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INHERITANCE OF SEED QUALITY TRAITS AND CONCENTRATIONS OF ZINC AND IRON IN MAIZE TOPCROSS HYBRIDS

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ABSTRACT

Information about the mode of inheritance of maize (*Zea mays* L.) seed quality traits is crucial in planning for improvement programmes for such traits. The objective study was to determine mode of inheritance and interrelationships between seed quality traits, and Fe and Zn contents in maize. Twenty-six maize genotypes were considered for evaluation in this study. Additive gene action was prevalent for most seed quality traits (>50%); while non-additive gene action was preponderant for Fe and Zn concentrations. Inbreds TZEEI82 and TZEEI64 were outstanding in terms of GCA male effects for conductivity (-0.13** and -0.06*), root number (0.79** and 0.30*), and root fresh weight (0.90*). Genotypes TZEEI81, DTE-STR-Y-SYN-POP-C3, 2009-TZEEI-OR1-STR and 2009-TZEE-OR1-STR-QPM were identified as excellent pollen parents for Fe concentration; and TZEEI58 and TZEEI64 for Zn concentration. In addition, only germination index had a significant additive genetic relationship with Fe content (r=0.57*); while both shoot fresh and dry weights had significant positive correlations with Zn content (r=0.45*, 0.53*). Overall, it is clear that different modes of gene action control inheritance of seed quality traits and Fe and Zn concentrations.

Key Words: Additive gene action, germination index, micronutrient

RÉSUMÉ

L‘ information sur le mode de transmission des caractères de qualité des semences de maïs (*Zea mays* L.) est cruciale dans la planification d’un programme d’amélioration de ces caractères. L’objectif de cette étude était de déterminer le mode d’hérédité et les relations entre les caractères de qualité des semences et les teneurs en Fe et Zn du maïs. Vingt-six génotypes de maïs ont été évalués pour les caractères de qualité des semences ainsi que pour les teneurs en Fe et Zn. L’action des gènes additifs était prédominante pour la plupart des caractères de qualité des semences (> 50%); tandis que l’action génique non additive était prépondérante pour les concentrations de Fe et de Zn. Les consanguines TZEEI82 et TZEEI64 ont été remarquables en termes d’effets GCA mâles pour la conductivité (-0,13 ** et -0,06 *), le nombre de racines (0,79 ** et 0,30 *) et le poids des racines fraîches (0,90 *). Les génotypes TZEEI81, DTE-STR-Y-SYN-POP-C3, 2009-TZEEI-OR1-STR et 2009-TZEE-OR1-STR-QPM ont été identifiés comme d’excellents parents de pollen pour la concentration de Fe; et TZEEI58 et

TZEEI64 pour la concentration de Zn. De plus, seul l'indice de germination avait une relation génétique additive significative avec la teneur en Fe (r = 0,57 *); tandis que les poids frais et secs des pousses avaient des corrélations positives significatives avec la teneur en Zn (r = 0,45 *, 0,53 *). Dans l'ensemble, il est clair que différents modes d'action génique contrôlaient l'hérédité des caractères de qualité des semences et des concentrations de Fe et Zn.

Mots Clés: Action génique additive, indice de germination, micronutriments

INTRODUCTION

The wide spread deficiencies of Fe and Zn in humans in developing countries are mostly due to predominant consumption of cereal-based foods with low concentrations and reduced bioavailability of these nutrients (Graham *et al.*, 2001). In order to improve on the nutrient quality of maize, assessment of genetic variability of grain micronutrient densities in genetic materials is the basic requirement.

Seed quality is substantially dependent on the biochemical composition of the seed, including macro- and micronutrients, as the latter determine germination rates, seedling vigour and storability (Carvalho and Nakagawa, 2000).

Seed vigour is one of the important parameters of seed quality, which potentially influence crop yield through seedling establishment (Ghassemi-Golezani, 2010). However, there is dearth of information on the genetic control of seed quality traits *viz-a-vis* the influence of kernel Fe and Zn concentrations on overall maize seed quality.

In plant breeding, it is imperative to examine the mode of inheritance of a desired trait since selection on the basis of phenotype is grossly unreliable. Thus, information on combining ability is important for determining the best breeding methods to employ to improve target traits, as well as identify promising genotypes that can be used as sources of alleles for introgression into populations that are deficient in qualities controlled by such genes. The objectives of this study were to determine genetic variability and mode of gene action of seed quality traits and iron and zinc concentrations of some topcross and hybrids of maize; and assess genetic relationships among measured traits.

MATERIALS AND METHODS

Genetic materials. A total of 30 maize types developed at the Teaching and Research Farm, Obafemi Awolowo University, Ile-Ife, Nigeria; from parental materials obtained from the International Institute of Tropical Agriculture (IITA) Ibadan, Nigeria were evaluated. The genotypes comprised 16 topcross hybrids developed by crossing four extra-early inbred lines with four open-pollinated varieties (OPVs), all possible crosses of the four open-pollinated varieties without reciprocal to produce 6 variety hybrids, the four OPV parents and 4 commercial checks. The description of the characteristics of the inbred lines and the open-pollinated varieties used to produce the topcross are presented in Table 1.

Field layout and maintenance of the nursery for developing topcross hybrids. The crossing field used for this study was located at the Teaching and Research Farm, Obafemi Awolowo University, Ile-Ife in Nigeria located at latitude7°28'N and longitude 5°4'E, at an altitude of 244 m above the sea level. Each of the four OPVs was planted in twenty rows and each of the inbred lines was planted in ten rows with plants of 0.75 m and 0.25 m, at the rate of two seeds per hill. This was later thinned to one seedling per stand. Each row was 10 m long.

Weeding was carried out manually twice; 2 weeks after planting (WAP) and 5 WAP. A compound fertiliser, NPK 15:15:15 was applied

TABLE 1. Description of the parental materials used for the development of the topcross hybrids

S/No.	Parental materials	Type	Characteristics
1	TZEEI 58	Inbred	Normal endosperm Drought tolerant
2	TZEEI 64	Inbred	Normal endosperm, Drought tolerant
3	TZEEI 81	Inbred	Normal endosperm, Drought tolerant
4	TZEEI 82	Inbred	Normal endosperm, Drought tolerant
5	2009 TZEEI-ORI STR	Open-pollinated variety	Pro-vitamin A, *Striga*-resistant
6	DTE-STR Y SYN POP C3	Open-pollinated variety	Drought-tolerant and Striga-resistant
7	2009 TZEE-ORI STR QPM	Open-pollinated variety	Pro-vitamin A, *Striga*-resistant and Quality Protein Maize
8	TZEE-Y POP DT STR	Open-pollinated variety	Drought-tolerant and Striga-resistant

2 WAP at the rate of 60 kg of N, P and K; and at 5 WAP, additional 30 kg N was supplied in the form of Urea fertiliser. Armyworm infestation was controlled using cypermetrin at recommended rate.

At flowering, pollen was randomly collected from the tassel of a minimum of 10 inbred plants (used as male) and used to pollinate a minimum of 20 randomly selected OPV plants (used as female) in a line-by-tester fashion. Similarly, pollen was collected from a minimum of 20 randomly selected plants from each OPVs and used to pollinate 20 randomly selected plants of other OPVs in a diallel fashion.

Evaluation for seed quality traits. In order to assess seed quality, the analyses carried out included electrical conductivity and germination test for vigour and viability. The experimental design used for the study was randomised complete block design and the tests were carried out in triplicates.

Electrical conductivity testing was carried out with 50 seeds from each seed lot. The initial weights of the seeds were taken using Metler electronic balance. The pre-weighed seeds were then put in a 200 ml beaker containing 100 ml of distilled water. The beaker was covered with aluminum foil for 24 hours to avoid contamination. Electrical conductivity of the leachate was determined using Jenway 4510 conductivity meter. The conductivity of distilled water was also measured in a beaker to serve as the control. The lower the value of EC, the greater was the seed vigour based on the method proposed by Sivritepe *et al.* (2015).

$$\text{Conductivity } (\mu\text{S cm}^{-1}\text{ g}^{-1}) = \frac{\text{Conductivity } (\mu\text{S}) \text{ of each flask - conductivity of distilled water}}{\text{Initial weight of seed (g)}}$$

Seed germination test. In this study, germination is considered as the emergence and development from the seed embryo of those essential structures which are indicative of the seed's capacity to produce a normal plant under favourable conditions (ISTA 2012). Fifty seeds from seed lots of the 30 genotypes were weighed and planted in plastic germination bowls, filled with sterilised river sand. The seeds were planted in such a way that the germinal sides faced downwards. The seeds were spaced evenly on the sand with uniform moisture, using measuring cylinders at an ambient temperature (27-32 ^{o}C). The germinated seeds were counted from the fourth day until the seventh day after planting.

The germination percentage and speed at which each genotype germinated (Germination Rate Index) were computed from the germination counts. The formulae for these two paramters are given in equations 1 and 3. Seven days after planting, the seedlings for each genotype were harvested and data were taken on ten seedlings selected randomly. Seedling traits assessed included average primary root length (PRL) and average shoot length (SL) using meter rule. In addition, average root number (RN) was recorded as the average of counts of number of roots of 5 plants. Fresh and dry shoot weights (FSW and DSW), as well as fresh and dry root weights (FRW and DRW) were measured using Metler electronic weighing balance. The germination percentage was computed as follows:

$$\text{Germination percentage (GP)} = \frac{\text{Number of normal seedlings that germinated}}{\text{Total number of seeds planted}} \times 100 \quad \text{……...………………………….. Equation 1}$$

The germination index (GI) was computed according to Ajayi and Fakorede [2000] as:

$$GI = \Sigma(Nx)\ (DAP) \quad \text{…….……….. Equation 2}$$

Where:

Nx = number of emerged seedlings on x DAP; DAP is days after planting.

$$\text{Germination rate index (GRI)} = \frac{\text{Germination index}}{\text{Germination percent/100}} \quad \text{…………………...………… Equation 3}$$

Fakorede and Agbana (2003).

GI – indicates the speed at which germination occur, while GRI – indicates the time required to for all the seeds to germinate. It shows the uniformity of the seed lot. The higher the GI, the higher the homogeneity of the seed lot.

Iron and zinc concentrations. Seed samples of the genotypes used for the determination of iron and zinc concentrations were obtained for breeding nursery where the hybrids were developed. The cross-pollinated ears were harvested in the nursery field carefully to avoid contact with soil and any metallic object. Harvesting was done when the ears had reached harvest maturity, (85 days after planting), processed and packaged manually. Seeds from the ears were hand-shelled and random samples from each genotype were taken to the laboratory for plant tissue analysis.

Determination of Fe and Zn concentrations was carried out as follows: seed samples from the genotypes were air-dried for about 2 days to bring the moisture content to about 14% in order to facilitate grinding into powder using a wooden mortar and pestle. Then, 0.5 g of each sample was digested with 0.1M H_2SO_4 using Tecator Digestion system, 2006 Model manufactured by Perstorp Analytical Company, Hoganas, Sweden. The Fe and Zn concentrations for each genotype were determined using the atomic absorption spectrometer, model AA500. Laboratory analysis was carried out in three replicates.

Statistical analyses. All data collected were subjected to analyses of variance (ANOVA) using SAS 9.1 (SAS Institute 2001). Significant treatment means were separated using the Least Square Difference (LSD) at 0.05 level of probability. In the analysis, all factors of the experiment were considered as fixed effects. The genotypic effects were partitioned into their combining ability components (general combining ability (GCA_{line}) for the inbred lines, general combining ability (GCA_{tester}) for the open-pollinated varieties and specific combining ability ($SCA_{line\ x\ tester}$) according to Comstock and Robinson (1962). In addition, GCA effects of the parental genotypes and SCA effects of the top-cross were computed using line x tester analysis. Correlation analysis was carried out to assess phenotypic and genotypic relationship among traits.

RESULTS AND DISCUSSION

Results revealed highly significant ($P<0.01$) genotypic effect for conductivity, germination percentage, germination rate index, average primary root length, average root number, dry root weight, dry shoot weight and Zn and Fe concentrations; but no significant differences were observed for germination index and average shoot length (Table 2). Thus, in most cases, there was wide genetic variability among the maize genotypes in terms of germination capacity, time to emergence of radicle, length of roots, number of roots, root and shoot weights (fresh and dry), and Zn and Fe concentrations (Table 2).

When the genotypic effect was partitioned into its genetic components, GCA for inbred line was significant for all traits, except for primary root length, shoot length, shoot fresh weight and root dry weight. GCA for the tester was also significant for all traits, except for germination index, number of roots, and shoot length. The SCA line x tester was significant for all traits, except for germination index and shoot length (Table 2).

From the results, all the components of genotype were significant for electrical conductivity, germination percentage, germination rate index, root fresh weight, shoot dry weight, and Fe and Zn concentrations. This indicates that both additive and non-additive gene actions were involved in the inheritance of these traits; and the traits can be improved by both selection method and through hybrid development. Nerling *et al.* (2013), however, reported in a study involving inter-varietal crossbreed of corn, that dominance effect was of greater importance for germination, germination speed rate, accelerated aging, field emergence and electrical conductivity; and they identified a number of hybrids which exhibited high heterosis for the seed quality traits.

Based on the proportion of additive effects, germination rate index, primary root length, root fresh weight, shoot fresh weight, root dry weight and shoot dry weight had high values (>50%), indicating that although both additive and non-additive gene effects were significant in the inheritance of these traits, the additive effect was more important than non-additive gene effect for most seed quality traits. The implication of this is that the genotypes under study can be improved by appropriate selection to develop synthetic varieties, recurrent selection or reciprocal recurrent selection. This result contradicts the findings of Cervantes-Ortiz *et al.* (2007), who detected mostly domi-nance variance in seedling traits when studying the inheritance of seedling vigour in maize. Moterle *et al.* (2011) also reported preponderance of SCA over GCA in a diallel study of nine maize inbreds.

The findings in the present study are in agreement with those of Cervantes-Ortiz *et al.* (2016), who later on reported predominance of GCA over SCA in the inheritance of seed quality and seedling vigour traits of S3 lines of maize. Barla-Szabo *et al.* (1989) evaluated six temperate maize lines and demonstrated the predomi-nance of genes with additive effects in the genetic control of seed vigour. From the discourse above, it is evident that despite the obvious environmental effects on seed quality traits, most seed quality traits are genetically controlled and additive genetic effect played important role in their inheritance. Thus, selection for seed quality traits can result in significant progress and genetic gains.

For Fe and Zn concentrations, conductivity, germination percentage, germination index, root number and shoot length, non-additive gene action was preponderant over the additive gene action, implying that significant improvement can be made for these traits through hybrid development.

From the estimate of GCA and SCA effects, significant positive effects are desirable for germination percentage, root and shoot characteristics, as well as Fe and Zn concentrations. In contrast, significant negative GCA and SCA effects are desirable for electrical conductivity, germination index and germination rate index. On this basis, TZEEI 82 and TZEEI 64 had superior GCA effects for conductivity (-0.13** and -0.06*) root number (0.79** and 0.30*) root fresh weight (0.90*) and for shoot dry weight (0.05*) (Table 3). All the four inbreds had outstanding GCA male effects for germination percentage and germination rate index. In addition to the

TABLE 2. Mean squares from analysis of variance for seedling traits and Fe and Zn concentration of 26 maize genotypes

Source	DF	COND	GPCT	GI	GRI	PRL	RN	SL	RFW	SFW	RDW	SDW	Fe	Zn
Rep	2	0.07**	90.05*	0.02	0.00	22.98	0.26	0.77	13.77**	3.80*	0.05	0.08**	0.15	0.00
Genotype	25	0.13**	1069.89**	0.05	0.01**	32.65**	1.50**	0.40	8.42**	2.04*	0.11**	0.01**	14977.67**	78.08**
GCA$_{LINE}$	7	0.36**	1593.20**	0.10*	0.01**	22.95	2.79**	0.65	5.85**	1.80	0.06	0.02*	21243.37**	158.04**
GCA$_{TESTER}$	3	0.04**	829.30**	0.04	0.01**	70.19**	0.35	0.69	12.77**	3.00*	0.32**	0.02*	16979.28**	22.71**
SCA$_{LINE*TESTER}$	15	0.04**	957.67**	0.03	0.01**	27.11*	1.04**	0.24	8.05**	2.08*	0.09**	0.01*	12001.75**	50.12**
Error	50	0.46	1315.90	1.53	0.01	556.09	11.79	16.37	81.23	44.29	1.49	0.28	121.69	0.50
Total	77	3.77	28243.33	2.75	0.22	1418.23	49.89	27.86	319.32	102.99	4.40	0.82	374563.70	1952.48
GCA/ SCA (%)		18.15	49.00	33.19	57.81	54.52	45.15	33.41	62.35	57.68	51.98	55.95	46.68	39.84
R-Square (%)		87.92	95.34	44.46	97.23	60.79	76.36	41.25	74.56	57.00	66.21	65.94	99.97	99.97
CV (%)		23.83	5.85	4.23	19.17	20.89	9.55	8.24	13.26	15.01	14.74	14.76	0.86	0.63

*, ** indicates significance at 0.05 and 0.01 level of probability; Cond (µS $cm^{-1}g^{-1}$) = Bulk leachate conductivity; G% = Germination percentage; GI = Germination index; GRI = Germination rate index; PRL= Primary root length (cm); RN= Number of roots; SL= Shoot length (cm); RFW = Root fresh weight (g); SFW = Shoot fresh weight (g); RDW = Root dry weight (g); SDW = Shoot dry weight (g); Fe = Iron (mg g^{-1}); Zn = Zinc (mg g^{-1})

TABLE 3. Estimates of general combining ability (GCA) effects of male parents for conductivity, germination test, seedling traits and iron and zinc contents

Parental materials	COND	GPCT	GI	GRI	PRL	RN	SL	RFW	SFW	RDW	SDW	Fe	Zn
TZEEI 58	-0.01	7.17**	-0.05	-0.01**	1.55	-0.09	-0.25	0.48	0.04	-0.05	-0.01	-51.60**	8.16**
TZEEI 64	-0.06*	4.83*	-0.07	-0.01**	1.75	0.30*	-0.09	0.90*	0.42	0.07	0.05*	-56.85**	1.90**
TZEEI 81	-0.04	6.50**	-0.02	-0.01**	-0.31	0.16	0.25*	-0.52	-0.42*	-0.07	-0.02	37.90**	-2.39**
TZEEI 82	-0.13**	8.17**	-0.07	-0.01**	0.01	0.79**	0.04	0.90*	0.33	0.02	0.05*	-12.47**	-2.49**
DTE-STR Y SYN POP C3	0.04	-17.89**	0.06	0.07**	-2.57*	-0.58**	-0.14	-1.13*	-0.53	-0.06	-0.03	62.49**	-1.63**
2009 TZEEI-OR1 STR	-0.03	1.67	0.03	-0.01*	0.91	-0.01	0.21	0.00	0.28	0.12*	0.00	34.78**	-3.00**
2009 TZEE-OR1 STR QPM	0.07*	-11.67**	0.26**	0.001	-2.49*	-0.70**	-0.39*	-1.00*	-0.56**	0.04	-0.06*	16.65**	-1.31**
TZEE-Y POP DT STR C4	0.84**	-36.33**	-0.05	0.02**	-2.93*	-1.42**	0.57*	-1.69**	0.09	-0.26**	-0.05*	-27.85**	-1.21**
SE	0.03	1.39	0.05	0.0001	0.90	0.13	0.15	0.34	0.25	0.05	0.02	0.41	0.03

*, ** indicates significance at 0.05 and 0.01 level of probability; Cond (µS $cm^{-1}g^{-1}$) = Bulk leachate conductivity; G% = Germination percentage; GI = Germination index; GRI = Germination rate index; PRL = Primary root length (cm); RN = Number of roots; SL = Shoot length (cm); RFW = Root fresh weight (g); SFW = Shoot fresh weight (g); RDW = Root dry weight (g); SDW = Shoot dry weight (g); Fe = Iron (mg g^{-1}); Zn = Zinc (mg g^{-1}); SE = standard error

four inbreds, 2009 TZEEI-OR1 STR had good GCA male effect for GRI. In terms of GCA male effect, there was no outstanding genotype for primary root length and germination index.

For Fe, inbred TZEEI 81 and varieties DTE-STR Y SYN POP C3, 2009 TZEEI-OR1 STR and 2009 TZEE-OR1 STR QPM had good GCA male effects; while inbreds TZEEI 58 and TZEEI 64 had good GCA male effects for Zn concentration (Table 3). It is important to note that although no open pollinated variety parents had desirable GCA male effects for Zn; inbreds TZEEI 58 and TZEEI 64 had desirable GCA male for Zn content and could be considered as pollen parents in improving Zn content. On the other hand, while TZEEI 81 was the only inbred with desirable GCA male effect for Fe content, DTE-STR Y SYN POP C3 and 2009 TZEE-OR1 STR QPM which are OPVs also had desirable GCA male effects for Fe, indicating that they can serve as good pollen parents for improving Fe content. Overall, TZEEI 64 and TZEEI 82 combined desirable GCA male effects for most seed quality traits; while TZEEI 82 was not good for any micronutrient, TZEEI 64 had desirable GCA male effect for Fe concentration.

The estimate of GCA female effects showed that 2009 TZEEI-OR1 STR and 2009 TZEE-OR1 STR QPM had good GCA for germination percentage, GRI and RFW (Table 4). DTE-STR Y SYN POP, 2009 TZEEI-OR1 STR, and 2009 TZEE-OR1 STR QPM had superior GCA female effects for conductivity and could serve as good female parental varieties for improving seedling vigour. For primary root length and number of roots, 2009 TZEEI-OR1 STR had superior GCA female effect; while for shoot length, 2009 TZEEI-OR1 STR, 2009 TZEE-OR1 STR QPM and TZEE-Y POP DT STR C4 were superior in terms of GCA female effects.

In summary, 2009 TZEEI-OR1 STR had desirable GCA female effects for most of the seed quality traits, implying that it is a good female parental material for seed quality trait

TABLE 4. Estimates of general combining ability (GCA) effect of female parents for conductivity, germination test, seedling traits and Iron and Zinc contents

TESTER	COND	GPCT	GI	GRI	PRL	RN	SL	RFW	SFW	RDW	SDW	Fe	Zn
DTE-STR Y SYN POP C3	0.00	-6.78**	0.05	0.03**	-2.32*	-0.10	-0.27	-0.37	-0.19	0.07	-0.01	-32.35**	-0.82**
2009 TZEEI-OR1 STR	-0.02*	3.00*	-0.02	-0.01*	2.76*	0.29*	0.03*	0.72*	-0.03	0.13*	0.01	-13.45**	2.20**
2009 TZEE-OR1 STR QPM	-0.03*	3.57*	-0.01	-0.01*	0.99	0.10	0.10*	0.89*	0.49*	0.04	0.04*	1.08*	-0.17**
TZEE-Y POP DT STR C4	0.04*	0.08	-0.01	-0.01*	-0.85	-0.19	0.10*	-0.96*	-0.27	-0.17**	-0.03	31.72**	-0.61**
SE	0.020	0.910	0.030	0.001	0.590	0.090	0.100	0.230	0.170	0.030	0.010	0.270	0.021

*, ** indicate significance at 0.05 and 0.01 levels of probability, respectively; Cond (µS cm^{-1}g^{-1}) = Bulk leachate conductivity; G% = Germination percentage; GI = Germination index; GRI = Germination rate index; PRL = Primary root length (cm); RN = Number of roots; SL = Shoot length (cm); RFW = Root fresh weight (g); SFW= Shoot fresh weight (g); RDW= Root dry weight (g); SDW= Shoot dry weight (g); Fe= Iron (mg g^{-1}); Zn = Zinc (mg g^{-1}); SE = standard error

improvement. For Fe concentration, TZEE-Y POP DT STR C4 and 2009 TZEE-OR1 STR QPM were superior; while for Zn concentration, only 2009 TZEE-OR1 STR was the superior female parent (Table 4). It is important to note that 2009 TZEE-OR1 STR QPM was outstanding for both GCA male and GCA female for Fe, indicating that the variety can be used as both pollen parent and female parent in a selection program for Fe improvement.

Based on SCA effects, topcross TZEEI 64 x 2009 TZEEI-OR1 STR had desirable SCA effects for most seed quality traits, but not micronutrients; variety cross DTE-STR Y SYN POP C3 x 2009 TZEE-OR1 STR QPM combined desirable SCA effects for most seed quality traits with Zn content. In addition, DTE-STR Y SYN POP C3 x TZEE-Y POP DT STR C4 was identified to combine desirable SCA effect for most seed quality traits with Fe content (Table 5). This implies that TZEEI 64 x 2009 TZEEI-OR1 STR was an outstanding topcross hybrid for seed quality traits while variety cross DTE-STR Y SYN POP C3 x 2009 TZEE-OR1 STR QPM and DTE-STR Y SYN POP C3 x TZEE-Y POP DT STR C4 were outstanding not just for seed quality traits but for Fe or Zn concentration.

Seven of the topcrosses and three variety crosses had significant positive SCA effects for Fe; while six topcrosses and three variety crosses had significant positive SCA effects for Zn (Table 5). Among these, four topcrosses, namely TZEEI 58 x DTE-STR Y SYN POP C3, TZEEI 64 x DTE-STR Y SYN POP C3, TZEEI 64 x 2009 TZEE-OR1 STR QPM, TZEEI 81 x 2009 TZEEI-OR1 STR, and one variety cross: 2009 TZEEI-OR1 STR x TZEE-Y POP DT STR C4 combined significant positive SCA effects for both Fe and Zn concentrations (Table 5).This implied that these hybrids can be recommended for further testing in a multi-location trials to confirm presence of appreciable Fe and Zn concentrations

Table 6 presents correlation coefficients between seed quality traits and Fe and Zn concentrations. Correlation analysis based on GCA effects showed highly significant negative coefficients between conductivity and germination percentage (r=-0.85**), primary root length (r=-0.68*), root number (r=-0.95**), root fresh weight (r=-0.85**), shoot fresh weight (r=-0.58*) and shoot dry weight (r=-0.87**), which indicates that the higher the bulk conductivity, the lower the values for germination percentage and associated traits. The implication of this is that germination capacity and seedling vigour traits of a seed are greatly influenced by seed coat integrity. There is a significant positive correlation between germination index and germination percentage (r=0.71**) and the two traits had significant positive correlation with conductivity. According to Odoba *et al.* (2016), viability plays a major role in determining the speed at which germination takes place.

On the basis of GCA effects (additive genetic action) among all the seed quality traits, only germination index and germination rate index had positive significant correlation (r = 0.52*; r = 0.76**) with Fe content and none with Zn content. This implies that variety with higher values for germination index also possess high Fe content. In addition, Fe and Zn contents had significant negative correlation (r=-0.66*) indicating that the higher the content of Fe in a genetic material, the lower the Zn content. The implication of this in breeding is that simultaneous improvement of both Fe and Zn contents in a genetic material will be difficult.

Correlation analysis based on SCA effects followed similar trends, largely with that of GCA effects (Table 6). On the basis of SCA effects, electrical conductivity had significant negative correlations with germination percentage (r=-0.66**), primary root length (r=-0.56*), root number (r=-0.58**), root fresh weight (r=-0.62**), shoot fresh weight (r=-0.39*) and shoot dry weight (r=-0.51*),

TABLE 5. Estimates of specific combining ability (SCA) effects of crosses for conductivity, germination test, seedling traits and Iron and Zinc contents

Hybrids	COND	GPCT	GI	GRI	PRL	RN	SL	RFW	SFW	RDW	SDW	Fe	Zn
TZEEI 58 x 2009 TZEEI-OR1 STR	0.03	4.61	-0.01	-0.03**	-1.04	-0.40	0.11	-1.55*	-0.15	-0.11	-0.03	56.60**	-1.35**
TZEEI 58 x DTE-STR Y SYN POP C3	-0.03	0.17	-0.05	0.01	0.83	-0.02	0.01	0.30	-0.02	-0.17*	0.00	23.70**	3.38**
TZEEI 58 x 2009 TZEE-OR1 STR QPM	0.05	-1.07	0.01	0.01	-1.53	0.50*	-0.36	0.02	-0.59	0.03	-0.04	-53.33**	-2.50**
TZEEI 58 x TZEE-Y POP DT STR C4	-0.04	-3.58	0.04	0.01	1.16	-0.18	0.29	0.94	0.77	0.18*	0.06	-13.97**	-0.12**
TZEEI 64 x 2009 TZEEI-OR1 STR	-0.09*	4.28	-0.04	-0.03**	4.19*	0.58*	0.14	1.82**	0.52	0.16*	0.06	-6.65**	-1.29**
TZEEI 64 x DTE-STR Y SYN POP C3	0.13**	-6.17*	0.03	0.01*	-5.93**	-0.70**	0.17	-1.93**	0.08	-0.10	0.01	24.95**	2.79**
TZEEI 64 x 2009 TZEE-OR1 STR QPM	0.04	-0.74	0.05	0.01	-1.16	0.29	-0.02	-0.82	-0.47	-0.15	-0.02	16.42**	2.76**
TZEEI 64 x TZEE-Y POP DT STR C4	-0.07	2.75	-0.04	0.01	2.32	-0.26	-0.24	0.64	-0.14	0.02	-0.05	-21.72**	-4.86**
TZEEI 81 x 2009 TZEEI-OR1 STR	-0.03	8.61**	-0.03	-0.03**	0.53	-0.04	-0.17	1.24*	0.40	0.06	0.01	47.10**	3.65**
TZEEI 81 x DTE-STR Y SYN POP C3	0.06	-1.17	0.13	0.01	-0.15	-0.03	-0.45	1.28*	0.48	0.30**	0.02	-16.80**	-3.27**
TZEEI 81 x 2009 TZEE-OR1 STR QPM	0.02	0.93	-0.08	0.01	2.18	-0.27	0.50	0.27	0.38	-0.10	0.04	-52.83**	1.35**
TZEEI 81 x TZEE-Y POP DT STR C4	-0.04	-8.25**	-0.02	0.01*	-3.14*	0.24	0.17	-3.08**	-1.26*	-0.33**	-0.08*	35.53**	-2.32**
TZEEI 82 x 2009 TZEEI-OR1 STR	-0.02	8.94**	-0.08	-0.03**	0.47	0.43	0.26	1.26*	0.51	0.07	0.04	-21.53**	-1.90**
TZEEI 82 x DTE-STR Y SYN POP C3	0.05	-0.83	-0.05	0.01	0.40	-0.19	0.16	-0.70	-0.85	-0.14	-0.06	-9.43**	-5.62**
TZEEI 82 x 2009 TZEE-OR1 STR QPM	0.03	-7.40**	0.03	0.01*	1.98	-0.44	-0.09	-0.57	-0.56	-0.03	-0.06	78.04**	-1.95**
TZEEI 82 x TZEE-Y POP DT STR C4	-0.04	-0.58	0.09	0.01	-3.42*	0.11	-0.28	-0.28	0.90*	0.03	0.07*	-34.09**	8.88**
DTE-STR Y SYN POP C3 x 2009 TZEEI-OR1 STR	0.31**	-48.33**	0.23*	0.15**	-3.70*	-1.33**	-0.27	-2.74**	-1.63**	-0.02	-0.13**	-13.49**	-1.76**
DTE-STR Y SYN POP C3 x 2009 TZEE-OR1 STR QPM	-23.98**	-0.08	-0.08**	0.74	0.44	0.12	1.28*	1.33**	0.06	0.12**	-78.92**	4.34**	0.14**
DTE-STR Y SYN POP C3 x TZEE-Y POP DT STR C4	-27.47**	-0.18*	-0.08**	5.14**	1.08**	0.22	1.89*	0.27	0.01	0.02	91.95**	-0.98**	0.19**
2009 TZEEI-OR1 STR x 2009 TZEE-OR1 STR QPM	0.04	11.44**	0.03	-0.03**	-1.80	0.19	-0.08	-0.67	0.23	-0.19*	0.01	-76.28**	2.11**
2009 TZEEI-OR1 STR x TZEE-Y POP DT STR C4	0.07	-20.33**	0.10	0.02**	0.94	-0.20	-0.04	-0.71	-0.34	0.03	-0.05	25.82**	0.54**
2009 TZEE-OR1 STR QPM x TZEE-Y POP DT STR C4	-0.04	4.43	-0.12	0.00	-0.21	0.10	0.14	0.44	0.29	-0.04	0.03	110.79**	-1.34**
SE	0.04	2.40	0.08	0.01	1.56	0.23	0.27	0.60	0.44	0.08	0.03	0.72	0.05

*, ** indicates significance at 0.05 and 0.01 level of probability; Cond (μS $cm^{-1}g^{-1}$) = Bulk leachate conductivity; G% = Germination percentage; GI = Germination index; GRI = Germination rate index; PRL= Primary root length (cm); RN= Number of roots; SL= Shoot length (cm); RFW= Root fresh weight (g); SFW= Shoot fresh weight (g); RDW = Root dry weight (g); SDW = Shoot dry weight (g); Fe= Iron (mg g^{-1}); Zn = Zinc (mg g^{-1})

TABLE 6. Spearman Correlation among general combining ability effects of the parents (above diagonal, N=12) and specific combining ability effects of the hybrids (below diagonal, N=26) for seed quality traits and Fe and Zn concentrations of extra-early maize genotypes evaluated at the Obafemi Awolowo University in 2017

	COND	GPCT	GI	GRI	PRL	RN	SL	RFW	SFW	RDW	SDW	Fe	Zn
COND		-0.85**	0.52*	0.76**	-0.68*	-0.95**	-0.15	-0.85**	-0.58*	-0.34	-0.87**	0.10	0.10
GPCT	-0.66**		-0.61*	-0.96**	0.73*	0.85**	0.05	0.80**	0.46	0.14	0.76**	-0.24	0.15
GI	0.54**	-0.66**		0.71*	-0.46	-0.59*	-0.36	-0.55	-0.66*	0.15	-0.59*	0.57*	-0.25
GRI	0.64**	-0.97**	0.72**		-0.72*	-0.80**	-0.15	-0.73*	-0.45	-0.08	-0.69*	0.27	-0.15
PRL	-0.56**	0.30	-0.43*	-0.34		0.79**	-0.05	0.87**	0.55	0.56	0.80**	-0.39	0.51
RN	-0.58**	0.56**	-0.34	-0.59**	0.16		0.10	0.90**	0.55	0.43	0.91**	-0.21	0.07
SL	-0.16	0.12	-0.53*	-0.2	0.22	0.01		-0.11	0.31	-0.42	0.05	0.31	-0.33
RFW	-0.62**	0.58**	-0.48*	-0.61**	0.64**	0.50*	0.07		0.73*	0.55	0.97**	-0.47	0.31
SFW	-0.39*	0.44*	-0.25	-0.46*	0.28	0.28	0.23	0.70**		0.23	0.79**	-0.49	0.19
RDW	-0.20	0.01	0.14	-0.02	0.33	0.09	-0.15	0.68**	0.54**		0.49	-0.25	0.13
SDW	-0.51*	0.53*	-0.29	-0.52*	0.28	0.47*	0.25	0.69**	0.92**	0.48*		-0.38	0.18
Fe	-0.04	-0.06	-0.09	0.07	0.10	-0.08	0.16	-0.17	-0.25	-0.34	-0.28		-0.66*
Zn	-0.20	0.31	0.03	-0.22	-0.02	0.20	0.01	0.06	0.45*	-0.09	0.53*	-0.01	

*, ** indicates significance at 0.05 and 0.01 level of probability; Cond (µS $cm^{-1}g^{-1}$) = Bulk leachate conductivity; G% = Germination percentage; GI = Germination index; GRI = Germination rate index; PRL = Primary root length (cm); RN = Number of roots; SL = Shoot length (cm); RFW = Root fresh weight (g); SFW = Shoot fresh weight (g); RDW = Root dry weight (g); SDW= Shoot dry weight (g); Fe = Iron (mg g^{-1}); Zn = Zinc (mg g^{-1})

and significant positive correlation with germination index (r-0.54**) and germination rate index (r=0.64**), which indicates seed coat integrity as measured by bulk electrical conductivity to be an important determinant of seed viability and seedling vigour. Shoot fresh weight and shoot dry weight both had significant positive correlations (r=0.45*, 0.53*) with Zn content, but none with Fe content. This also implies that the higher the fresh and dry weights of shoot, the higher the Zn content of the genetic material.

There are contradictory reports on relationship between Fe and Zn concentrations in maize kernels and between the micronutrient concentrations and agronomic traits. Menkir [2008] and Akinwale and Adewopo [2016] reported positive significant correlation; while Prassana *et al.* (2011) reported no correlation. The significant negative relationship between Fe and Zn agreed with that reported by Akinwale and Adewopo [2016], which based their correlation analysis on phenotype, that is, means of the traits.

CONCLUSION

Overall, there was wide genetic variation among the maize genotypes evaluated in this study. Although, both additive and non-additive gene actions were involved in the inheritance of the traits studied, additive gene action was preponderant for most seed quality traits while non-additive gene action was predominant for Fe and Zn concentrations. TZEEI 82 and TZEEI 64 were identified as superior pollen parents for seed quality traits in terms of general combining ability Inbred TZEEI 81 and varieties DTE-STR Y SYN POP C3, 2009 TZEEI-OR1 STR and 2009 TZEE-OR1 STR QPM were good pollen parents for Fe concentration while inbreds TZEEI 58 and TZEEI 64 were for Zn concentration. 2009 TZEE-OR1 STR QPM was identified as outstanding pollen parent and female parent Fe concentration. In addition**,** germination index only had significant association with grain Fe content while shoot dry weight both had significant positive correlations with Zn content. Fe and Zn contents had significant negative correlation.

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REFERENCES

Ajayi, S.A. and Fakorede, M.A.B. 2000. Physiological maturity effects on seed quality, seedling vigour and mature plant characteristics of maize in a tropical environment. *Seed Science and Technology* 28:301-319.

Akinwale, R.O. and Adewopo, O.A. 2016. Grain iron and zinc concentrations and their relationship with selected agronomic traits in early and extra-early maize. *Journal of Crop Improvement* 30:641-656. doi: 10.1080/15427528.2016.1211577.

Barla-Szabo, G., Bocsi, J., Dolinka, B. and Odiemah, M. 1989. Diallel analysis of seed vigour in maize. *Seed Science and Technology* 18:721-729.

Carvalho, N.M. and Nakagawa, J. 2000. Seeds: Science, Technology and Production. 4th Edition, FUNEP, 5 Jaboticabal. 88pp.

Cervantes-Ortiz, F. de los Santos, G., Carballo, A.G., Bergvinson, D., Crossa, J.L., Elos, M.M. and Moreno-Martinez, M. 2007. Seedling vigor inheritance and its relationship to adult plant traits in inbred tropical maize lines *Agrociência* 41:425-434.

Cervantes-Ortiz, F., Hernández-Esparza, J., Rangel-Lucio, J.A., Andrio-Enríquez, E., Mendoza-Elos, M. Rodríguez-Pérez, G., and Guevara-Acevedo, L.P. 2016. General and specific combining ability on seed quality of S_3 maize inbred lines. *Revista fitotecnia mexicana* 39(3):259-268.

Fakorede, M.A.B. and Agbana, S.B. 2003 Maize revolution in West and Central Africa: an overview. In: *Maize revolution in West and Central Africa*. Badu-Apraku, B., Fakorede, M.A.B., Ouedraogo, R.J. Carsky, M. and Menkir, A. (Eds.) *Proceedings for a Regional Maize Workshop*, IITA-Cotonou, Benin Republic, 14-18 May, 2001. WECAMAN/IITA.

Ghassemi-Golezani, K., Khamari, S., Dalil, B. Hosseinzadeh-Mahootohy, A. and Chadordooz-Feddi, A. 2010. Effect of seed aging on field performance of winter oil-seed rape. *Journal of Food, Agriculture and Environment* 8:175-178

Graham, R.D., Welch, R.M. and Bouis, H.E. 2001. Addressing micronutrient malnutrition through enhancing the nutritional quality of staple foods: principles, perspectives and knowledge gaps. *Advances in Agronomy* 70:77-142.

ISTA 2012 International Rules for Seed Testing. International Seed Testing Association, Bassersdorf, Switzerland.

Menkir, A. 2008. Genetic variation for grain mineral content in tropical-adapted maize inbred lines. *Food Chemistry* 110: 454–64.

Moterle, L.M., Braccini, A.L.,. Scapim, C.A., Pinto, R.J.B., Gonçalves, L.S.A., Júnior, A., Tdo, A. and Silva, T.R.C. 2011. Combining ability of tropical maize lines for seed quality and agronomic traits. *Genetic and Molecular Research* 10 (3): 2268-2278.

Nerling, D., Coelho, C.M.M. and Nodari, R. O. 2013. Genetic diversity for physiological quality of seeds from corn (*Zea mays* L.) intervarietal crossbreeds. *Journal of Seed Science* 35:449-456.

Odoba, A., Odiaka, N.I., Gbanguba, A.U. and Bashiru, M. 2016. Germination characteristics of twenty varieties of soybean (*Glycine max* (L.) Merr.) stored for seven months. *Scientia Agriculturae* 13 (3):151-155.

Prasanna, B.M., Mazumdar, S., Chakraborti, M., Hossain, F., Manjaiah, K.M., Agrawal, P.K., Guleria, S.K., and Gupta, H.S. 2011. Genetic variability and genotype x environment interactions for kernel iron and zinc concentrations in maize (*Zea mays* L.) genotypes. *Indian Journal of Agricultural Sciences* 81:704-711.

SAS Institute. 2001. Statistical Analysis Software (SAS) user's guide. SAS Institute, Inc., Cary, NC, USA.

Sivritepe, H.O., Senturk, B., Teoman, S. 2015. Electrical conductivity tests in maize seeds. *Advances in Plants and Agricultural Research* 2(7):00075 doi: 10.15406/apar.2015.02.00075