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Research Article

Assessing the Potential of Extra-Early Maturing Multiple Stress-tolerant Maize Hybrids Under Different Rates of Nitrogen

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Abstract

Decline in soil fertility is a major constraint to maize production. This study aimed to assess the agronomic performance of improved maize varieties under different nitrogen rates to identify low nitrogen tolerant varieties. Five multiple stress-tolerant maize hybrids, developed by maize improvement program of the International Institute of Tropical Agriculture (IITA), and an open-pollinated variety used as check were evaluated under three levels nitrogen at two locations during 2019 growing season. The experiment was laid out in a split-plot experiment with three replications at each location. Nitrogen rates and varieties were the main and secondary factors, respectively. Data collected on grain yield and its related traits and were subjected to analysis of variance at 5% level of significance. The average grain yield of the six varieties under different nitrogen levels ranged from 2.2 t/ha at 0 kgN/ha in Angaradébou to 5.3 t/ha at 76 kgN/ha in Komkoma. Hybrid TZEEQI 342 × TZEEQI 7 showed high grain yield (4.0 t/ha) across the two agro-ecologies while varieties TZEE-W Pop STR QPM Co × TZEEQI 7 (3.7 t/ha) and TZdEEI 91 × TZEEI 21 (3.6 t/ha) had comparable grain yield. These hybrids were also less susceptible to nitrogen stress. They are the promising genotypes for Angaradébou localities while farmers around Komkoma should continue to cultivate TZEE-W Pop DT STR QPM.

Keywords

Maize Production, Nitrogen Use Efficiency, Plant Nutrition, Multiple Stress-tolerant Maize Hybrids

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1. Introduction

Maize (*Zea mays* L.) is a major crop grown in several agro-ecological zones in the world. In the Republic of Benin, it is the most important cereal produced and consumed and its production is constantly increasing. Maize occupies up to 84% of the total area devoted to cereals and accounts for around 73% of cereal production in the country [1]. Dynamics of maize production over the past ten years reveal that it has risen from 1,065,329 tons in 2009-2010 to almost 1,580,750 tons in 2019-2020, and the cultivated area from 924,764 to 1,470,250 ha, an increase of 48.38% and 58.98%, respectively [1]. This clearly indicates that the increase in production observed over the period was mainly from increase in area cultivated to maize and not increase in average yield. The average yield decreased from 1.152 t/ha in 2009-2010 to 1,075 t/ha in 2019-2020.

Maize is the most important cereal in the national food system, far ahead of rice and sorghum [2, 3]. It is an essential resource and a mainstay of animal feed [4, 5]. The average level of maize consumption is estimated at more than 91 kg/inhabitant/year [6], which places Benin at the second position in the ranking of maize-consuming countries in West Africa (WA) [7]. In addition, maize production is the most cost-efficient and the only cereal for which Benin has exportable surpluses to neighbouring countries like Nigeria, Niger, Burkina Faso, and Togo [8-10]. Maize is therefore an essential commodity chain for guaranteeing food security and reducing poverty in Benin.

Generally, maize yield in Benin remains relatively static, despite its increasing production in recent years. In fact, the observed decrease in maize yield from 1,75 kg/ha in 2019-2020, representing a regression rate of around 8% after 10 years [11]. The decline in maize yield is due to several reasons including biotic (diseases, pests, weeds, insects, etc.) and abiotic stresses. The abiotic factors are more difficult to control and can have severe consequences on maize productivity. Among the abiotic stresses, drought, high temperatures, floods, and declining soil fertility, particularly soil nitrogen (N) deficiency, are the main constraints that most frequently limit maize production and productivity in most Sub-Saharan African countries, including Benin [7, 12].

Nitrogen (N) is one of the most limiting nutrients in maize production [13]. It is an essential plant nutrient and a key yield determinant for maize production [14, 15]. The response of maize plants to the application of N fertilizers depends on variety, location, and the availability other nutrients [15]. Maize plants have high nitrogen requirements from the bolting stage (V10) through to the silking stage (R1). During these developmental stages, significant quantities of N are transferred from leaf tissue to grain. During the grain-filling stage, a decline in N supply decreases dry matter partitioning to grain [16]. N fertilizer is one of the most important factors affecting the growth and grain yield of hybrid maize [17-19]. Grain yield, days to flowering, plant height, ear height, kernel rows per ear, number of kernels per row, ear length, and thousand-grain weight are significantly affected due to growing seasons and split applications of nitrogen [20]. Studies carried out in WA have shown that annual losses in maize grain yields due to soil N deficiency vary between 10 and 50% [21, 22]. Soil N deficiency is a common problem on almost all farms in South-southern Africa (SSA). In African countries where the supply of nitrogen fertilizers is limited, very expensive, and often unavailable when small-scale producers need it, the use of tolerant cultivars to low-N levels is therefore highly desirable [23]. In the Republic of Benin, it is projected that, by 2050, maize yield will be reduced by 30% due to drought [24] about 90% of the soils are deficient in nutrient, especially in nitrogen [25]. This makes the use of fertilizers compulsory for an efficient maize production. In fact, the cost of mineral fertilizers accounts for about 45% of the total production cost [26]. To overcome these challenge, the use of maize hybrids tolerant to water stress and low-N levels would be a major asset for increasing maize production in Benin.

The International Institute of Tropical Agriculture (IITA) has developed multiple stress-tolerant varieties under Stress Tolerant Maize for Africa (STMA) project, and adapted to different agro-ecological zones in Africa. However, little is known on the adaptability of these maize varieties to growing conditions in Benin. The present study aimed at identifying Low-N tolerant extra-early maturing maize hybrids by exploring agronomic and morpho-physiological traits along with grain yield.

2. Materials and Methods

2.1. Study Sites

The study was carried out at two locations in the Republic of Benin, the experimental farm of the Faculty of Agronomy of the University of Parakou at Komkoma, Parakou district (longitude 2°36'E, latitude 09°21'N and altitude 350 m) and the North-East Agricultural Research Centre (CRA Nord-Est) site at Angaradébou, Kandi district (longitude 2°43'E, latitude 11°20'N and altitude 256 m) during 2019 growing season. Komkoma and Angaradébou sites are located in Sudan-Guinean and Sudan climatic zones of Benin, respectively. The cumulative mean rainfall at Komkoma during the cropping periods (June to October) of 2019 was 660.8 mm while at Angaradébou, the cumulative mean rainfall was 971.5 mm (Table 1).

Table 1. *Rainfall at two locations during the study period in Benin Republic in 2019.*

Month	Precipitation (mm)		Number of rain days	
	Komkoma	Angaradébou	Komkoma	Angaradébou
June	69.5	65.5	3	2
July	264.8	231.0	20	9
August	120.5	462.5	14	18
September	206.0	196.0	19	13
October	-	16.5	-	4
Total	660.8	971.5	56	46

2.2. Plant Materials

Five extra-early maturing hybrid maize selected for their high yielding and drought tolerance from 2017 and 2018 regionals trials across Benin and Nigeria countries, and a check which is an opened pollinated variety (OPV) from certified seed grower are used in this study (Table 2).

Table 2. *Extra-early maturing maize hybrids and the check evaluated in this study during 2019 growing season in Benin Republic.*

Genotypes	Codes	Source	Type	Response to nitrogen stress
TZEEQI 342 × TZEEQI 7	V1	MIP/IITA	Hybrid	Unknown
TZEE-W Pop STR QPM Co × TZEEQI 7	V2	MIP/IITA	Hybrid	Unknown
TZdEEI 51 × TZEEI 13	V3	MIP/IITA	Hybrid	Unknown
TZdEEI 91 × TZEEI 21	V4	MIP/IITA	Hybrid	Unknown
TZEEQI 294 × TZEEQI 7	V5	MIP/IITA	Hybrid	Unknown
TZEE-W Pop DT STR QPM	V6	INRAB (Released in 2016, [27])	OPV	Susceptible

2.3. Agronomic Management

At both sites, the experiment was laid out in a split plot design with three replications. The main factor was nitrogen stress with three levels (76 kgN/ha, 30 kgN/ha, and 0 kgN/ha) and the maize varieties were assigned to the sub-plots. The spacings between two replicates and adjacent plots were 1.5m and 1 m, respectively. Each sub-plot was made up of two rows of 3 m each spaced 0.80 m apart while plant spacing within row was 0.40 m giving a density of 62,500 plants per hectare (two seeds per hill). Non-selective herbicide (Glyphosate 480 g/L SL) was applied at a rate of 1 L/ha one week before soil tillage and the mixture of the non-selective herbicide and pre-emergence herbicide (atrazine) was applied at the rate of 1 and 2 L/ha, respectively one day after sowing. Compound fertilizer N-P-K-S-B-Zn 13-17-17-6-0.5-1.5 was applied at the rate of 30 kgN/ha at 2 Weeks After Sowing (WAS) to all the plots for high and low N treatments. An additional 46 kgN/ha was applied to high N plots only at 5 WAS using urea while no fertilizer was added to the plots for control (0 kgN/ha). Weeding was done manually to keep the fields relatively weed-free throughout the season. Emacot (Emamectin Benzoate 5% SG) and carbodan 3% insecticides were used to manage armyworm at 4 WAS and termite at 9 WAS, respectively.

2.4. Traits Measurement

During the trial's evaluation, data were collected as described in the Table 3. Rainfall data were recorded per day during the experimentation. Soil samples were collected at 0 to 30 cm depth from the two sites and analysed for physical and chemical properties in the laboratory of Soil Sciences at the University of Abomey-Calavi (Table 4).

Table 3. *Description of the measured traits of extra-early maize hybrids evaluated in Benin Republic in 2019.*

Traits	**Description**	**Unit**
Days to 50% anthesis (DYTS)	It was recorded when 50% of the plants in a plot had shed pollen.	day
Days 50% silking (DYSK)	It was recorded when 50% of the plants in a plot had extruded silks.	day
Anthesis silking interval (ASI)	It was computed as DYSK minus DYTS.	day
Plant height (PLHT)	At physiological maturity, plant heights were measured on ten representative plants per plot as the length from the base of the plant to the point of the first tassel branch.	cm
Ear height (EHT)	At physiological maturity, ear heights were measured on ten representative plants per plot as the length from the base of the plant to the node bearing the upper ear.	cm
Plant aspect (PASP)	It was visually scored based on the general appeal of plants in a plot (stand-ability, vigour, plant, and ear height, uniformity of plants, ear placement and size, as well as disease damage and lodging) using a scale of 1 to 9, where 1 = excellent overall phenotypic appeal; 2 = very good overall phenotypic appeal; 3 = good overall phenotypic appeal; 4 = satisfactory overall phenotypic appeal; 5 = acceptable phenotypic appeal; 6 = undesirable phenotypic appeal, 7 = poor overall phenotypic appeal, 8 = very poor phenotypic appeal and 9 = completely undesirable phenotypic appeal.	Scale
Ear aspect (EASP)	At harvest, Ear aspect was rated based on the general appeal of the ears without the husks (ear size and number; uniformity of size, colour, and texture; extent of grain filling, insect and disease damage) using a scale of 1 to 9, where 1 = excellent (clean, uniform, large, and well-filled and disease-free ears); and 9 = only one or no ears produced.	Scale
Disease severity	Disease severity was evaluated on a scale of 1 (clean, no infection) to 9 (severely diseased). These diseases are Rust *polysora* or *sorghi* (RUST), Blight *maydis* or *turcicum* (BLT or BLIGHT), Curvularia (CURV), Maize Streak Virus (STREAK).	Scale
Stay green (STGR)	Stay green was scored as percentage of leaf senescence (1= 10% leaf senescence and 5= 50% leaf senescence) at 70 days after planting.	Scale
Grain yield (YIELD)	At harvest, all the cobs in each plot were shelled and the grain weight was measured and used to estimate grain yield adjusted to 12% moisture content.	t/ha
1000 seeds weight (1000 SWT)	It was also measured using a sensitive scale.	g

Table 4. *Chemical and physical properties of the soils at two locations in Benin Republic in 2019.*

Elements	**Critical values**	**Komkoma**		**Angaradébou**	
		Value	**Interpretation**	**Value**	**Interpretation**
pH (H_2O)	5.2 - 8.5	5.43	Moderately acidic	4.53	Strongly acidic
pH (KCl)	5.2 - 8.5	4.81	Strongly acidic	4.08	Strongly acidic
Organic matter (%)	<0.5	0.52	Low	1.08	Moderate
Total nitrogen (%)	<0.03	0.03	Low	0.01	Very low
Available phosphorus (mg/kg)	<5	6.82	Low	4.62	Very low
Clay (%)		16.40		2.80	
Silt (%)		38.40	Loam	11.20	Loamy sand
Sand (%)		43.91		83.12	

2.5. Statistical Analysis

Disease score (Rust, Blight, *Curvularia* and Maize Streak Virus) data were standardized (1 = 1 to 2.5 and 2 = 3 to 5) and summed up to assess disease resistance (from 4 = highly resistant to 8 = highly susceptible). Inverse logit ($\frac{100}{1+exp(-x)}$) transformation was also used for stay green, plant aspect, ears aspect and ASI data. The data were checked for normality and homogeneity of variance using Shapiro-wilk and Bartlett's tests, respectively, before running the analysis of variance (ANOVA) with GenStat 17th edition (VSN International Ltd, UK). Duncan's Multiple Range Test at 5% level of probability were used for separation of significantly different means. Stress indices were calculated based on formulas shown in Table 5.

Table 5. *Stress indices.*

Index	Formula	Authors
Stress susceptibility index	$SSI = \frac{1-\frac{Ys}{Yp}}{1-\frac{Yms}{Ymp}}$	[28]
Yield stability index	$YSI = \frac{Ys}{Yp}$	[29]
Stress tolerance index	$STI = \frac{Yp \times Ys}{(Ymp)^2}$	[30]
Low nitrogen tolerance index	$LNTI = \frac{YP-Ys}{Yp}$	[31]
Gemeotric mean productivity	$GMP = \sqrt{YP \times Ys}$	[30]
Harmonic mean	$HM = \frac{2 \times Yp \times Ys}{Yp+Ys}$	[31]
Mean productivity	$MP = \frac{YP+Ys}{2}$	[32]

Where Ys is the yield of the cultivar under LN conditions; Yp is the yield of cultivar under optimal condition; Yms and Ymp are the mean yields of all cultivar under stress and non-stress conditions, respectively.

3. Results

3.1. Analysis of Variance (ANOVA)

Detailed values for variance components are presented in Table 6. Except for ear aspect and number of ears per plant, there were significant differences ($p < 0.001$) between the two locations for grain yield and all other traits. There were significant differences among the varieties due to nitrogen level at each location and across the both locations for grain yield. Plant height, plant aspect, ear aspect, number of ears per plant, 1 000 seeds weight, and disease resistance significantly varied among the maize varieties at Komkoma while only number of ears per plant was significant at Angaradébou. In contrast, varieties were not significantly different at Komkoma for grain yield but they were significantly different ($p < 0.05$) different at Angaradébou and across the both locations for grain yield. There were no significant interactions between the factors (nitrogen rates, varieties, and locations) for most traits in this study except for grain yield and number of ears per, and resistance to diseases (Table 6).

3.2. Performance of Hybrids Under Different Rates of Nitrogen and Stress Indices

There were no significant differences among the varieties for ASI, plant height, ear height, number of leaves per plant, plant aspect and ear aspect (Table 7). TZEEQI 342 × TZEEQI 7 (4.0 t/ha ±0.27) had the highest grain yield with comparable performance to TZEE-W Pop STR QPM Co × TZEEQI 7 (3.7 t/ha ±0.28) and TZdEEI 91 × TZEEI 21 (3.6 t/ha ±0.32). Variety TZEEQI 294 × TZEEQI 7 (2.8 ±0.23) had the maximum value of stay-green and comparable to TZdEEI 51 × TZEEI 13 (2.9 ±0.25), TZdEEI 91 × TZEEI 21 (2.9 ±0.17) and TZEE-W Pop DT STR QPM (3.1 ±0.20). Variety TZEEQI 294 × TZEEQI 7 (1.1 ±0.03) had the maximum number of ears per plant with comparable performance to TZdEEI 51 × TZEEI 13 (1.1 ±0.03). TZEEQI 342 × TZEEQI 7 (4.1 ±0.06) and TZdEEI 51 × TZEEI 13 (4.1 ±0.08) were most suitable for disease resistance while TZEEQI 342 × TZEEQI 7 (0.9 ±0.49), TZEE-W Pop STR QPM Co × TZEEQI 7 (1.8 ±0.79) and TZEE-W Pop DT STR QPM (1.6 ±0.58) had minimum value of root lodging and had comparable value with TZdEEI 91 × TZEEI 21 (1.8 ±0.80) and TZEEQI 294 × TZEEQI 7 (2.0 ±0.77) (Table 7). The maize varieties had higher yield under both normal and Low N conditions at Komkoma than at Angaradébou (Table 8).

At Angaradébou and across both locations there were significant differences among the varieties for grain yield with TZEEQI 342 × TZEEQI 7 (3.2 t/ha ±0.29; 4.0 t/ha ±0.27) having the the highest grain yield with comparable performance to TZEE-W Pop STR QPM Co × TZEEQI 7 (3.0 ±0.31; 3.7 t/ha ±0.28) and TZdEEI 91 × TZEEI 21 (2.7 ±0.33; 3.6 t/ha ±0.32) (Table 9).

Mean values for grain yield and other stress indices under low and without nitrogen conditions are presented in Table 9. Variety TZEEQI 342 ×TZEEQI 7 had the highest value for the means (geometric mean productivity, harmonic mean and mean productivity), yield stability index and stress tolerance index in both conditions. Only TZEE-W Pop DT STR QPM had a stress susceptibility index superior to one under low nitrogen and without nitrogen conditions. In addition, all the varieties had a low nitrogen tolerance index less than to 35% except TZEE-W Pop DT STR QPM with no nitrogen (Table 10).

Table 6. *Mean squares derived of ANOVA of grain yield and other agronomic traits of extra- early maturing maize varieties at two locations in Benin during 2019 growing season.*

Source of variation	d.f.	Yield (t/ha)	ASI	Plant Height (cm)	Ear height (cm)	Plant aspect	Ear aspect	EPP	1000 kernels weight	Disease resistance
Komkoma										
Rep	2	4.7	56.5	907.9	605.5	16.9	11.3	0.0	2351.1	0.7
Nitrogen (N)	2	14.6***	421.6	1112.7	697.2	295.7*	116.1*	0.0	3422.6*	0.4
Residual	4	0.0	169.6	286.1	206.8	72.8	7.0	0.0	188.6	0.2
Variety (V)	5	0.2	250.0	186.8**	114.1	107.7***	53.7***	0.1***	2132.4***	3.3***
N*V	10	0.1	155.5	59.1	30.7	97.1*	13.0	0.0	283.6	0.2
Residual	30	0.2	138.0	44.3	50.0	100.2	6.9	0.0	196.8	0.3
CV (%)		9.6	17.2	4.2	9.2	2.0	2.8	4.3	5.5	10.9
Angaradebou										
Rep	2	3.6	168.8	580.7	11.5	162.8	264.8	0.0	942.7	0.0
Nitrogen (N)	2	4.5*	14.5	199.9	125.9*	256.9	179.1	0.1	2585.6**	0.0
Residual	4	0.5	39.6	400.0	10.7	124.7	111.4	0.0	116.6	0.0
Variety (V)	5	1.3*	51.1	205.7	8.3	77.5	48.6	0.1**	864.3	0.0
N*V	10	0.4	61.0	158.1	19.0*	74.1	41.9	0.0	944.8	0.0
Residual	30	0.4	43.8	124.6	7.8	52.9	50.3	0.0	520.1	0.0
CV (%)		24.0	7.2	7.5	4.0	8.7	8.8	10.6	9.8	3.2
Across the two locations										
Rep	2	6.6	181.8	1253.1	225.4	105.9	94.5	0.1	2747.3	0.4
Location (L)	1	91.4***	18983.5***	3909.6***	1488.9***	2860.8***	3796.4	0.1	10631.8***	19.6***
Nitrogen (N)	2	16.1***	262.5	1127.6***	707.7***	397.3***	287.4	0.1***	5550.0***	0.2
Variety (V)	5	1.1*	168.9	223.6	42.4	83.3	83.0	0.1***	2218.2***	1.8***
L*N	2	2.1**	173.6	185.1	115.4	7.5	7.9	0.1**	458.2	0.2
L*V	5	0.5	132.2	168.9	80.0	15.8	19.3	0.1	778.6*	1.5***
N*V	10	0.3	95.5	52.4	11.2	42.0	36.7	0.1	453.6	0.2
L*N*V	10	0.3	121.0	164.7	38.5	41.8	18.2	0.1	774.9*	0.1
Residual	70	0.3	91.1	118.3	48.4	34.1	36.5	0.1	340.3	0.2
CV (%)		16.2	12.1	7.1	9.5	6.6	7.0	8.9	7.6	8.8

*, **, *** = Significant F test at 0.05, 0.01 and 0.001 levels of probability, respectively; ASI= Anthesis–silking interval; EPP= ears per plant; and STGR= stay-green characteristic.

Table 7. *Means of grain yield and fifteen other agronomic traits of six extra-early maturing maize varieties across two locations in Benin during 2019 growing season.*

Variety	Yield (t/ha)	Emergence (%)	Days to anthesis	Days to silking	ASI	Disease resistance	STGR	Ears per plant
V1	4.0 ±0.27a	82.4 ±2.25a	54.2 ±0.34ab	55.9 ±0.50bc	1.7 ±0.28	4.1 ±0.06a	3.3 ±0.17b	1.0 ±0.02b
V2	3.7 ±0.28ab	82.6 ±2.63a	54.1 ±0.40ab	55.9 ±0.62bc	1.8 ±0.32	4.6 ±0.18 b	3.2 ±0.17b	1.0 ±0.02bc
V3	3.4 ±0.32b	76.2 ±4.75a	54.3 ±0.31ab	55.1 ±0.49ab	0.8 ±0.45	4.1 ±0.08a	2.9 ±0.25ab	1.1 ±0.03ab
V4	3.6 ±0.32ab	80.6 ±3.48a	53.5 ±0.37a	54.6 ±0.53 a	1.1 ±0.37	4.9 ±0.21c	2.9 ±0.17ab	1.0 ±0.03b
V5	3.4 ±0.35b	69.6 ±4.49b	55.1 ±0.33b	56.4 ±0.64c	1.4 ±0.43	4.4 ±0.15b	2.8 ±0.23a	1.1 ±0.03a
V6	3.4 ±0.30b	79.0 ±2.99c	54.5 ±0.42b	56.3 ±0.61c	1.8 ±0.35	4.6 ±0.16c	3.1 ±0.20ab	0.9 ±0.02c
Mean	3.6 ±0.47	78.4 ±5.70	54.3 ±0.76	55.7 ±0.85	1.7 ±0.50	4.4 ±0.22	3.0 ±0.39	1.0 ±0.05
CV (%)	36.2	19.6	2.9	4.4	72.7	15.5	28.3	10.8

Variety	Height (cm)	Height ear insertion (cm)	Number of leaves	Stem girth (cm)	Plant aspect	Ear aspect	Root lodging	1000 kernels weight (g)
V1	151.8 ±3.08	71.0 ±1.53	18.3 ±0.13	5.1 ±0.15ab	2.0 ±0.21	2.2 ±0.22	0.9 ±0.49a	263.0 ±5.31a
V2	155.2 ±3.08	72.9 ±1.67	18.1 ±0.15	5.3 ±0.18a	2.2 ±0.21	2.3 ±0.21	1.8 ±0.79a	244.6 ±7.04bc
V3	153.3 ±3.47	75.8 ±2.25	18.1 ±0.15	4.8 ±0.15b	2.4 ±0.18	1.8 ±0.18	5.8 ±1.81b	232.0 ±3.20c
V4	160.4 ±3.30	73.5 ±2.62	18.2 ±0.16	5.1 ±0.16ab	2.4 ±0.23	1.8 ±0.16	1.8 ±0.80ab	236.9 ±7.34bc
V5	153.1 ±3.03	73.3 ±1.77	18.5 ±0.22	4.8 ±0.17b	2.6 ±0.17	2.3 ±0.17	2.0 ±0.77ab	236.5 ±3.41bc
V6	150.2 ±3.39	73.0 ±2.36	18.3 ±0.16	5.0 ±0.13b	2.4 ±0.22	2.2 ±0.17	1.6 ±0.58a	246.6 ±8.33b
Mean	154.0 ±6.28	73.3 ±4.02	18.3 ±0.27	5.0 ±0.23	2.3 ±0.33	2.1 ±0.30	2.3 ±1.31	243.3 ±10.65
CV (%)	9.2	11.9	3.8	13.4	37.5	38.1	188.1	11.2

Means with the same letter are not significantly different at 0.05 probability level. ASI= Anthesis–silking interval, STGR= stay-green characteristic, V1= TZEEQI 342 × TZEEQI 7, V2= TZEE-W Pop STR QPM Co × TZEEQI 7, V3= TZdEEI 51 × TZEEI 13, V4= TZdEEI 91 × TZEEI 21, V5= TZEEQI 294 × TZEEQI 7, V6= TZEE-W Pop DT STR QPM

Table 8. *Average grain yield of six extra-early maturing maize varieties under three levels of nitrogen at two locations (Komkoma and Angaradébou) in Benin Republic in 2019.*

Environment		Nitrogen level applied (kgN/ha)	Grain yield (t/ha)
Komkoma	normal	76	5.3a
	low	30	4.7b
	control	0	3.5c
	Mean		4.5
	CV (%)		20.9
Angaradébou	normal	76	3.2c
	low	30	2.5d
	control	0	2.2d
	Mean		2.7

Environment	Nitrogen level applied (kgN/ha)	Grain yield (t/ha)
CV (%)		33.1

Means with the same letter are not significantly different at 0.05 probability level.

Table 9. *Grain yield (t/ha) of six maize varieties at two locations under different rates of Nitrogen in Benin Republic.*

Variety	Nitrogen	Angaradébou	Combined mean	Komkoma	Combined mean	Average	combined Mean
	control	2.4		4.1		3.2	
TZEEQI 342 × TZEEQI 7	Low	3.2		4.7		3.9	
	normal	4.1	3.2 a	5.6	4.8	4.8	4.0 a
	control	2.4		3.4		2.9	
TZEE-W Pop STR QPM Co × TZEEQI 7	Low	2.8		4.4		3.6	
	normal	3.7	3.0 ab	5.3	4.4	4.5	3.7 ab
	control	2.2		3.4		2.8	
TZdEEI 51 × TZEEI 13	Low	2.3		4.6		3.5	
	normal	2.6	2.4 bc	5.3	4.5	3.9	3.4 b
	control	2.0		3.3		2.7	
TZdEEI 91 × TZEEI 21	low	2.4		4.7		3.6	
	normal	3.7	2.7 abc	5.5	4.5	4.6	3.6 ab
	control	2.3		3.5		2.9	
TZEEQI 294 × TZEEQI 7	low	2.0		4.8		3.4	
	normal	2.4	2.3 c	5.3	4.5	3.8	3.4 b
	control	2.1		3.4		2.8	
TZEE-W Pop DT STR QPM	low	2.5		4.7		3.6	
	normal	2.8	2.5 bc	4.8	4.3	3.8	3.4 b

Means with the same letter are not significantly different at 0.05 probability level.

Table 10. *Means, yield stability index, stress susceptibility index, stress tolerance index and low nitrogen tolerance index of six maize varieties at two locations in Benin Republic during 2019 growing season.*

variety	GPM1 (t/ha)	GMP2 (t/ha)	HM1 (t/ha)	HM2 (t/ha)	MP1 (t/ha)	MP2 (t/ha)	YSI1	YSI2	SSI1	SSI2	STI1	STI2	LNTI1 (%)	LNTI2 (%)
V1	4.18	3.78	4.16	3.72	4.20	3.84	0.91	0.74	0.74	0.80	0.98	0.78	09	26
V2	3.92	3.49	3.89	3.42	3.96	3.55	0.88	0.69	0.62	0.97	0.86	0.74	12	31
V3	3.89	3.44	3.86	3.37	3.91	3.52	0.89	0.68	0.82	1.00	0.84	0.69	11	32
V4	3.75	3.20	3.74	3.13	3.76	3.27	0.96	0.73	0.28	0.84	0.77	0.58	04	27
V5	3.85	3.52	3.79	3.40	3.91	3.65	0.85	0.75	1.14	0.77	0.84	0.71	15	25
V6	3.67	3.46	3.54	3.36	3.84	3.56	0.79	0.63	1.12	1.17	0.75	0.70	21	37
Mean	3.87	3.48	3.83	3.40	3.93	3.57	0.88	0.70	0.79	0.92	0.84	0.69	12	30

variety	GPM1 (t/ha)	GMP2 (t/ha)	HM1 (t/ha)	HM2 (t/ha)	MP1 (t/ha)	MP2 (t/ha)	YSI1	YSI2	SSI1	SSI2	STI1	STI2	LNTI1 (%)	LNTI2 (%)
CV (%)	32.05	30.03	33.33	30.46	30.73	29.70	28.07	27.16	166.5	66.83	31.64	40.04	203	64

GMP = geometric mean productivity, HM = harmonic mean, PM = mean productivity, YSI = yield stability index, SSI = stress susceptibility index, STI = stress tolerance index, LNTI = low nitrogen tolerance index, 1 = at low nitrogen condition, 2 = at no nitrogen condition, V1 = TZEEQI 342 × TZEEQI 7, V2 = TZEE-W Pop STR QPM Co × TZEEQI7, V3 = TZdEEI 51 × TZEEI 13, V4 = TZdEEI 91 × TZEEI 21, V5 = TZEEQI 294 × TZEEQI 7, V6 = TZEE-W Pop DT STR QPM.

4. Discussion

Nitrogen (N) deficiency is one of the main characteristics of soils in Benin, limiting maize production and productivity. This study was conducted to examine the agronomic performance of five hybrids under nitrogen stress. The main cause of the observed difference in grain yield between the two locations is mainly due to soil properties as reported by Igué *et al*. [33]. The total precipitation of 661 mm at Komkoma and 972 mm at Angaradébou is sufficient for maize production but the distribution of rainfall was irregular with some prolonged dry spells at Angaradébou.

Secondary traits are much more important than grain yields under stressed environments as they are precise for identification of drought and low nitrogen tolerant genotypes and determine the degree to which the crop was stressed [34, 35]. Low nitrogen is regarded as an abiotic stress for the growth of maize plants, which hinders or limits the expression of their genetic potential in growth and development stages, thereby affecting the performance of grain yield [36, 37]. The highly significant mean square obtained for nitrogen level in this study and grain yield were considerably influenced by nitrogen rate. The significant difference observed in grain yield at Angaradébou but not at Komkoma implies that the soil nitrogen level in Angaradébou is low enough to discriminate the varieties. Based on the result obtained in this study, farmers are advised to use TZEE-W Pop DT STR QPM on soils with moderate fertility. In fact, seeds of an OPV are cheaper than that of hybrid, so it is more benefit to use an OPV instead of hybrid if they have similar yield. On a very poor soil like that of Kandi district, varieties TZEEQI 342 × TZEEQI 7, TZEE-W Pop STR QPM Co × TZEEQI 7, and TZdEEI 91 × TZEEI 21 are the promising genotypes.

It is reported that the modern high yielding crop cultivars are more adaptable to high nitrogen conditions [38, 39]. In this study, seven screening indices were used to evaluate the performance of the maize varieties under low nitrogen tolerance. Geometric mean productivity (GMP) indicated the mean performance of a genotype across the two environments with high nitrogen and without or low nitrogen fertilizer [30, 40]. The mean productivity index (MP) is the mean of grain yield in high and low nitrogen environments. Based on these indices, TZEEQI 342 × TZEEQI 7 is the most suitable genotype under nitrogen stress condition. Jamshidi and Javanmard [41] also reported that the stress tolerance index (STI) could be used to evaluate genotypes that have high productivity under both normal and stressed conditions. The value of the harmonic mean (HM) is used to identify high-yielding yield and stable genotypes [31]. The yield stability index (YSI) is used to identify stable genotypes under both stressed and non-stressed conditions [42]. These indices (GMP, MP, STI, HM and YSI) and grain yield under both high nitrogen and low nitrogen conditions have been reported to have high positive correlation among them and they reflect together the character of high yield and stable yield for maize plants [31, 43, 41]. Genotypes with a high value of these indices are more desirable [30, 44, 45]. This is confirmed by the result from this study where TZEEQI 342 × TZEEQI 7 was identified as the best genotype across all these indices. The stress susceptibility index (SSI) and low nitrogen tolerance index (LNTI) could be used as supplementary indices [28]. The SSI exhibited a degree of reduction in the grain yield under low nitrogen condition when compared to the grain yield under the high nitrogen condition [28]. These indices show the sensitivity and the tolerance of maize genotypes under low nitrogen conditions. Genotypes with SSI values less than 1 are more tolerant to low nitrogen [28]. Hence, TZdEEI 51 × TZEEI 13, TZEEQI 294 × TZEEQI 7 and TZEE-W Pop DT STR QPM are more susceptible to low nitrogen stress. The LNTI was proposed for evaluating the low nitrogen tolerant genotypes under stressed condition [30]. According to Bänziger and Lafitte [46] genotype is considered tolerant to low nitrogen stress when its yield loss is less than 35% of the potential yield under optimum conditions. The variety TZEE-W Pop DT STR QPM cannot be categorised among varieties tolerant to low nitrogen. Thus, the two indices (LNTI and SSI) were helpful to identify TZEEQI 342 × TZEEQI 7, TZEE-W Pop STR QPM Co × TZEEQI 7 and TZdEEI 91 × TZEEI 21 as the most tolerant to low nitrogen stress among the hybrid varieties in the northern Benin.

5. Conclusions

This study uncovered striking levels of multiple environments stress tolerance assessing among the extra-early hybrid's maize and selected hybrid potentially tolerant to Low-N stress. Highly significant mean square due to nitrogen level was obtained in this study indicating that maize grain yield is considerably influenced by nitrogen rate. In contrast, varieties were not significantly different at Komkoma for grain yield whereas the opposite happened at Angaradébou and across the two locations. This means that these varieties have similar response to nitrogen under favourable condition but differ in their responses under unfavourable condition for grain yield. Varieties TZEEQI 342 × TZEEQI 7, TZEE-W Pop STR QPM Co × TZEEQI 7 and TZdEEI 91 × TZEEI were identified as most tolerant to low nitrogen in this study. These varieties are recommended for further evaluation at Kandi district while farmers around Parakou district should continue to cultivate TZEE-W Pop DT STR QPM.

Abbreviations

ANOVA: Analysis of Variance
ASI: Anthesis–Silking Interval
CRA: Agricultural Research Centre
EPP: Ears Per Plant
GMP: Gemeotric Mean Productivity
HM: Harmonic Mean
IITA: International Institute of Tropical Agriculture
INRAB: National Institute for Agricultural Research of Benin
LaPAPP: Laboratory of Phytotechny, Plant Breeding and Plant Protection
LNTI: Low Nitrogen Tolerance Index
MP: Mean Productivity
OPV: Open Pollinated Variety
SSA: Sub-Saharan African
SSI: Stress Susceptibility Index
STGR: Stay-Green characteristic
STI: Stress Tolerance Index
STMA: Stress Tolerant Maize for Africa
WA: West Africa
WAS: Weeks After Sowing
YSI: Yield Stability Index

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Conflicts of Interest

The authors declare no conflicts of interest.

References

[1] DSA/ MAEP. 2021. https://dsa.agriculture.gouv.bj Consulted on 15/06/23

[2] Houngbo N. E. 2015. Diversité et critères d'adoption des cultivars de maïs (Zea mays L.) dans le village Zounnou, Centre Bénin. J. Appl. Biosci. 96: 9094 – 9101, ISSN 1997–5902. https://doi.org/10.4314/jab.v96i1.1

[3] Hongbete, F., Kindossi, J. M., Hounhouigan, J. D., & Nago, M. C. 2017. Production et qualité nutritionnelle des épis de maïs frais bouillis consommés au Bénin. *Int. J. Biol. Chem. Sci.* 11(5): 2378–2392. https://doi.org/10.4314/ijbcs.v11i5.34

[4] Guedou, M. S. E.; Houndonougbo, M. F.; Chrysostome, C. A. A. M. et Mensah, G. A., 2015. Le maiis grain et ses sous-produits en alimentation de volailleau Bénin: synthèse bibliographique. *Annales des sciences agronomiques* 19(2): 149-164.

[5] Guedou M. S. E., Kouato G. O., Houndonougbo M. F., Chrysostome C. A. A. M., Mensah G. A., 2018. Performances de ponte et qualité des œufs de poules pondeuses nourries avec des aliments à base de différentes variétés de grains de maïs. *Int. J. Biol. Chem. Sci.* 12(6): 2846-2855. ISSN: 1997-342X (Online), ISSN: 1991-8631 (Print). http://ajol.info/index.php/ijbcs; http://indexmedicus.afro.who.int; https://dx.doi.org/10.4314/ijbcs.v12i6.29

[6] DSA/ MAEP. 2022. https://dsa.agriculture.gouv.bj. Consulted on 12/07/23

[7] Badu-Apraku, B. and Fakorede, M. A. B. 2017. Advances in Genetic Enhancement of Early and Extra-Early Maize for Sub-Saharan Africa. Ibadan, Nigeria. 632 pp.

[8] FAO, Union européenne et Cirad. 2023. Profil des systèmes alimentaires – Bénin. Activer la transformation durable et inclusive de nos des systèmes alimentaires. Rome, Bruxelles et Montpellier, France. https://doi.org/10.4060/cc3787fr/

[9] Yessoufou A. R., Adegnika M. 2018. Analyse de la compétivité de la filière maïs au nord du Bénin: Cas de la Commune de Parakou. Journal of Economic Literature (JEL) 7: 149-174. http://revues.imist.ma/?journal=REMSE&page=index

[10] Zohoungbogbo H. P. F., Montin A., Lègba E. C., Houdégbé C. A., Fassinou Hotègni N. V., Achigan-Dako E. G., 2018. Fiche technique synthétique pour la production du maïs jaune (Zea mays L.). Laboratory of Genetics Horticulture and Seed Science (GBioS), Dépôt légal N°10668 du 06/09/2018, 3ème Trimestre Septembre, Bibliothèque Nationale (BN) du Bénin, ISBN: 978-99919-78-48-2; Website: www.gbios-uac.org

[11] DSA/ MAEP. 2022. https://dsa.agriculture.gouv.bj. Consulted on 02/06/23

[12] Badu-Apraku, B., Abamu, F. J., Menkir, A., Fakorede, M. A. B., Obeng-Antwi, K. and The, C. (2003). Genotype by environment interactions in the regional early variety trials in West and Central Africa. *Maydica* 48: 93-104.

[13] Carsky, R. J. and Iwuafor, E. N. O (1995). Contribution of soil fertility research and maintenance to improved production and productivity in sub-Saharan Africa. In: Proceedings of Regional Maize Workshop, 29 May–2 June, 1995, IITA, Cotonuo, Benin Republic.

[14] Onasanya, R. O., Aiyelari, O. P., Onasanya, A., Oikeh, S., Nwilene, F. E., & Oyelakin, O. O. (2009). Growth and yield response of maize (Zea mays L.) to different rates of nitrogen and phosphorus fertilizers in southern Nigeria. World Journal of Agricultural Sciences, 5(4), 400-407.

[15] Andrade, F. H.; Echarte, L.; Rizzalli, R.; Della, M. A.; Casanovas, M. Kernel number prediction in maize under nitrogen or water stress. Crop Sci. 2002, 42, 1173–1179.

[16] Ciampitti, I. A.; Vyn, T. J. A comprehensive study of plant density consequences on nitrogen uptake dynamics of maize plants from vegetative to reproductive stage. Field Crops Res. 2011, 121, 2–18. https://doi.org/10.1016/j.fcr.2010.10.009

[17] Zhang, G. Q.; Shen, D. P.; Xie, R. Z.; Ming, B.; Hou, P.; Xue, J.; Li, R. F.; Chen, J. L.; Wang, K. R.; Li, S. K. Optimizing planting density to improve nitrogen use of super high-yield maize. Agron. J. 2020, 112, 4147–4158. https://doi.org/10.1002/agj2.20334

[18] Adhikari, K., Bhandari, S., Aryal, K., Mahato, M., & Shrestha, J. (2021). Effect of different levels of nitrogen on growth and yield of hybrid maize (Zea mays L.) varieties. Journal of Agriculture and Natural Resources, 4(2), 48-62. https://doi.org/10.3126/janr.v4i2.3365

[19] Adhikari, K. et al. 2016. A genome-wide association scan in admixed Latin Americans identifies loci influencing facial and scalp hair features. Nat. Commun. 7: 10815. https://doi.org/10.1038/ncomms10815

[20] Logrono M., J. E. Lothrop, (1997) Impact of drought and low nitrogen on maize production in Asia. pp. 39-43. In: G. O. Edmeades et al. (Eds.), Developing Drought- and Low N-Tolerant Maize. CIMMYT/UNDP. Mexico, D. F.

[21] Wolfe D. W., D. W. Henderson, T. C. Hsiao, A. Alvio, (1988) Interactive water and nitrogen effects on maize. II. Photosynthetic decline and longevity of individual leaves. Agron. J. 80: 865- 870.

[22] Banziger, M. and Cooper, M. (2001) Breeding for low input conditions and consequences for participatory plant breeding: Examples from tropical maize and wheat, *Euphytica*, 122, pp. 503-519. https://doi.org/10.1023/A:1017510928038

[23] Akponikpe P. B. I., Tovihoudji P., Lokonon B., Kpadonou E., Amegnaglo J., Segnon A. C., Yegbemey R., Hounsou M., Wabi M., Totin E., Fandohan-Bonou A., Dossa E., Ahoyo N., Laourou D., Aho N., 2019. Etude de Vulnérabilité aux changements climatiques du Secteur Agriculture au Bénin. Report produced under the project "Projet d'Appui Scientifique aux processus de Plans Nationaux d'Adaptation dans les pays francophones les moins avancés d'Afrique subsaharienne", Climate Analytics gGmbH, Berlin.

[24] Ministère du Cadre de Vie et du Développement Durable (MCVDD). 2018. Etudes de vulnérabilité: résultats préliminaires, Agriculture. GIZ/Climate Analytics, Cotonou. 31 pp.

[25] Tokoudagba, S. F. 2014. Economie de la production du maïs au Nord-Bénin: une analyse du compte de résultat des exploitations agricoles. Bulletin de la Recherche Agronomique du Bénin (BRAB) 3: 20-28. http://www.slire.net/download/2238/article_3_pg_brab_n_sp_cial_esr_d_cembre_2014_tokoudagba_economie-production-ma_s.pdf

[26] Yallou, C. G., Aïhou, K., Adjanohoun, A., Toukourou, M., Sanni, O. A. and Ali, D. 2010. Itinéraires techniques de production de maïs au Bénin. Bibliothèque Nationale du Bénin, Cotonou. 18 pp.

[27] MAEP (Ministère de l'Agriculture, de l'Elevage et de la Pêche), 2016. Catalogue Béninois des Espèces et Variétés végétales (CaBEV), 2016. *INRAB/DPVPPAAO/ProCAD/MAEP & CORAF/WAAPP*. 339 p. Dépôt légal N° 8982 du 21 octobre 2016, Bibliothèque Nationale (BN) du Bénin, 4ème trimestre. ISBN:

[28] Fischer, R. A. and Maurer, R. 1978. Drought resistance in spring wheat cultivars: Grain yield responses. *Journal of Agricultural Resources* 29: 897-912. http://dx.doi.org/10.1071/AR9780897

[29] Bouslama, M. and Schapaugh, W. T. 1984. Stress tolerance in soybean. Part 1: Evaluation of three screening techniques for heat and drought tolerance. *Crop Science* 24: 933-937. https://doi.org/10.2135/cropsci1984.0011183X002400050026x

[30] Francisco, M., Pangirayi, T. and John, D. 2010. S1 selection of local maize landraces for low soil nitrogen tolerance in Zambia. *African Journal of Plant Science* 4: 67-81. www.internationalscholarsjournals.org

[31] Kristin, A. S., Senra, R. R., Perez, F. I., Enriquez, B. C., Gallegos, J. A. A., Vallego, P. R., Wassimi, N. and Kelley, J. D. 1997. Improving common bean performance under drought stress. *Crop Science* 37: 43-50. https://doi.org/10.2135/cropsci1997.0011183X003700010007x

[32] Rosielle, A. A. and Hamblin, J. 1981. Theoretical aspects of selection for yield in stress and non-stress environment. *Crop Science* 21: 943-946. http://dx.doi.org/10.2135/cropsci1981.0011183X00210

[33] Igué, A. M., Gaiser, T. and Stahr, K. 2014. Landscape related variability of physical and chemical soil characteristics in the Moist Savannah of Benin. *International Journal of AgriScience* 4(1): 28-48.

[34] Banzinger, M., Edmeades, G. O., Beck, D. and Bellon, M. 2000. From Theory to Practice Breeding for Drought and Nitrogen Stress Tolerance in Maize Breeding for Drought and Nitrogen Stress Tolerance in Maize: from Theory to Practice. CIMMYT, Mexico. 70 pp. http://hdl.handle.net/10883/765

[35] Santos, T. d. O.; Amaral Junior, A. T. d.; Moulin, M. M., 2023. Maize Breeding for Low Nitrogen Inputs in Agriculture. *Mechanisms Underlying the Tolerance to the Abiotic Stress* 3: 136–152. https:// doi.org/10.3390/stresses3010011

[36] Rehman, S. U., Nietert, P. J., Cope, D. W. and Kilpatrick, A. O. 2005. What to wear today? Effect of doctor's attire on the trust and confidence of patients, The American Journal of Medicine, 118(11): 1279–1286. https://doi.org/1016/j.amjmed.2005.04.026

[37] Hammad HM, Chawla MS, Jawad R, Alhuqail A, Bakhat HF, Farhad W, Khan F, Mubeen M, Shah AN, Liu K, Harrison MT, Saud S and Fahad S, 2022. Evaluating the Impact of Nitrogen Application on Growth and Productivity of Maize under Control Conditions. *Front. Plant Sci.* 13: 885479. https://doi.org/10.3389/fpls.2022.885479

[38] Dencic, S., Kastori, R., Kobiljski, B. and Duggan, B. 2000. Evaluation of grain yield and its components in wheat cultivars and landraces under near optimal and drought conditions. *Euphytica* 113: 43–52. https://doi.org/10.1023/A:1003997700865

[39] Akçura, M., Partigoç, F. and Kaya, Y. 2011. Evaluating of drought stress tolerance based on selections indices in Turkish bread wheat landraces. *Journal of Animal and Plant Science* 21: 700-709.

[40] Fernandez, G. C. J. 1992. Effective selection criteria for assessing stress tolerance. In Kuo, O. G. Ed. *Proceedings of the International Symposium on Adaptation of Vegetables and Other Food Crops in Temperature and Water Stress held in August 13–18, 1992 at Taiman,* Taiwan. 12-27 pp. https://doi.org/10.22001/wvc.72511

[41] Jamshidi, A. and Javanmard, H. R., 2018. Evaluation of barley (Hordeum vulgare L.) genotypes for salinity tolerance under field conditions using the stress indices. Ain Shams Eng. J. 9(4), 2093–2099. https://doi.org/10.1016/j.asej.2017.02.006

[42] Jafari, A., Paknejad, F. and Alahmadi, M. J. 2009. Evaluation of selection indices for drought tolerance of corn (Zea mays L.) hybrids. *International Journal of Plant Production* 3: 33-38.

[43] Lyra, D. H., de Freitas M. L., Galli, G., Alves, F. C., Granato, Í. S. C. and Fritsche-Neto, R. 2017. Multi-trait genomic prediction for nitrogen response indices in tropical maize hybrids. *Molecular Breeding* 37: 80-87. https://doi.org/10.1007/s11032-017-0681-1

[44] Zhixin, Z., Kunhui, H., Zhiqian, F., Yanan, L., Liguo, C., Xinghua, Z., Shutu, X., Jianchao, L. and Jiquan, X. 2019. Evaluation of yield-based low nitrogen tolerance indices for screening maize (*Zea mays* L.) inbred lines. *Agronomy* 9: 240-247. https://doi.org/10.3390/agronomy9050240

[45] Tyagi, B. S. et al., 2020. Identification of wheat cultivars for low nitrogen tolerance using multivariable screening approaches. Agronomy 10(3), 417. https://doi.org/10.3390/agronomy10030417

[46] Bänziger, M. and Lafitte, H. R. 1997. Efficiency of secondary traits for improving maize for low nitrogen target environments. *Crop Science* 37: 110-117. https://doi.org/10.2135/cropsci1997.0011183X003700040013x