MOOR JOURNAL OF AGRICULTURAL RESEARCH
Journal homepage: https://iart.gov.ng/moorjournal/index.php/mjar/

Yield Performance of Extra-Early Quality Protein Maize Inbreds in Humid and Savanna Agro-environments of Nigeria

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Article Info

Article history:
Received: August 11, 2025
Revised: May 11, 2026
Accepted: July 17 2026

Keywords:
Coefficients of variation
Grain yield
Humid and Savanna agro-ecologies
Pearson correlation
Quality protein maize inbreds

Abstract

Periodic evaluation and selection of quality protein maize inbred lines for the development of extra-early and high grain yielding maize hybrids are crucial to fostering food security in the face of climate change. This research work was conducted to assess quality protein maize (QPM) inbred lines for grain yield (GY) and other agronomic traits in humid and savanna agro-ecologies of Nigeria and the relationship among pairs of agronomic traits. Ten maize inbred lines were evaluated in three locations (Ibadan, Ile-Ife and Kishi) for two years and data were collected on GY and 12 other agronomic traits. Results obtained showed that the effects of genotypes, locations, years and their interactions were significant for most of the traits in this study at $p< 0.01$ across locations. Considerable variation existed among the inbred lines as reflected by coefficients of variation (CV). Highest CV (57.78%) was found for GY while the least (2.87%) was found for days to 50% silking (DS). The grain yield of the inbred lines was higher in Kishi than in Ibadan and Ile-Ife by 57.55% and 38.76%, respectively. Inbred line TZEEQI 7 had highest GY of 1512.83 kg ha^{-1} with good plants architecture across locations, indicating that it has favourable gene(s) to withstand weather effect than other inbred lines. Hence, it is a good inbred line for improvement for drought prone environments. It was observed that highly significant and positive relationships existed between GY and most agronomic traits. However, the trait negatively correlated with days to 50% anthesis and silking, plant aspect and ear aspect. The traits with positive and significant correlated with GY can, therefore, be used for indirect selection for yield improvement. Also, inbred TZEEQI 7 can be hybridized with normal endosperm maize genotypes for conversion to QPM for enhanced nutritional quality.

Introduction

Maize (*Zea mays* L.) is an important cereal crop in Africa serving as source of food and industrial raw material for industries such as brewery, confectionary, livestock and flour feed mills (FAO, 2020; Akinyosoye *et al.*, 2025a). In sub-Saharan Africa (SSA), maize is an important source of carbohydrates and proteins, accounting for 17 – 60% of people's total daily protein supply (Akinyosoye *et al.*, 2025a, b). In SSA, about 12 countries depend on maize for at least one fifth of their total daily calorie intake and up to 60% for their total daily protein intake (Emily *et al.*, 2011). Such dependence on maize as the primary or only protein source can lead to protein-energy malnutrition because of its inherent deficiency in two essential amino acids, lysine and tryptophan (WHO, 2000). An effort to improve normal endosperm maize, led to the discovery of *opaque-2 mutant* gene. The *opaque-2* gene was incorporated into maize germplasm with improved agronomic and kernel traits; this effort led to the release of quality protein maize. Hence, QPM contains double the amount of lysine and tryptophan compared to normal endosperm maize (Annor and Badu-Apraku, 2016).

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The major goal of breeding programmes is expanding the genetic pools of germplasms for yield improvement, and adaptation to various agro-ecologies against biotic and abiotic stresses in the face of climate change. Presently, efforts are geared towards genetic improvement of QPM for higher grain yield with enhanced nutritional quality in sub-Saharan Africa among some agricultural research institutions such as International Maize and Wheat Improvement Center (CIMMYT), International Institute of Tropical Agriculture (IITA) and National Agricultural Research Systems (NARS). Their partnership was focused on development of improved genotypes, exchange of germplasms and evaluation of promising genotypes in various agro-ecologies in the SSA (CIMMYT, 2005). So far, a great quantity of adapted QPM inbreds had been developed in SSA through the partnership. This had led to the intensified efforts on development of QPM hybrids at National and International levels in maize breeding programmes in sub-Saharan Africa.

The appropriate information on the relationship between grain yield and its contributing traits can appreciably improve the selection effectiveness by using appropriate selection indicators in breeding programs (Fazelifard *et al.,* 2014). Hence, the need to track the relationship between the pairs of yield components for effective selection for grain yield improvement. Breeding could be very effective, provided there is positive relationship among yield components, but when yield components are negatively correlated, it becomes compulsory to employ simultaneous selection in improvement programs (Nemati *et al.* 2009).

The major challenge to QPM cultivation is the presence of many undesirable pleiotropic effects associated with *Opaque-2 mutant* gene especially low grain yield (Vietmeyer, 2000; Prasanna *et al.,* 2001; Vasal, 2001). Hence, there is urgent need to evaluate the yield performance of available QPM inbreds in various agro-ecologies of Nigeria for the development of high yielding QPM hybrids. Thus, this research work was conducted to assess selected promising QPM inbred lines for grain yield in humid and savanna agro-ecologies of Nigeria and assess the relationship between the pair of agronomic traits for yield improvement.

Materials and Methods

Ten extra-early maturing white quality protein maize (QPM) inbreds developed for tropical climate were used as genetic materials for this study. The maize lines were obtained from the Maize Improvement Programme of the International Institute of Tropical Agriculture (IITA), Ibadan, Nigeria. The pedigree information of the inbreds is presented in Table 1. The QPM inbreds were developed from hybridization between two extra-early white *Striga* resistant normal endosperm maize inbreds and QPM-donor source (Pool-15 SR). The F_1 progenies were backcrossed to the recurrent parents to get BC_1 and BC_2. The BC_2 was selfed to develop S_6 inbreds with selection for improved grain yield, high lysine and tryptophan and other agronomic characters (Annor and Badu-Apraku, 2016).

The 10 inbred lines were evaluated at three locations, namely Ibadan (Rainforest-Savanna Transition agro-ecology, 7.38‘N, 3.84‘E, 160 m asl); Ile-Ife (Rain Forest agro-ecology, 7.55’N, 4.56’E, 280 m asl), and Kishi (Southern Guinea Savanna agro-ecology, 8.98'N, 3.94'E, 380 m asl). These locations represent the humid and savanna agroecologies of Nigeria. The dominant soils types at the experimental sites were classified as Ferric Luxisols in Kishi and only as Ferric Lixisols in Ibadan and Ile-Ife (Sonneveld, 2005). Three seeds were sown per hole and thinned to two plants per stand at two weeks after planting (2 WAP). Spacing of 75 cm × 50 cm between and within rows respectively was used. The experiment was laid out in a randomized complete block design (RCBD) with three replicates, in a 5 m long single row plot. Cultural practices such as weeding, fertilizer application, pest and disease control were carried out according to IAR&T (2010) package of recommendation. Soil samples were obtained from each location (0-15 cm depth) before planting in both cropping seasons and analyzed for soil nutrient status using Chapman and Pratt (2001) procedures at soil laboratory of IAR&T. The weather information (rainfall distribution and temperature) was also collected from the meterological stations in each location.

Table 1: Name and pedigree of the maize inbred lines

Entry No	Inbred lines	Pedigree
P1	TZEEQI-10	TZEE-W Pop x 1368 STR S7 Inb 40 x Pool 15 SR QPM BC1S7 (7) 8-10-1-1
P2	TZEEQI-9	TZEE-W Pop x 1368 STR S7 Inb 40 x Pool 15 SR QPM BC1S7 (7) 7-10-1-1
P3	TZEEQI-5	TZEE-W Pop x 1368 STR S7 Inb 40 x Pool 15 SR QPM BC1S7 (17) 4-5-1-1
P4	TZEEQI-8	TZEE-W Pop x 1368 STR S7 Inb 40 x Pool 15 SR QPM BC1S7 (7) 6-10-4-5
P5	TZEEQI-2	TZEE-W Pop x 1368 STR S7 Inb 40 x Pool 15 SR QPM BC1S7 (3/4) 3-7-3-7
P6	TZEEQI-12	TZEE-W Pop x 1368 STR S7 Inb 40 x Pool 15 SR QPM BC1S7 (7) 10-10-10-10
P7	TZEEQI-7	TZEE-W Pop x 1368 STR S7 Inb 40 x Pool 15 SR QPM BC1S7 (7) 4-10-1-1
P8	TZEEQI-16	TZEE-W Pop x 1368 STR S7 Inb 40 x Pool 15 SR QPM BC2S7 (2) 2/5-3/3-1/1
P9	TZEEQI-6	TZEE-W Pop x 1368 STR S7 Inb 40 x Pool 15 SR QPM BC1S7 (7) 1-10-1-10
P10	TZEEQI-3	TZEE-W Pop x 1368 STR S7 Inb 40 x Pool 15 SR QPM BC1S7 (3/4) 6-7-1-1

TZEEQI: Tropical *Zea* extra-early maturing quality protein maize inbred lines

Data were collected based on International Board for Plant Genetic Resources (IBPGR,1991) procedures: days to anthesis (DTA) and silking (DS), as number of days from planting to 50% tasseling and days from planting to 50% silk emergence, respectively. Plant and ear heights were taken at 70% physiological maturity.

Ear length (EL) (in cm) was taken by selecting five ears at random from the harvested ears from each plot and lengths of the ears were determined using tape rule and values were recorded for each plot. Ear diameter (ED) (in cm) was taken by selecting five ears at random after harvesting from each plot and it was measured mid-way along the ear length using Vernier calliper and values were recorded for each plot. Number of kernel rows per ear (NRPE) was taken by counting number of rows per ear on five randomly selected ears and values were recorded for each plot. Number of kernels per row (NKPR) was taken by counting number of kernels per row on five randomly selected ears and values were recorded for each plot.

One hundred kernel weight (in gram) was taken by selecting five ears at random and were hand threshed and three samples of 100 kernels were weighed on electronic balance to obtain average 100-kernel weight for each plot (Akinyosoye *et al.*, 2025a). Plant Aspect (PAS) was taken based on general appeal of plants in the whole plot, which includes assessment of plant and ear heights, uniformity of the stand, reaction to diseases and insects, and lodging resistance. This was taken at brown silk stage before harvesting when plants were still green and when the ears were fully developed. Plant aspect was scored on a scale of 1 to 5, where score 1 represents excellent appearance; and 5: represents very poor appearance (Olakojo and Olaoye, 2005). Ear Aspect was taken based on visual assessment of quality scored on a scale of 1 to 5 where 1= excellent and 5= very poor. The score was taken on the pile of harvested ears of each plot when spread out and the general look of the ears was taken into account such as ear size, uniformity of colour and texture, grain fill, disease and insect damage were considered for this score (Olakojo and Olaoye, 2005; Badu-Apraku *et al.,* 2012). Ear rot was taken at harvest after dehusking on a scale of 1–5, where 1 = 0-1%, 2 = 1-10%, 3 = 10-25%, 4 = 25-50%, 5 = 50-100% of the ear rotted (Akinyosoye, 2022) and grain yield adjusted to 15 % moisture content was estimated according to Badu-Apraku *et al.* (2012). Data collected were subjected to analyses of variance (ANOVA) per location and across locations using Statistical Tool for Agricultural Research (STAR, Version: 2.0.1). Pearson's correlation coefficient between pairs of agronomic traits were determined using Statistical Tool for Agricultural Research (STAR, Version: 2.0.1).

The laboratory analysis of the soil samples collected at three locations before cultivation in 2017 and 2018 are presented in Table 2. The environmental condition of the experimental sites during the trials in 2017 and 2018 are presented in Figure 1.

Table 2: Soil nutrient status of the experimental sites before maize cultivation in Ibadan, Ile-Ife and Kishi, 2017 and 2018

	2017			2018		
Parameters	Ibadan	Ile-Ife	Kishi	Ibadan	Ile-Ife	Kishi
Chemical characteristics						
PH	6.77	6.80	6.72	6.70	6.80	6.70
Organic carbon (%)	6.42	12.58	14.41	7.13	12.74	14.40
Total nitrogen (%)	0.05	1.21	1.31	0.06	1.25	1.34
Exchangeable $Na^{+}(cmolkg^{-1})$	0.37	0.54	0.54	0.41	0.57	0.56
Exchangeable $K^{+}(cmolkg^{-1})$	0.51	0.73	0.76	0.56	0.77	0.74
Exchangeable Ca^{2+} $(cmolkg^{-1})$	0.27	0.40	0.45	0.25	0.43	0.44
Exchangeable Mg^{2+} $(cmolkg^{-1})$	0.18	1.24	1.26	0.20	1.25	1.27
Available Phosphorus $(mgkg^{1})$	5.81	8.46	13.43	5.75	8.40	13.20
Physical characteristics						
Silt (%)	15.62	12.82	10.58	20.7	14.4	12.10
Sand (%)	75.42	80.84	87.01	74.75	76.41	80.40
Clay (%)	8.96	6.35	6.42	4.55	9.19	7.50
Texture	Sand loamy	Sand loamy	Sand loamy	Sand loamy	Sand loamy	Sand loamy

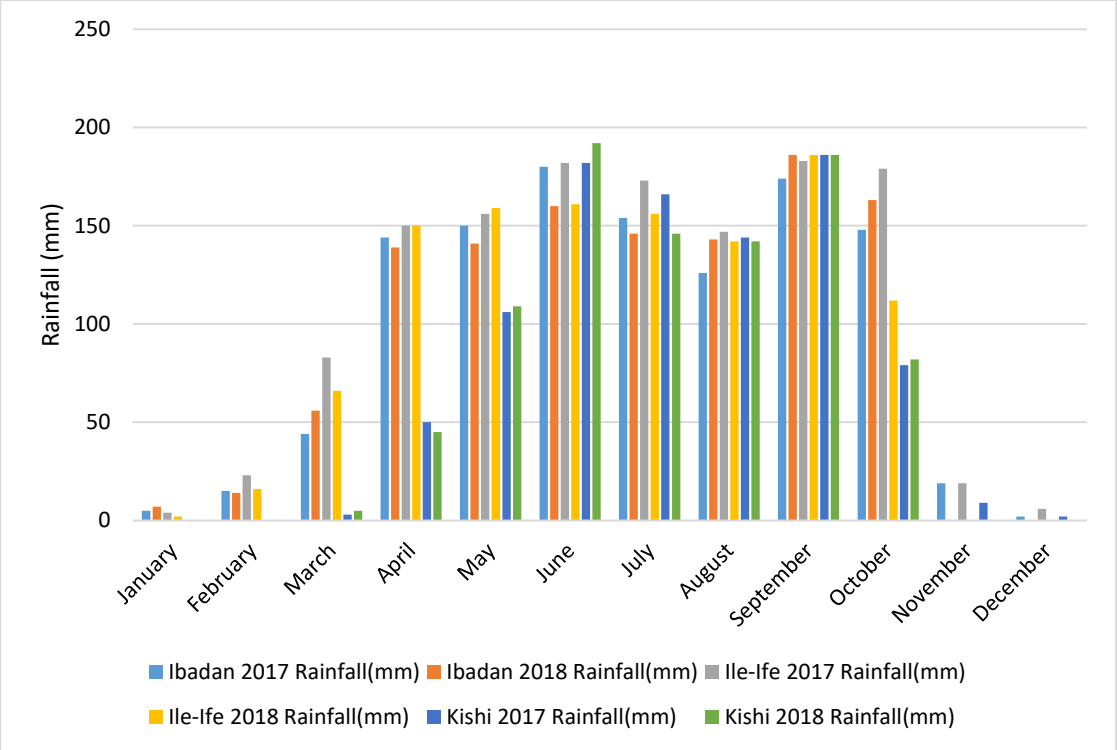


Figure 1: Monthly rainfall at the experimental sites during the trials in 2017 and 2018.

Analysis of variances for grain yield and other agronomic traits among the quality protein maize inbred lines evaluated in the three locations

Analysis of variance across locations showed that the effects of genotype, locations, years and their interactions were significant for most traits considered in this study Table 3). Considerable variability existed among the inbreds as reflected by coefficients of variation (CV), where the CV ranged from 2.47% for days to 50% anthesis (DTA) in Ile-Ife to 62.58% for grain yield (GY) in Ibadan (Table 4). Significant variations also existed in the mean performance of the inbreds evaluated at the three locations. Thus, highest grain yield was recorded in Kishi (1335.92 kg/ha), while the least was obtained in Ibadan (567.16 kg/ha).

The performance of the inbred lines evaluated differed across the three locations for yield and other agronomic traits. For instance, ten inbred lines evaluated in Kishi flowered (50% anthesis) earliest and also had highest plant and ear heights with mean of 133.25 cm and 53.45 cm, respectively and also exhibited better performance in most of the other agronomic traits measured such as ear length (EL), number of kernel row/ear (NRPE), ear diameter (ED), number of kernel/row (NKPR) and 100-seed weight, whereas poorest performance in most of the agronomic traits were recorded in Ibadan (Table 4).

Across locations, the highest CV (58.21%) was found in grain yield, while the least was found in days to 50% silking (DS) (3.08%) (Table 5). Highest GY (1512.83 kg ha^{-1}) was found in inbred line TZEEQI 7, followed by TZEEQI 8 with mean GY of 1227.50 kg ha^{-1} while the least (596.91 kg ha^{-1}) was obtained by TZEEQI 16. The inbred lines evaluated had grand mean GY of 907.07 kg ha^{-1} across locations. Inbred TZEEQI 6 had lowest DTA and DS than other inbreds evaluated in this study, whereas TZEEQI 16 had lowest values for other traits such as ED, NRPE and 100-seed weight. It also had highest DTA and DS than other inbreds (Table 5).

Table 3: Mean squares for grain yield and agronomic traits of extra-early quality protein maize inbred lines evaluated across three locations in Nigeria in 2017 and 2018

SoV	Genotype (G)	Location (L)	Year (Y)	G × L	G × Y	Y × L	G × L × Y	Pooled Error
	df= 9	df= 2	df= 1	df= 18	df= 9	df= 2	df= 18	df= 116
GY	1514373.72**	9220724.29**	3360520.57*	190564.10	86127.74	920104.27*	131974.84	32339668
DTA	22.00**	152.60**	74.76*	2.83	2.78	33.76**	2.1	347.22
DS	20.87**	202.65**	13.34	3.55	2.43	81.54**	4.59	332.29
PH	961.11**	5910.62**	2425.87*	361.81	395.42	636.64	565.25*	30513.9
EH	371.99**	2231.80**	1180.21*	75.78	90.49	328.19*	127.36*	8382.04
PAS	0.65	13.09**	0.01	0.17	0.28	1.858*	0.35	34.17
EAS	0.86**	1.61**	20.81**	0.24	0.58*	6.27**	0.4	28.97
Erot	0.36	4.86	0.4	0.36*	0.08	0.01	0.06	23.56
EL	4.90**	19.128*	36.40*	3.56*	5.05**	24.11**	1.51	196.34
ED	0.51**	1.86**	0.51	0.27**	0.08	2.34**	0.13	12.13
NKPE	14.93**	36.59**	6.13*	3.28**	2.87*	8.46**	3.01*	159.08
NRPE	29.83**	587.20**	144.70*	28.03**	27.07**	63.25**	13.69*	950.88
100sw	50.53**	0.51	60.28**	33.10**	6.79	0.08	6.79	487.82

SoV: Source of variation; df: degree of freedom; GY: Grain yield ($kgha^{-1}$); DTA: Days to 50% anthesis; DS: Days to 50% silking; PH: Plant height (cm); EH: Ear height (cm); PAS: Plant aspect (0-5); EAS: Ear aspect (0-5); Erot: Ear rot (0-5); EL: Ear length (cm); ED: Ear diameter (cm); NRPE: Number of kernel rows per ear; NKPR: Number of kernels per row; 100sw: 100 seed weight (g)

Table 4: Mean, range and coefficient of variation of grain yield and agronomic traits of maize inbred lines evaluated in three locations in Nigeria in 2017 and 2018

Parameter	GY	DTA	DAS	PH	EH	PAS	EAS	E.rot	EL	ED	NRPE	NKPR	100sw
						Ibadan							
Mean	567.16	53.23	57.00	113.42	41.33	4.01	2.42	1.53	9.87	3.14	10.96	18.32	18.59
Minimum	88.28	49.00	53.00	80.00	18.00	3.00	1.00	1.00	7.30	2.50	7.40	8.00	13.80
Maximum	2088.08	58.00	60.00	158.00	68.00	5.00	4.00	3.00	14.50	4.20	14.30	26.00	24.84
F test	343124.94*	11.56**	14.37**	663.53**	216.26**	0.10	0.61*	0.48	7.52**	0.67**	9.17**	50.31**	39.98**
CV	62.58	3.33	3.81	9.26	16.91	10.18	20.24	33.24	12.95	8.13	10.09	13.56	6.76
						Ile-Ife							
Mean	818.15	50.63	54.40	124.10	46.18	3.08	2.46	1.90	10.63	3.34	11.78	23.26	18.60
Minimum	192.15	48.00	50.00	87.00	26.00	2.00	1.50	1.00	7.00	2.15	6.00	9.00	13.30
Maximum	2196.08	55.00	61.00	180.00	72.00	4.50	3.50	3.00	13.75	4.89	16.00	31.50	28.82
F test	283795.20*	3.91 *	4.74 *	642.74	171.83	0.54	0.33	0.35 **	3.84 *	0.16	8.55 **	15.47	54.80 **
CV	56.39	2.47	2.69	14.35	20.39	20.46	18.84	16.80	11.54	13.86	11.27	13.74	5.31
						Kishi							
Mean	1335.92	50.33	53.45	133.25	53.45	3.58	2.16	2.08	10.97	3.50	12.53	24.11	18.44
Minimum	59.17	45.00	49.00	85.67	33.50	1.50	1.00	1.00	8.19	2.70	10.45	17.70	10.79
Maximum	3689.04	56.00	58.00	169.00	83.50	4.50	3.00	3.00	14.00	4.20	17.45	30.60	29.06
F test	1268581.75*	12.18 **	8.85 *	378.43	135.46 *	0.33		0.23	0.64	0.20 **	3.76 *	20.11*	21.92*
CV	52.14	3.57	3.11	13.72	12.06	13.38	17.35	16.91	11.77	6.13	9.16	11.89	16.25

GY: Grain yield (kgha^{-1}); DTA: Days to 50% anthesis; DS: Days to 50% silking; PH: Plant height (cm); EH: Ear height (cm); PAS: Plant aspect (0-5); EAS: Ear aspect (0-5); Erot: Ear rot (0-5); EL: Ear length (cm); ED: Ear diameter (cm); NRPE: Number of kernel rows per ear; NKPR: Number of kernels per row; 100seed: 100 seed weight

Table 5: Mean values for agronomic traits of quality protein maize inbred lines evaluated across three locations in Nigeria in 2017 and 2018

Inbreds	GY	DTA	DS	PH	EH	PAS	EAS	EROT	EL	ED	NRPE	NKPR	100SW
TZEEQI 10	928.15	51.72	54.44	117.22	51.23	3.17	2.19	1.72	9.61	3.76	13.58	21.40	18.04
TZEEQI 9	757.04	50.56	54.06	120.15	43.81	3.64	2.22	1.86	10.91	3.37	12.58	21.50	19.41
TZEEQI 5	652.43	51.39	55.78	127.93	48.18	3.83	2.61	1.86	11.10	3.33	12.08	22.08	17.68
TZEEQI 8	1227.50	52.33	55.06	124.01	46.84	3.44	1.97	1.58	10.20	3.20	10.68	23.36	19.78
TZEEQI 2	892.70	50.61	54.72	123.60	46.02	3.64	2.69	1.83	10.04	3.33	11.86	21.99	17.61
TZEEQI 12	890.90	51.67	55.11	136.30	51.35	3.42	2.19	1.72	10.66	3.39	11.45	23.53	20.09
TZEEQI 7	1512.83	50.78	54.06	123.67	45.02	3.42	2.25	1.78	11.18	3.27	11.13	23.66	21.78
TZEEQI 16	596.91	53.83	57.00	132.21	54.38	3.64	2.44	2.06	10.67	3.18	10.59	20.36	16.42
TZEEQI 6	602.75	49.89	53.33	110.96	38.53	3.69	2.40	1.97	10.19	3.22	11.40	21.04	17.93
TZEEQI 3	1009.52	51.22	55.94	119.87	44.48	3.64	2.47	1.97	10.24	3.23	12.22	20.04	16.70
Mean	907.07	51.40	54.95	123.59	46.99	3.55	2.35	1.84	10.49	3.33	11.76	21.90	18.54
Minimum	59.17	45.00	49.00	80.00	18.00	1.50	1.00	1.00	7.00	2.15	6.00	8.00	10.79
Maximum	3689.04	58.00	61.00	180.00	83.50	5.00	4.00	3.00	14.50	4.89	17.45	31.50	29.06
CV (%)	58.21	3.37	3.08	13.12	18.09	15.28	21.31	24.55	12.40	9.72	9.96	13.08	11.06
LSD (0.05)	341.00	1.25	1.31	11.80	5.96			0.43	1.02	0.43	1.53	3.89	2.46

CV%: Percentage coefficient of variation, LSD: Least significance difference, GY: Grain yield (kgha^{-1}); DTA: Days to 50% anthesis; DS: Days to 50% silking; PH: Plant height (cm); EH: Ear height (cm); PAS: Plant aspect (0-5); EAS: Ear aspect (0-5); Erot: Ear rot (0-5); EL: Ear length (cm); ED: Ear diameter (cm); NRPE: Number of kernel rows per ear; NKPR: Number of kernels per row; 100seed: 100 seed weight (g)

Table 6: Phenotypic correlation coefficients for agronomic traits of maize inbred lines evaluated

	GY	DTA	DS	PH	EH	PAS	EAS	Ear rot	EL	ED	NRPE	NKPR	100sw
GY	-	-0.13	-0.26*	0.34**	0.35**	-0.24**	-0.09	0.08	0.27**	0.34**	0.20**	0.38**	0.12
DTA		-	0.73**	-0.12	-0.09	0.15*	0.13	-0.15*	-0.13	-0.16*	-0.22**	-0.26**	0.05
DS			-	-0.14	-0.20**	0.18*	0.10	-0.18*	0.03	-0.13	-0.23**	-0.29**	-0.12
PH				-	0.80**	-0.21**	0.05	0.20**	0.31**	0.12	-0.01	0.32**	0.00
EH					-	-0.17*	0.06	0.18*	0.18*	0.17*	0.07	0.22**	-0.03
PAS						-	0.11	-0.16*	-0.21**	-0.31**	-0.21**	-0.41**	-0.05
EAS							-	0.21**	-0.26**	-0.23**	-0.17*	-0.35**	-0.04
Ear rot								-	0.16*	0.00	0.09	0.14	0.00
EL									-	0.29**	0.20**	0.56**	0.01
ED										-	0.66**	0.50**	-0.01
NRPE											-	0.40**	-0.09
NKPR												-	0.15*

GY: Grain yield (kgha^{-1}); DTA: Days to 50% anthesis; DS: Days to 50% silking; PH: Plant height (cm); EH: Ear height (cm); PAS: Plant aspect (0-5); EAS: Ear aspect (0-5); Erot: Ear rot (0-5); EL: Ear length (cm); ED: Ear diameter (cm); NRPE: Number of kernel rows per ear; NKPR: Number of kernels per row; 100sw: 100 seed weight

Association between pairs of agronomic traits of extra early white quality protein maize inbred lines

Relationships between pairs of some agronomic characters among the inbreds are presented in Table 6. It was observed that highly significant and positive relationship existed between GY and the other agronomic characters such as GY with plant height (PH) (r= 0.34**), ear height (EH) (0.35**), ear length (EL) (0.27**), ear diameter (ED) (0.34**), NRPE (0.20**) and NKPR (0.38**). However, the GY negatively correlated with days to silking, (DS) (-0.26**) and, plant aspect (PAS) (-0.24**). Highly significant and positive association existed between DTA and DS (0.73**) and these same traits had significant and negative correlation with some traits such as ear rot, ED, NRPE and NKPR. Significant and positive relationship was also found among the other yield components. For example, positive and highly significant associations were found between pair of EL with ED (0.29**), NRPE (0.20**) and NKPR (0.56**). NRPE and NKPR were significant and positively associated with ED with correlation coefficient of r= 0.66** and 0.50**, respectively. Similarly, NRPE and NKPR had significant and positive correlation (r= 0.40**) and 100-seed weight positively correlated with NKPR (0.15*).

Discussion

Significant phenotypic differences detected among inbreds for most of the traits across locations, showed the occurrence of substantial genetic variability in the inbreds evaluated in this study. Presence of some substantial variability had been earlier reported among tropical quality protein maize inbreds by several scientists (Annor and Badu-Apraku, 2016). The occurrence of the high variability detected among the inbreds for grain yield (GY) as reflected by high coefficient of variations (CVs) (>50%) per location and across locations. This creates an avenue for breeders and geneticists to improve GY through selection, hybridization and recombination among available inbreds. However, lowest CVs (<4%) obtained in days to 50% anthesis (DTA) and days to 50% silking (DS) among the inbreds at three locations and across locations, show genotypic uniformity within the lines in this study. This pointed out that variability can be created among inbreds for

DTA and DS through mutation, hybridization and recombination.

High GY, early anthesis and tall plants obtained in Kishi compared to Ile-Ife and Ibadan are expected because Kishi had the most suitable weather conditions. The Kishi location had higher insolation (solar radiation) and adequate rainfall distribution during the period of evaluation, for instance, Ibadan received lowest rainfall of 152.50 mm and 147.50 mm; mean rainfall of 164.50 mm and 154.50 mm was received in Ile-Ife, while highest rainfall was received in Kishi (169.50 mm and 166.50 mm) in 2017 and 2018, respectively. However, low grain yield, delayed anthesis and silking, as well as short plant height recorded in Ibadan could be attributed to the poor soil fertility status and unfavorable rainfall pattern of the experimental site. The experimental field had been under continuous maize cultivation for more than fifteen years without fallowing, leading to severe depletion of essential soil nutrients, particularly nitrogen (N), which is critical for vegetative growth, chlorophyll formation, and reproductive development in maize. Nitrogen deficiency is known to reduce plant vigour, shorten plant height, delay flowering, and ultimately decrease grain yield (Anjorin, 2013; Akinyosoye *et al*., 2018; Akinyosoye *et al*., 2025b).

In addition, the location is characterized by low and erratic rainfall with severe early rain cessation. This exposes the crop to moisture stress during critical growth stages such as tasseling and silking in Ibadan. Moisture stress during these stages often delays anthesis and silking, reduces assimilate translocation, and limits grain filling, thereby resulting in poor yield performance (Akinyosoye, 2022; Akinyosoye *et al*., 2025a). The combined effects of nutrient depletion and terminal drought stress therefore explain the poor agronomic performance observed in Ibadan.

Positive and significant correlations in GY with EL, ED, NRPE, NKPR suggests that these traits (GY, EL, ED, NRPE, NKPR) could be governed by similar genes with pleiotropic effect or closely linked genes (Chebib and Guillaume, 2021). Hence, any of these traits may possibly be used for indirect selection for GY improvement. However, positive and significant correlation between GY with PH and EH is undesirable because taller plants with high ear placement are susceptible to lodging. Thus, breeders and farmers preferred moderately short plants with good yield potentials, because this makes harvesting easier and requires few labourers. Positive correlation between GY with PH and EH had been previously reported (Ofori *et al.*, 2015; Ogunniyan and Olakojo, 2015). The observed negative relationships between GY and DTA and DS suggest that breeding for earliness has the tendency of improving GY.

Negative correlations between pairs of grain yield and DTA or DS had been previously reported (Betran *et al.*, 2003). Bello *et al*. (2014) reported that grain yield and earliness are among the most important traits for ranking maize genotypes for adaptation to drought-prone environments because they directly influence the ability of a genotype to complete its life cycle before the onset of severe moisture stress. In drought-affected ecologies, genotypes that flower and mature early are often able to escape terminal drought stress, particularly when rainfall distribution is erratic or when early cessation of rainfall occurs during the reproductive stage. This explains why earliness has remained a major selection criterion in maize improvement programmes targeting stress-prone environments.

Similarly, studies by others (Akbar *et al.*, 2008; Majid *et al.*, 2010; Akinyosoye, 2022) demonstrated that early anthesis and silking shorten the growth duration and hasten physiological maturity. These characteristics constitute important drought escape mechanisms because the crop is able to complete flowering, fertilization, and grain filling before severe soil moisture depletion occurs. Under late-season drought conditions, late-maturing genotypes often experience prolonged exposure to moisture stress during tasseling and grain filling, leading to poor pollination, kernel abortion, reduced assimilate partitioning, and ultimately lower grain yield. In contrast, earlier flowering genotypes are better adapted because they synchronize their reproductive phase with periods of relatively adequate soil moisture availability.

Furthermore, the negative association observed between grain yield (GY) and both plant aspect score (PAS) and ear aspect score (EAS) in this study suggests that genotypes with better plant architecture and superior ear characteristics contributed positively to grain yield performance. Since lower PAS and EAS values generally indicate desirable phenotypic appearance, uniformity, reduced lodging tendency,

and better ear formation, the negative correlation implies that inbreds with moderate plant height, good plant vigour, and attractive ear characteristics are more efficient in converting assimilates into grain yield. Moderate plant height is particularly advantageous under drought conditions because very tall plants often require greater water and nutrient demand, making them more susceptible to moisture stress and lodging. Therefore, the superior performance of moderately tall inbreds with good ear appearance indicates their better adaptation and yield stability under the stress conditions prevailing in the study environments. In this study, inbred TZEEQI 7 recorded the highest grain yield (1512.83 kg ha^{-1}) with moderate plant height across the three locations, indicating its superior adaptability and stability under varying environmental conditions. The outstanding performance of this inbred suggests the presence of favourable gene(s) associated with tolerance to erratic rainfall patterns and moisture stress compared with the other evaluated inbreds. Its ability to maintain relatively high grain yield under conditions characterized by inconsistent rainfall and possible drought stress demonstrates its potential resilience to adverse environmental conditions. Therefore, TZEEQI 7 could serve as a valuable genetic resource in maize breeding programmes targeted at developing drought-tolerant and climate-resilient varieties for drought-prone environments.

Conclusion

Inbred TZEEQI 7 had highest grain yield with moderate plants stature and, therefore, recommended for further improvement for adaptation to drought prone environments. Gene from the inbred line can be introgressed into other normal maize endosperm for conversion to quality protein maize. Ear length, ear diameter, number of kernel rows per ear and number of kernels per row could be used for indirect selection for QPM yield improvement.

Acknowledgement

Author appreciates Institute of Agricultural Research and Training (IAR&T), Moor Plantation, Obafemi Awolowo University, Ibadan, Nigeria for providing facilities to carry out the research. Author appreciates the immense contributions of Prof. Morufat O. Balogun of the Department of Crop Protection and Environmental Biology, University of Ibadan, Nigeria, and Prof. Samuel A. Olakojo of IAR&T., Ibadan, Nigeria to this research work. Author also appreciates the members of staff of Ibadan, Ile-Ife and Kishi out-stations of IAR&T for their technical assistance.

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