Seedling height was measured at 4 WAP, using five representative plants in each plot, as the distance from the soil surface to the upper most visible collar. Seedling length was also measured at 4 WAP on the same sampled plants in each plot, as the distance from the soil surface to the tip of the leaf blade when held in an upright position. (Adetimirin, 2007).

Plant height and ear height were measured at 10 WAP on five plants per plot, as the distance from the soil level to the collar of the upper most leaf and collar of the leaf bearing the upper most ear, respectively. Days to anthesis was determined as the number of days from planting to when 50% of the plants in a plot shed pollen; while days to silking was the number of days from planting to when 50% of the plants in a plot showed silk extrusion. Husk cover was scored on plot basis on a scale of 1 to 9, where 1 = tight husk cover and 9 = poor husk cover with part of the ear exposed. Plant aspect, based on desirability of plant type, was scored on a scale of 1 to 9, where 1 = excellent plant type and 9 = poor plant type. Foliar diseases were scored on a scale of 1 to 9 based on the severity of the endemic diseases; on this scale 1 = highly resistant with clean leaves and 9 = severe foliar symptoms. Plants in each plot were harvested at 21 days after 50% silking. Data collected at harvest were number of ears per plant, number of cobs (ears with husk removed) per plant, ear weight per plant and cob weight per plant. Only cobs with approximately 250 filled kernels were considered marketable and included in cob weight determination. Other data collected were number of kernel rows, number of kernels per row, cob length and cob width. These were measured on five cobs; cob width was measured at the widest part of the cob using a digital Vernier calliper.

Laboratory experiment. Seeds of the eight inbred lines used in the field study were planted in pots. Three weeks after planting, DNA was extracted from leaf tissues on Whatman Flinders Technology Associates (FTA) plant cards using the direct press method (Whatman FTA protocol BDOS). Purification of DNA samples for polymerase chain reaction (PCR) was as described by Iboyi *et al.* (2020). The eight inbred lines were genotyped at 23 simple sequence repeat (SSR) marker loci covering the 10 linkage groups and previously reported to have a minimum polymorphic information content (PIC) of 0.75 (Senior *et al.*, 1998; Krishna*et al.*, 2012); three of the markers were on each of chromosomes2, (bnlg1297, mmc0401 and phi127), 3 (umc2369, phi053 and umc2050), 4 (phi072, bnlg1937 and phi006) and 6 (phi126, umc1656 and umc2165); each of chromosomes 1 (umc 1568 and phi064), 7 (phi034 and phi051), 8 (umc1483, umc1728), 9 (phi022 and bnlg1506) and 10 (umc1152 and phi050) had two markers; while chromosome 5 (umc1153) had one marker. Primer dilution, PCR amplification, electrophoresis and gel scoring were carried out as described by Iboyi *et al.* (2020).

Data analysis. Analysis of variance (ANOVA) was carried out on all field-collected data using PB Tools, version 1.4 (2014). Genetic similarity (GS) among pairs of inbred lines was computed according to Nei and Li (1979), using the Numeric Taxonomy System of Statistic (NTSYS) software package 2.1 (Rohlf, 2000). Genetic distance (GD) was 1-GS. Pearson's correlation coefficient was calculated among pairs of selected field traits as well as between genetic distance between parental inbred lines on one hand and field traits of their hybrids on the other.

RESULTS AND DISCUSSION

There were significant differences (P <0.01) among the hybrids for all traits measured, an indication of genetic variation, thus providing a rational basis for selection of superior genotypes (Table 1). In addition to yield, the most desirable *sh-2* maize hybrids must show superiority in a large number of important traits among which is field emergence. Poor field emergence of *sh-2*maize is one of the problems that has limited its wide adoption for cultivation (Zhao *et al.*, 2007), making improvement in field emergence one of the breeding goals in the crop. Field emergence has implications for stand establishment, and ultimately productivity. Nine (UI 1 x UI 75, UI 1 x UI 64,UI 1 x UI 77, UI 61 x UI 7, UI 61 x UI 10, UI 64 x UI 77, UI 64 x UI 7, UI 77 x UI 7 and UI 7 x UI 10) of the 21 hybrids had field emergence values higher than 75%; the average emergence of the seven hybrid checks was 77.5%. Inbred line UI 7 was a parent in four of the nine hybrids; while UI 64 and UI 77 were each involved as a parent in three of the hybrids (Table 2). Although the incompleteness of the diallel precluded analysis for combining ability, the three inbred lines involved as parents in three to four of the nine hybrids with the highest emergence have potential for use as parents in a breeding programme for high field emergence. In a study carried out using the tropicalised *shrunken-2* maize population from which the inbred lines used in this study were extracted, Adetimirin (2008) reported a considerably higher dominance variance for field emergence relative to additive variance with broad and narrow-sense heritability values of 53 and 7.2%, respectively. The results of the present study and those of Adetimirin (2008) indicate the possibility of improvement in field emergence through the development of hybrids that optimise this trait using UI 7 as one of the parents.

In addition to field emergence, rapid seedling growth is of utmost importance for maximising use of available soil water after planting, especially given the erratic rainfall at the commencement of the rains in many tropical countries, which has become more frequent in recent times as result of global climate change. Seedling vigour score, seedling height and seedling length are three indices of seedling vigour; the three traits were significantly correlated in the present study (r = -0.68- 0.93, P < 0.01; Table 3). Seedling vigour has an advantage over the other two traits because it is rapid and incorporates leaf blade colour, which is not reflected in seedling height and seedling length measurements (Adetimirin, 2007). With the exception of UI 1 x UI 64, which had a seedling vigour score of 5.7, all the hybrids with emergence values higher than 75.0% had vigour scores ranging between 2.3 and 3.7. These results indicate that majority of the hybrids with high field emergence also had high seedling vigour.

The 21 hybrids obtained from the partial diallel crossing attained (50%) mid-silking at 51.7-57.0 DAP and harvest maturity at 72-83 DAP; harvest maturity of the hybrid checks was attained at 71-77 DAP. The eight hybrids with high emergence and high seedling vigour from the partial diallel had a mean time taken to harvest maturity of 76 DAP. In the present study, harvest maturity was 21 days after mid-silking. Both days to anthesis and silking were significantly correlated (r = 0.80; P< 0.01). Sweet maize is not considered a full-season crop because they are harvested at 20-21 days after mid-silking. Full season normal endosperm maize (grown for grain) and grouped as extra-early attain mid-silking and maturity at 49-54 DAP and 85-90 DAP, respectively. Consequently, the *sh-2* maize hybrids evaluated in the present study can be considered extra-early. Earliness to maturity is a genetic strategy to avoid end-of-season drought (Olaoye *et al.,* 2009).

Cob and ear traits of the hybrids were, in general, significantly correlated (0.65 - 0.94, P < 0.01; mean = 0.76). This implies that any

TABLE 1. Mean squares from analysis of variance for seedling and mature plant traits of *Shrunken-2* hybrids evaluated in Ibadan, Nigeria

Source	Df	Emergence (%)	Vigour score (1-9)	Seedling height (cm)	Seedling length (cm)	50% anthesis	50% silking	Ear height (cm)
Rep	2	522.2*	0.8^{ns}	71.6**	327.1**	39.6^{ns}	0.00^{ns}	56.4^{ns}
Hybrids	27	3499.6**	8.3**	354.5**	4688.6**	1739.3**	1912.2**	4083.3**
Error	54	43.9	0.4	13.4	59.1	32.4	611.5	25.0
CV (%)		21.6	25.7	21.1	11.8	10.3	6.9	8.2

Source	Df	Plant height (cm)	Number of ears per plant	Number of cobs per plant	Ear weight per plant (kg)	Cob weight per plant (kg)	Ear aspect score (1-9)	Number of kernel rows
Rep	2	263.3^{ns}	0.02^{ns}	0.02^{ns}	0.00^{ns}	0.00^{ns}	0.73^{ns}	0.29^{ns}
Hybrids	27	25426.6**	0.5**	0.4**	0.03**	0.01**	17.75**	102.37**
Error	54	84.3	0.01	0.01	0.00	0.00	0.62	0.22
CV (%)		5.9	22.4	23.7	21.0	21.6	19.8	4.7

Source	Df	Number of kernels per row	Cob length (cm)	Cob diameter (mm)	Foliar disease score (1-9)	Plant aspect score (1-9)	Husk cover score (1-9)
Rep	2	6.34^{ns}	0.36^{ns}	0.90^{ns}	1.48**	2.89**	0.58^{ns}
Hybrids	27	786.68**	154.26**	1055.85**	8.19**	11.15**	18.22**
Error	54	2.67	0.58	0.96	0.18	0.42	0.81
CV (%)		6.1	6.4	3.1	17.8	22.2	24.1

N.B: CV = Coefficient of Variation, ns = non-significant, * = significant at P<0.05, ** = significant at P <0.01

TABLE 2. Means of agronomic and fresh yield traits of *sh-2* genotypes

S/N	Hybrids	Emergence (%)	Vigour score (1-9)	Seedling height (cm)	Seedling length (cm)	Days to 50% anthesis	Days to 50% silking	Ear height (cm)	Plant height (cm)	Number of ears per plant	Number of cobs per plant	Ear weight per plant (kg)
1.	UI 1 x UI 61	58.9	3.0	21.2	83.8	54.3	58.7	81.0	215.3	1.0	0.8	0.23
2.	UI 1 x UI 75	76.9	3.7	24.6	87.6	55.0	57.7	81.3	226.6	1.0	0.9	0.25
3.	UI 1 x UI 64	79.5	5.7	16.9	58.3	58.7	65.3	62.4	181.8	0.8	0.5	0.09
4.	UI 1 x UI 77	97.4	2.7	30.1	103.7	52.7	53.3	87.6	227.9	1.0	0.9	0.25
5.	UI 1 x UI 58	64.1	3.3	23.1	88.0	57.0	60.0	101.7	236.3	0.9	0.8	0.24
6.	UI 61 x UI 75	64.1	4.0	18.7	78.9	54.7	56.3	67.9	207.1	0.9	0.8	0.25
7.	UI 61 x UI 64	66.7	4.3	17.7	78.0	54.7	57.3	75.4	215.2	1.0	0.9	0.25
8.	UI 61 x UI 77	74.3	3.0	24.3	97.2	53.3	54.3	80.5	213.2	1.0	0.9	0.26
9.	UI 61 x UI 58	46.1	4.3	16.4	72.7	57.0	61.3	72.9	199.2	1.0	0.8	0.21
10.	UI 61 x UI 7	87.2	3.7	17.6	77.6	54.7	57.3	62.0	161.7	1.0	0.8	0.22
11.	UI 61 x UI 10	84.6	2.7	21.4	88.9	53.0	55.3	80.0	186.8	1.0	0.9	0.25
12.	UI 75 x UI 64	61.5	3.0	25.7	95.1	51.7	56.0	89.2	209.7	0.9	0.7	0.15
13.	UI 75 x UI 77	28.2	3.3	27.6	94.4	53.3	51.2	81.3	204.5	1.1	1.1	0.26
14.	UI 75 x UI 7	74.3	4.0	21.6	81.0	56.0	57.7	78.7	190.6	0.9	0.8	0.19
15.	UI 64 x UI 77	79.5	2.3	28.9	109.3	52.0	52.7	89.5	228.1	1.0	0.8	0.24
16.	UI 64 x UI 58	53.9	3.7	22.0	83.9	56.3	60.0	102.2	232.9	1.0	0.8	0.25
17.	UI 64 x UI 7	82.0	3.7	29.2	85.0	53.7	55.7	79.4	198.5	1.0	0.8	0.19
18.	UI 64 x UI 10	69.2	3.7	19.1	70.5	55.0	58.0	82.0	209.6	1.0	0.8	0.26
19.	UI 77 x UI 7	79.5	2.3	29.0	101.4	53.7	53.3	88.1	191.7	0.9	0.9	0.20
20.	UI 77 x UI 10	74.3	3.0	24.8	91.4	55.0	55.7	88.6	200.6	0.9	0.8	0.24
21.	UI 7 x UI 10	89.7	3.0	25.9	91.6	56.3	57.7	70.2	166.1	1.0	0.9	0.21
22.	UISHH-CK1	61.6	2.3	32.2	105.7	51.0	53.0	86.0	214.1	1.2	0.9	0.31
23.	UISHH-CK2	82.0	3.0	26.4	100.6	52.0	54.0	80.8	188.3	1.0	0.9	0.37
24.	UISHH-CK3	74.4	2.3	33.6	109.8	49.0	51.0	87.1	220.8	1.1	0.9	0.32
25.	UISHH-CK4	87.2	2.3	33.8	116.3	48.0	50.0	75.4	185.4	1.0	0.9	0.37
26.	UISHH-CK5	70.9	3.3	22.3	88.5	54.0	56.0	110.5	246.7	1.4	1.1	0.33
27.	UISHH-CK6	79.5	2.3	33.4	112.7	54.0	53.0	103.6	242.3	1.0	0.9	0.33
28.	UISHH-CK7	86.6	2.0	32.4	115.1	48.0	50.0	69.3	180.3	1.0	0.9	0.35
	S.E	6.97	0.39	2.27	4.78	3.30	0.99	2.95	5.50	0.05	0.07	0.02

TABLE 2. Contd.

S/N	Hybrids	Ear weight per plant (kg)	Cob weight per plant (kg)	Ear aspect score (1-9)	Number of kernel rows	Number of kernels per row	Cob length (cm)	Cob diameter (mm)	Foliar disease score (1-9)	Plant aspect score (1-9)	Husk cover score (1-9)
1.	UI 1 x UI 61	0.23	0.14	5.0	13.1	37.1	16.7	44.2	2.3	4.0	6.7
2.	UI 1 x UI 75	0.25	0.16	4.3	12.4	39.5	16.8	41.5	3.0	3.3	2.7
3.	UI 1 x UI 64	0.09	0.05	7.0	12.4	23.4	10.7	36.2	3.0	7.0	6.0
4.	UI 1 x UI 77	0.25	0.16	4.7	13.2	40.0	17.4	45.9	3.0	3.0	5.3
5.	UI 1 x UI 58	0.24	0.14	5.0	13.5	39.8	17.7	42.3	2.7	4.0	6.3
6.	UI 61 x UI 75	0.25	0.15	4.3	12.9	35.5	16.5	44.8	3.0	3.7	4.0
7.	UI 61 x UI 64	0.25	0.15	5.3	13.4	35.6	15.5	44.2	2.7	4.7	6.7
8.	UI 61 x UI 77	0.26	0.16	5.7	12.4	36.7	16.7	45.0	3.3	3.3	3.7
9.	UI 61 x UI 58	0.21	0.15	6.3	13.4	32.6	15.9	43.5	2.7	5.3	5.7
10.	UI 61 x UI 7	0.22	0.15	4.3	13.5	33.1	14.7	44.7	2.3	3.3	5.3
11.	UI 61 x UI 10	0.25	0.17	6.0	12.4	39.9	16.8	42.5	2.0	2.7	6.7
12.	UI 75 x UI 64	0.15	0.10	6.0	13.6	32.5	14.1	39.4	7.0	5.0	4.3
13.	UI 75 x UI 77	0.26	0.16	6.3	13.4	33.7	15.8	40.9	4.3	4.0	3.7
14.	UI 75 x UI 7	0.19	0.12	3.7	13.5	35.9	14.9	40.8	3.3	3.7	3.0
15.	UI 64 x UI 77	0.24	0.15	5.7	13.1	38.7	16.9	44.1	3.0	2.7	4.7
16.	UI 64 x UI 58	0.25	0.16	5.3	13.0	40.2	17.9	41.9	3.3	4.7	6.0
17.	UI 64 x UI 7	0.19	0.12	4.3	14.4	31.3	13.6	42.2	3.3	3.7	5.3
18.	UI 64 x UI 10	0.26	0.16	6.0	13.6	40.0	17.5	41.2	2.3	3.7	6.7
19.	UI 77 x UI 7	0.20	0.12	5.0	13.2	34.1	14.5	41.8	3.7	3.3	3.3
20.	UI 77 x UI 10	0.24	0.14	5.3	12.9	37.3	17.1	41.2	3.0	3.0	4.3
21.	UI 7 x UI 10	0.21	0.13	5.0	14.0	36.5	16.5	40.5	3.3	4.0	4.0
22.	UISHH-CK1	0.31	0.17	5.0	14.0	36.3	17.8	42.5	3.0	3.3	4.0
23.	UISHH-CK2	0.37	0.20	3.0	14.4	38.8	17.5	48.7	3.0	2.7	2.3
24.	UISHH-CK3	0.32	0.17	4.7	13.7	38.8	17.7	43.7	3.0	2.7	4.0
25.	UISHH-CK4	0.37	0.22	3.0	13.6	37.4	16.3	48.9	2.0	2.0	2.0
26.	UISHH-CK5	0.33	0.17	3.7	15.3	32.1	15.6	42.3	3.0	3.7	3.0
27.	UISHH-CK6	0.33	0.16	3.7	15.2	37.0	15.7	45.0	2.3	3.7	2.3
28.	UISHH-CK7	0.35	0.19	3.0	13.2	38.1	17.3	48.2	2.3	2.3	2.0
	S.E	0.02	0.01	0.45	0.27	0.97	0.44	0.57	0.27	0.41	0.52

TABLE 3. Correlation among selected traits of *Shrunken-2* maize hybrids evaluated in Ibadan, Nigeria

Trait	Vigour score	Seedling length	50% silking	Ear height	Ear weight/ plant	Cob weight/ plant	Ear aspect	Cob length	Cob diameter	Plant aspect (1-9)
Emergence	-0.39ns	0.57**	-0.29ns	0.07ns	-0.12ns	-0.09ns	-0.33ns	0.15ns	0.15ns	-0.28ns
Vigour score		-0.78**	0.64**	-0.29ns	-0.26ns	-0.23ns	0.07ns	-0.36ns	-0.54**	0.57*
Seedling length			-0.71**	0.52*	0.02ns	-0.06ns	-0.32ns	0.30ns	0.50*	-0.40ns
50% silking				-0.24ns	-0.25ns	-0.14ns	0.15ns	-0.32ns	-0.44*	0.56**
Ear height					0.12ns	0.11ns	-0.09ns	0.43ns	0.15ns	-0.29ns
Ear weight per plant						0.94**	0.13ns	0.82**	0.58**	-0.49*
Cob weight per plant							0.12ns	0.78**	0.49*	-0.48*
Ear aspect score								-0.01ns	-0.36ns	0.27ns
Cob length									0.51*	-0.57**
Cob diameter										-0.46*

of these traits could be used in breeding programme for fresh cob yield improvement in super-sweet maize. The husk of the *sh-2* hybrids in some of the hybrids evaluated in the present study constituted on average 37 and 47% of the weight of the ears of the 21 hybrids and seven checks, respectively. Consequently, cob weight was the most important of the yield traits, and ranged from 0.10 kg plant^{-1} (5.3 t ha^{-1}) to 0.17 kg plant^{-1} (9.0 t ha^{-1}), with a mean of 0.15 kg plant^{-1} (7.5 t ha^{-1}) for eight of the 21 hybrids of the incomplete diallel with high emergence and seedling vigour. Mean cob yield for the 21 hybrids was 0.12 kg plant^{-1} (6.4 t ha^{-1}). Fresh cob yield of the eight hybrids was 16.7% higher than the mean cob yield of the 21 hybrids but 28% lower than the cob yield of the seven hybrid checks, which ranged from 0.16 kg plant^{-1} (8.5 t ha^{-1}) to 0.22 kg plant^{-1} (11.7 t ha^{-1}). These results indicate tremendous opportunity to select high yielding super-sweet hybrids for the Nigerian environment. Akintunde (2017) reported a fresh cob yield of 10.0 - 10.2 t ha^{-1} for three experimental *sh-2* maize hybrids developed at the University of Ibadan. The fresh cob yields of the most promising hybrids and checks identified in the present study are much higher than the fresh cob yield of 6.9 to 7.7 tha^{-1} reported by Kim *et al*. (2008) for normal endosperm tropical white maize and 6.9 to 7.1 t ha^{-1} obtained by the authors for yellow kernel maize grown at similar level of nitrogen application (60 kg N ha^{-1}) in Ibadan, Nigeria.

Ear quality goes beyond cob yield; while ear aspect, which integrates yield, kernel set and appeal, ranged from 3.7 to 7.0 for the 21 hybrids of the incomplete diallel, with only three of the eight hybrids with high emergence and high vigour having acceptable ear aspect scores less than 5.0 (Table 2). The three hybrids were UI 1 x UI 75 (ear aspect score = 4.3), UI 1 x UI 77 (ear aspect score = 4.7) and UI 64 x UI 7 (ear aspect score = 4.3). Among these, UI 1 x UI 75 was the only hybrid that had very good plant type, husk cover and resistance to local foliar diseases. Better plant type (assessed by plant aspect score) was significantly associated with higher cob weight per plant (-0.48), higher number of kernels per row (-0.61), cob length (-0.57) and cob diameter (-0.46) (Table 3). These results indicate the usefulness of plant aspect in the breeding of high yielding *sh-2* maize hybrids. Plant aspect was also reported to be significantly correlated with grain yield in normal endosperm maize (Oyekunle and Badu-Apraku, 2018).

Genetic distance between pairs of the *sh-2* maize inbred lines ranged between 0.04 for UI 58 x UI 61 and 0.48 for UI 10 x UI 61, with a mean of 0.33 (Table 4). Correlations between SSR-based genetic distance on one hand and field traits on the other hand were non-significant (Table 5). Genetic distance of inbred lines is known to play a major role in predicting the field performance of hybrids (Melchinger, 1999). In Nigeria, Akintunde (2017) reported fresh cob yield >10 t ha^{-1} from *shrunken-2* maize hybrid produced from two inbred lines with SSR-based genetic distance of 0.52. The genetic distances between pairs of parental inbred lines used in the present study were lower than the value for the inbred parents that produced high yield in the study by Akintunde (2017) and may have accounted for the low correlation obtained. Our results indicate that SSR-based genetic distance of inbred parents in the population studied is of limited value in predicting field performance of their hybrids. Several authors (Menkir *et al.,* 2004; Xia *et al.,* 2004; Barata and Carena, 2006; Dhliwayo *et al.,* 2009; Badu-Apraku *et al.,* 2013) have also reported non-significant correlation between genetic distance and field performance. In contrast to the results of the present study, however, other researchers (Choukan *et al.,* 2006; Badu-Apraku *et al.*, 2016; Obeng-Bio, 2018) reported high correlation between genetic distance of tropical normal endosperm maize inbred lines and performance of their F1 hybrids. Low correlation between genetic distance and field performance has been attributed to lack of linkage between genes controlling important traits and markers used to estimate genetic distance, inadequate genome coverage and different levels of dominance among hybrids (Bernado, 1992). Xia *et al.* (2005) suggested that non-significant correlation between genetic distance and field performance may also be due to the use of diverse populations and genotypes in the development of populations from which inbred lines were extracted.

Even where genetic distances do not show high correlation with field performance, hybrids from genetically diverse parents can offer stability of performance (Adetimirin *et al.,* 2008). The high yield and superior agronomic traits of UI 1 x UI 75 is indicative of heterosis. Inbred lines U1 1 and UI 75, which were parents of this hybrid, have potential of use as testers for classifying *sh-2* inbred lines developed for the West Africa sub-region into heterotic groups.

TABLE 4. Genetic distance among *shrunken-2* maize lines used in the study based on SSR markers

	UI 7	UI 10	UI 58	UI 61	UI 64	UI 75	UI 77
UI 1	-	-	0.45	0.40	0.26	0.24	0.37
UI 7		0.26	-	0.45	0.30	0.26	0.38
UI 10			-	0.48	0.24	-	0.37
UI 58				0.04	0.43	-	-
UI 61					0.33	0.41	0.45
UI 64						0.37	0.29
UI 75							0.19

TABLE 5. Correlation between SSR-based genetic distance of inbred lines and field performance of their crosses

Field traits	Emergence and seedling traits	Flowering traits and height	Husk cover, plant aspect and foliar disease	Ear characteristics and yield
Emergence (%)	0.25			
Seedling height (cm)	0.20			
Seedling length (cm)	0.28			
Vigour score (1-9)	-0.34			
Days to 50% anthesis		-0.09		
Days to 50% silking		-0.14		
Ear height (cm)		0.17		
Plant height (cm)		-0.02		
Foliar disease score (1-9)			0.00	
Plant aspect score (1-9)			-0.21	
Husk cover score (1-9)			0.21	
Number of ears per plant				-0.20
Number of cobs per plant				-0.27
Ear weight per plant (kg)				0.11
Cob weight per plant (kg)				0.02
Ear aspect score (1-9)				0.28
Number of kernel rows				0.04
Number of kernels per row				0.17
Cob length (cm)				0.08
Cob diameter (mm)				0.30

CONCLUSION

Field performance of *sh-2* maize hybrids was evaluated in Ibadan, Nigeria and its relationship with genetic distance of their inbred parents determined. The hybrids showed genetic variation for the 20 traits studied. Significant correlation was found within each set of (i) emergence and seedling vigour traits, (ii) flowering traits, and (iii) ear and cob traits. The most promising of the hybrid from the partial diallel had a fresh cob yield of 8.5 tha^{-1} and desirable agronomic traits. Correlations between SSR-based genetic distance on one hand and field performance of hybrids were not significant. Genetic distance of inbred parents was of limited use for predicting the field performance of hybrids in the population of *sh-2* maize lines studied. The high yield and field emergence obtained in the present study indicate that some of the hybrids have potential for cultivation in West Africa where no sweet maize varieties have been officially released to date.

ACKNOWLEDGEMENT

This study was funded by the Pan African University of the African Union, Addis Ababa, Ethiopia.

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