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Assessing grain yield of quality protein maize under low soil nitrogen through associated agronomic traits

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ABSTRACT

The study was conducted to improve a quality protein maize (QPM) population, ART/98/ILE 1-OB, for tolerance to low soil nitrogen, and to investigate the agronomic characters that are linked to grain yield of QPM in low soil nitrogen environments. S1 lines were selected in the maize population at cycle one (C1) in a recurrent selection programme, for evaluation to move to cycle 2 (C2). Data were collected on agronomic traits, stay-green ability (SGR) and grain yield (GY) and analysed using SAS. SGR rating at 8 weeks after planting (8WAP) was moderate under low nitrogen (3.09). GY was slightly higher under low nitrogen (LN) (2.19 tons/ha) than under high nitrogen (HN) condition (1.98 tons/ha). There were notable negative phenotypic and genotypic correlations between grain yield (GY) and traits such as days to 50% anthesis and silking, stay green rating (SGR), ear aspect (EA), and plant aspect (PA). In contrast, positive correlations were observed with plant height (PH) and number of ears per plant (EPP). In stepwise regression, EPP emerged as the most significant character under LN (R^2 = 45%), with EA, SGR at 8WAP (SGR8), and PH following closely. EPP showed the highest positive direct effect on grain yield, followed by SGR8. EA had the highest negative direct effect. PC1 alone, which was mostly linked to PH, accounted for 96.5% of the overall variation. These findings underscore the importance of EPP, EA, SGR8 and PH as selection criteria in enhancing QPM productivity under LN conditions.

Contribution/Originality: This study is novel in that it provides an insight into the key traits to be considered during selection in the improvement of quality protein maize for tolerance to low soil nitrogen. Most of the studies on low soil nitrogen have focused on normal maize.

1. INTRODUCTION

The livelihoods and food security of millions of resource-limited individuals are at risk due to factors such as population growth, climate change, resource depletion, and recurring food price crises. Maize accounts for up to 51% of calories consumed and is the main crop in many parts of sub-Saharan Africa (SSA) [1]. Maize accounts for around 15% of the total energy consumed in rural populations in West and Central Africa [2].

Nitrogen (N) is an essential nutrient for the growth of plants, playing a key role in improving crop yield and productivity [3, 4]. It is the primary nutrient required by maize for optimal growth and grain yield [5, 6]. To boost maize yield in nitrogen-deficient soils, [7] suggested utilizing populations with a tolerance for low N to develop low N cultivars.

Maize grain yield is a multifaceted quantitative trait, affected by a variety of factors such as environmental influences and different growth and physiological processes during the plant's life cycle. Gaining insight into the relationship between yield and its contributing factors is crucial for identifying selection criteria that can improve the effectiveness of a breeding programs [8]. Direct yield selection can be misleading due to significant environmental influences [9]. Correlation coefficient analysis provides insight into traits that can be selected concurrently for grain yield improvement [10]. Correlation analyses assess the associations between yield and other characteristics. Indirect selection in breeding programs is possible through both genotypic and phenotypic association [11]. To determine the cause and impact of a correlation, path analysis [12] breaks it down into direct and indirect effects.

Partial regression analysis has also been employed to predict agronomic traits that could influence yield. Sellam and Poovammal [13] found that Partial Least Square Regression (PLSR) analysis had limited predictive accuracy for maize grain yield, which could be enhanced by including more physiological traits and evaluating in more environments. Accurate phenotypic data is crucial for developing prediction models, making phenotyping a cornerstone of predictive breeding [14]. Selecting multiple traits simultaneously can be difficult, as the weakness of one trait may negatively impact the strength of another, resulting in inconsistent outcomes. Finding the essential traits that most influence yield is crucial for increasing selection accuracy. Grain yield and secondary traits must have high heritability, substantial genetic correlations with yield, and simplicity of measurement in order to be selected for efficiently in low nitrogen conditions.

There is inconsistent evidence about the key agronomic traits that affect grain yield in low nitrogen soil conditions. Traits such as the Anthesis-Silking Interval (ASI) and the number of ears per plant are considered vital in low nitrogen and drought situations, forming the basis for selection criteria. Bänziger, et al. [15]; Edmeades, et al. [16]; Badu-Apraku, et al. [17]; Ajala, et al. [18] and Badu-Apraku, et al. [19]. Ajala, et al. [20] highlighted stay green ability, plant height, and ear aspect, while [21] reported kernel number per ear as crucial for grain yield under low nitrogen. This suggests that the contribution of associated traits may vary between populations. However, all these studies focused on normal maize. For breeding efforts on improvement of quality protein maize (QPM) for low soil nitrogen tolerance, research on agronomic traits influencing QPM grain yield is necessary.

The objectives of this study are to: (i) increase the tolerance of a quality protein maize to low soil nitrogen; and (ii) identify the agronomic features that are predictive of quality protein maize grain yield in low soil nitrogen conditions.

2. MATERIALS AND METHODS

2.1. Test Population

The open-pollinated ART/98/ILE 1-OB maize variety was developed primarily for its excellent protein characteristics by the Institute of Agricultural Research and Training (IAR&T), Nigeria. It is an intermediate-maturing white-kernel maize that is well suited to Nigeria's southwest environment.

2.2. Development of Cycles of Recurrent Selection

To increase the population's resistance to low soil nitrogen, two rounds of recurrent selection were applied to the QPM maize population. In 2018, at low nitrogen screening sites in Mokwa and Zaria, two hundred and fifty (250) S1 lines were generated from the original population for evaluation with six checks under low nitrogen (LN) and high nitrogen (HN) conditions. The LN block received N at the rate of 30 kgN/ha, while the HN received N at 90 kgN/ha. The top-performing S1 lines were selected using 20% selection intensity. The chosen lines were screened under a lightbox to eliminate lines/kernels without the opaque genes before recombination to cycle 1 (C1). The recombination was done twice in 2019 to bring the population to C1F2.

2.3. Field Evaluation to Move to Cycle 2

The C1 population was planted, and about 300 plants were self-pollinated in 2020. Out of these, only 131 S1s were got with a reasonable quantity of kernels due to the erratic rainfall during the period, which affected the grain filling of some of the selfed plants. During the 2021 cropping season, the 131 S1s with a check were assessed under low (LN) and high (HN) soil nitrogen conditions at the low N screening locations in Ilora and Ile-Ife, Nigeria. Ile-Ife is in the agro-ecological zone of the rainforest, whereas Ilora is in the derived savanna. The fields at the two sites have been mopped up on their nitrogen for years by continuously planting maize without organic or inorganic fertilizer. After every harvest, the plants were often completely pulled out of the field. Prior to the experiment, soil samples were collected from various areas of the field and bulked for physio-chemical analysis at both sites. According to the results of the soil study, the soil at Ilora has 0.23 cmol/kg K, 5.96 mg/kg P, and 0.05% N. Ile-Ife's soil has 0.25 cmol/kg K, 11.98 mg/kg P, and 0.05% N.

A 12x11 lattice design with two replicates was used in the experiment. To prevent any nitrogen seepage, the LN and HN blocks were spaced 5 meters apart. Every S1 was planted in a 3 m long single-row plot with 0.75 m between rows and 0.25 m inside rows of each other. To achieve a population of 53,333 plants/ha, thinning was carried out two weeks after planting (WAP) one plant per hill. Two and four WAP, a divided dosage of urea fertilizer was administered. Fertilizer was applied at a rate of 30 kgN/ha to LN plots and 90 kgN/ha to HN plots. At planting, 60 kg P_2O_5/ha P was applied as a single superphosphate to the LN and HN fields. Throughout the trials, weeds were kept out of the fields.

2.4. Data Collection

The number of days to 50% anthesis (DTA) and silking (DTS) were recorded in each plot as the number of days from sowing to when half of the plants shed pollen and emerge silks, respectively. Anthesis-silking interval (ASI) is computed as the difference in days between silking and anthesis. Stay green ability (SGR) was scored only on LN plots at 8 (SGR8) and 10 (SGR10) weeks after planting (WAP) on a scale of 1 to 9, where 1 = less than 10 % senesced leaf and 9 = more than 80 % senesced leaf area below the ear. Plant height (PH) was measured in centimetres at maturity, the distance from the ground to the base of the tassel. Plant aspect (PA) was rated on a scale of 1 to 9, where 1 = excellent overall phenotypic appeal of the plants in a plot, and 9 = poor overall phenotypic appeal. Ear aspect (EA) was also rated on a scale of 1-9. One represents clean and well-filled cobs, while 9 represents cobs without kernels or with very few kernels. The number of ears per plant (EPP) was estimated as the proportion of the ears divided by the number of harvested plants. A few ears were shelled from each plot to determine the moisture percentage. Grain yield (GY) adjusted to 14 % moisture was estimated from field weight at 80 % shelling percentage.

2.5. Statistical Analyses

Mean values, coefficients of variation (CV), and ranges were calculated for the data. Separate combined analyses of variance (ANOVA) were conducted for LN and HN conditions using a random model in SAS version 9.0 [22] from which heritability estimates were derived. Phenotypic and genotypic correlation analyses were performed to explore the relationships among different traits. Additionally, stepwise multiple regression analysis was carried out for each nitrogen (N) level, taking grain yield as the dependent variable. Path coefficient analysis was employed to break down significant phenotypic correlation coefficients into their direct and indirect effects, also using grain yield as the dependent variable [12]. The total correlation was determined by summing both direct and indirect impacts. Furthermore, principal component analysis was executed, considering components with Eigenvalues greater than 1.0, and characters with principal component (PC) values exceeding 0.6 were identified as significant contributors to the principal components [23].

3. RESULTS AND DISCUSSION

3.1. Mean Performance of the Maize Population

Means, ranges, CVs, and broad-sense heritability estimates of traits under LN and HN conditions are presented in Table 1. Stay green ability ranged between 3.09 at 8 WAP to 3.60 at 10 WAP under low N condition with a heritability estimate of 36 %. For the majority of the traits, heritability ranged from moderate to high, with the exception of ASI, days to 50% anthesis and ears per plant, under low N.

Ranges were high for all the traits under both LN and HN. Stay-green ability is crucial for crop resilience and yield stability, particularly under low nutrient conditions [24]. On a scale of 1 to 9, stay-green ability varied in this study in low nitrogen conditions, with a heritability estimate of 36%. It ranged from 3.09 at eight weeks after planting to 3.60 at ten weeks after planting. The relatively low stay-green ratings suggest that maize plants can sustain their photosynthetic capacity longer under low nitrogen conditions. The moderate heritability indicates potential for improvement through selective breeding [25].

In this cycle, grain yield was greater under low nitrogen conditions (2.19 tons/ha) compared to high nitrogen (1.98 tons/ha). In low nitrogen environments, the anthesis-silking interval (ASI) was longer while the days to anthesis and silking were shorter. The quantity of ears per plant and the scores for plant and ear aspect did not significantly change between the high and low nitrogen conditions. It is possible that adaptation processes, such as improved nitrogen use efficiency (NUE) in the studied maize population, are responsible for the higher grain production observed in low nitrogen environment in contrast to the high nitrogen environment. Some maize varieties are naturally adapted to low-input conditions, using available nutrients more efficiently. Varieties that perform better under low nitrogen stress are often better adapted to local conditions and allocate resources more effectively for grain production rather than vegetative growth, as excessive nitrogen can sometimes lead to luxuriant vegetative growth at the expense of reproductive development [26]. The plant expedited its reproductive period in low nitrogen conditions to ensure seed production before nutrient depletion, as seen by the shorter days to anthesis and silking. On the other hand, a prolonged Anthesis-Silking Interval (ASI) in low-nitrogen environments suggests stress since it slows down the growth of both male and female flowers, which affects grain set and pollination efficiency.

Table 1. Estimates of mean, range, coefficient of variation (CV), and broad sense heritability (H_2) of traits from evaluation of the S1 lines of ART/98/ ILE 1-OB population at Cycle 2 under LN and HN conditions at Ile-Ife and Ilora in 2021.

Traits	Mean± S.E		Range		CV (%)		H_2 (%)	
	LN	HN	LN	HN	LN	HN	LN	HN
Stay-green 8WAP (1-9)	3.09± 0.58	-	1-9	-	26.3	-	36.9	-
Stay-green 10WAP (1-9)	3.60± 0.53	-	1-9	-	20.77	-	36.3	-
Grain yield (t/ha)	2.19± 0.55	1.98± 0.58	0.04-6.15	0.06- 6.03	35.5	41.8	30.8	32.4
Days to 50% silking	63.9± 1.49	66.17± 1.82	55-79	59-73.6	3.28	3.89	43.1	32.4
Days to 50% anthesis	63.6± 2.1	65.53± 1.76	55-78	66-77	4.66	3.8	14.16	34.16
Anthesis-silking interval (ASI)	3.9± 0.17	2.85± 1.21	1-5	-1-9	6.33	59.9	-7.23	-0.36
Plant height (cm)	123.22± 6.5	110.8± 8.04	58.5-172	57-152	7.47	10.26	66.9	42.56
Ears per plant	0.84± 0.31	0.74± 0.28	0.01-3.2	0.12-3.9	52.1	53.6	19.41	8.7
Ear aspect (1-9)	3.87± 0.83	4.14± 0.89	1-9	1-9	30.22	30.29	23.21	30.29
Plant aspect (1-9)	3.78± 0.62	4.3± 0.52	1-8	2-8	23.08	17.31	41.15	26.9

Note: S.E: Standard error; (1-9): 1 for excellent, 9 for poor; cm: centimeter, LN: Low nitrogen; HN: High nitrogen.

3.2. Relationship Between Grain Yield and Other Agronomic Traits

Table 2 illustrates the relationships between various agronomic parameters and grain yield (GY). There was a strong negative phenotypic correlation between GY and stay green ratings at 8 weeks (SGR8) and 10 weeks (SGR10), with correlation coefficients of -0.37** and -0.38**, respectively. Additionally, GY was negatively associated with days to anthesis (DTA) and days to silking (DTS), with values of -0.36** and -0.26**, respectively, observed under low nitrogen (LN) conditions. Similarly, negative correlations were observed between grain yield (GY) and both ear (EA) and plant aspect (PA). In contrast, plant height and ears per plant (EPP) demonstrated markedly strong positive correlations with GY, with correlation coefficients of 0.38** and 0.71**, respectively. The anthesis-silking interval (ASI) did not exhibit a significant phenotypic correlation with GY under low nitrogen conditions. Among the traits measured, EPP had the strongest correlation with GY, followed by EA and PA.

Table 2. Phenotypic (above diagonal) and genotypic (below diagonal) correlation coefficients obtained from the evaluation of the S1 lines of ART/98/ ILE 1-OB population at Cycle 2 under low N condition at Ile-Ife and Ilora in 2021.

Traits	Stay green ability at 8WAP (SGR8)	Stay green ability at 10WAP (SGR10)	Grain yield (GY)	Days to 50% silking (DTS)	Plant height (PH)	Ears per plant (EPP)	Ear aspect (EA)	Anthesis-Silking Interval (ASI)	Plant aspect (PA)	Days to 50% anthesis (DTA)
SGR8		0.68**	-0.37**	0.39**	-0.38**	-0.50**	0.41**	-0.03	0.41**	0.33**
SGR10	1.0**		-0.38**	0.24**	-0.31**	-0.47**	0.32**	0.01	0.40**	0.08
GY	-0.48**	-0.57**		-0.36**	0.38**	0.71**	-0.53**	0.07	-0.47**	-0.26**
DTS	0.63**	0.40**	-0.51**		-0.38**	-0.32**	0.34**	0.06	0.19*	0.63**
PH	-0.68**	-0.55**	0.70**	-0.58**		0.41**	-0.26**	0.05	-0.40**	-0.21*
EPP	-0.62**	-0.73**	1.00**	-0.43**	0.80**		-0.40**	0.11	-0.32**	-0.14*
EA	0.52**	0.71**	-0.87**	0.55**	-0.65**	-0.89**		0.02	0.34**	0.13*
ASI	NaN	NaN	NaN	NaN	NaN	NaN	NaN		0.07	-0.37**
PA	0.51**	0.63**	-0.73**	0.39**	-0.59**	-0.52**	0.67**	NaN		0.16*
DTA	0.31**	0.49**	-0.25*	1.00**	-0.61**	-0.34**	0.15	NaN	0.24*	

Note: NaN: due to negative genotypic variances for one or more traits.
*, ** significant at P= 0.05, 0.01 respectively.

In the light of the intricate nature of grain yield, a trait marked by its elusive heritability in the face of environmental stresses, it becomes apparent that an exclusive reliance on yield as the sole criterion for selection may prove to be rather inefficient [27]. Thus, selecting for grain yield under low nitrogen conditions along with secondary traits can enhance selection efficiency, provided the secondary traits are easy to measure, have high heritability and significant genetic correlation with grain yield [28, 29]. Yield is influenced by numerous interacting factors throughout the plant's life cycle [30]. There are differing views on which agronomic traits are most critical for maize yield under low nitrogen conditions. Correlation studies play an essential role in understanding the relationships among traits. A notable negative relationship between grain yield and stay-green ability suggests that maize plants that can maintain photosynthesis for a longer period in low nitrogen environments are likely to produce higher yields [31]. The impressive grain yield achieved in low nitrogen condition, coupled with an extended green leaf duration, demonstrates the capacity of the maize genotype to effectively re-mobilize nitrogen and manage the distribution of assimilates. Prior investigations by Chen, et al. [32] and Liu, et al. [33] have noted variations in nitrogen allocation and remobilization in response to low nitrogen stress among contemporary stay-green hybrids.

A similar pattern was seen in the genotypic relationships (Table 2). The genotypic association between GY and SGR8 (-0.48**) and SGR10 (-0.57**) was found to be strong and negative. Furthermore, there were very strong negative relationship between GY and DTA (-0.25*) and DTS (-0.51**). Positive and highly significant correlations were noted between PH and EPP, with values of 0.70** and 1.00**, respectively. Both plant and ear aspect showed significant negative correlations with GY (-0.73** and -0.87**, respectively). EPP exhibited the highest genotypic correlation with GY, followed by EA and PA. The strong negative relationship between grain yield and days to 50% anthesis suggest that earlier-flowering plants under low nitrogen conditions tend to produce higher yields. The contrasting significant correlations between ASI and grain yield (GY), as well as between GY and stay-green rating (SGR), suggest that hybrids combining early flowering with enhanced stay-green capacity post-grain filling can achieve greater yields. Early flowering proves beneficial under low nitrogen conditions as it allows the plant to complete its reproductive stage before experiencing severe nutrient stress, thereby improving grain yield [34].

The inverse relationships found between plant and ear characteristics and grain production implied that healthier plants with fewer disease symptoms,—generally yield more. In a similar vein, the results of Emmanuel, et al. [35] and Adewumi, et al. [36] are supported by the positive correlations observed between grain yield, plant height, and the number of ears on each plant. Taller plants with more ears provide higher yields. Larger leaf areas on taller plants probably enhance photosynthetic ability, and more ears per plant will translate into better grain production potential. Both under nitrogen-limited and ideal conditions, studies by Inamullah, et al. [37] and Al-Naggar, et al. [38] revealed favourable relationships between grain yield (GY) and ears per plant (EPP). Udo, et al. [39] similarly observed a positive relationship between GY and plant height under low nitrogen. This correlation is significant for breeding programs focused on improving yields in low nitrogen environments [40]. However, caution is necessary with tall plants, as they may be more susceptible to lodging, so selecting for an optimal height range is important.

Among the traits, EPP showed the strongest correlation with grain yield, followed by ear aspect (EA) and plant aspect (PA), underscoring their importance in low nitrogen conditions. The consistent genotypic and phenotypic correlations confirm the genetic linkage of these traits, indicating that selecting for them can directly improve grain yield under low nitrogen stress. The strong positive associations may arise from gene linkage or pleiotropic effects where the same genes influence multiple traits in the same direction Kearsey and Pooni [41]. Amegbor, et al. [42] also found significant negative phenotypic and genotypic correlations between GY and DTS, PA, EA, and SGR, while observing a positive correlation between GY and EPP in hybrid maize under low nitrogen conditions.

3.3. Regression of Yield on Other Agronomic Traits

A stepwise multiple regression analysis examining the relationship between yield and different agronomic traits under low nitrogen conditions indicated that ears per plant (EPP) was the most significant factor influencing yield in the maize population (Table 3), accounting for 45% of the variation ($R^2 = 0.45$). Ear aspect (EA) accounted for an additional 8% of the variance. The contributions of SGR8 and PH, though significant, were only 1 % each under LN. Plant height was picked as the most essential trait contributing to GY under HN with an R^2 value of 21%. EPP and EA contributed an additional 8 % and 7 % respectively. Though significant, PA and DTS contributed only 2 % and 1 % under HN (Table 3). This result emphasizes how crucial EPP is in determining yield in nutrient-stressed environments. Grain production is increased when there are more ears per plant since more ears equal more kernels [26]. Under low N conditions, ear aspect added an extra 8% to the variability in grain yield. The ear aspect typically refers to the appearance and health of the ears, which can impact the quantity and quality of the grains produced. Good ear aspect indicates better grain filling and less susceptibility to diseases and pests, leading to higher yields [43]. Stay-green ability and plant height, though significant, contributed minimally, adding only 1% to yield variability under low nitrogen.

Table 3. Partial regression coefficients from stepwise regression of grain yield on agronomic traits in S1 lines of ART/98/ILE 1-OB at Cycle 2 under low and high N conditions, Ile-Ife and Ilora, 2021.

Trait	b-value	R^2	ΔR^2	Probability
Low N				
Ears per plant	0.97	0.45	0.45	<.0001
Ear aspect (1-9)	-0.23	0.54	0.08	<.0001
Stay green ability 8 WAP (1-9)	0.09	0.54	0.01	0.0193
Plant height (cm)	0.01	0.55	0.01	0.0164
High N				
Plant height (cm)	0.02	0.21	0.21	<.0001
Ears per plant	0.72	0.28	0.08	<.0001
Ear aspect (1-9)	-0.17	0.35	0.07	<.0001
Plant aspect (1-9)	-0.16	0.37	0.02	0.0002
Days to 50 % silking	-0.04	0.38	0.01	0.0044

Note: (1-9): 1 for excellent, 9 for poor; cm: centimeter; N: Nitrogen, R^2 :Coefficient of Determination ΔR^2 : change in R^2

Under high nitrogen, plant height was the most significant trait, explaining 21% of yield variability. Taller plants generally have greater leaf area, enhancing photosynthetic capacity and biomass accumulation, leading to higher yields. This highlights the importance of plant height under optimal nutrient conditions. EPP and EA contributed an additional 8 % and 7 %, respectively, to yield variability under high nitrogen, emphasizing their roles in yield determination. Plant aspect and days to 50 % silking contributed minimally, suggesting that under high nitrogen, flowering time has lesser impact on yield than plant height and ear characteristics.

3.4. Path Coefficient Analysis of the Significant Phenotypic Correlation Coefficients of Traits Studied

Significant correlations were analyzed in greater detail through path analysis, with grain yield serving as the dependent variable. Ears per plant (EPP) showed the strongest positive direct effect (1.15), followed by SGR8 (0.23) (Table 4). Both days to silking (DTS) and plant height (PH) also exhibited positive direct effects, while other traits had negative direct effects. Ear aspect (EA) had the largest negative direct effect (-0.18), closely followed by plant aspect (PA) at -0.17. The most significant negative indirect effects for EA and EPP occurred through SGR8 (-0.076 and -0.58, respectively). EPP's largest positive indirect effect was observed through PH (0.47).

Prior research has consistently identified ASI and EPP as critical characters for enhancing grain production in low-nitrogen environments, however, ASI made a small contribution to yield of the QPM population utilized in this investigation. The high direct effects of EPP, SGR8 and EA, along with the positive indirect effect of EPP via plant height, highlight these traits' importance under low nitrogen. The high negative indirect effects of EA and EPP through SGR8 further emphasizes the importance of SGR. Maize genotypes with strong stay-green traits are typically more resilient to post-silking environmental stresses, including reduced nitrogen uptake and extended leaf longevity [44]. This allows them to maintain photosynthesis during periods of high nitrogen demand [45]. Therefore, stay-green ability plays a crucial role in the maize's nitrogen use efficiency (NUE) [15]. However, plant height should be carefully managed when developing a selection index for low nitrogen conditions, as very tall plants are more prone to lodging in strong winds [20].

Table 4. Direct (bold on diagonal) and indirect effects (off diagonal) from path coefficient analysis of significant phenotypic correlation coefficients of traits obtained from S1 lines of ART/98/ ILE 1 -OB at Cycle 2 under low N condition at Ile-Ife and Ilora in 2021.

Traits	Stay green ability 8 WAP (SGR8)	Stay green ability 10 WAP (SGR10)	Days to 50 % silking (DTS)	Plant height (PH)	Ears per plant (EPP)	Ear aspect (EA)	Anthesis-Silking Interval (ASI)	Plant aspect (PA)	Days to 50 % anthesis (DTA)	Total correlation	Total Indirect effects
SGR8	**0.232**	0.159	0.087	-0.088	-0.117	0.097	-0.002	0.102	0.069	0.539	0.307
SGR10	-0.050	**-0.074**	-0.016	0.022	0.035	-0.025	-0.003	-0.033	-0.003	-0.147	-0.073
DTS	0.003	0.001	**0.007**	-0.003	-0.002	0.002	0.000	0.001	0.004	0.014	0.007
PH	0.000	0.000	0.001	**0.001**	0.001	0.000	0.000	0.000	0.000	-0.001	-0.002
EPP	-0.583	-0.550	-0.350	0.468	**1.157**	-0.473	0.113	-0.393	-0.140	-0.751	-1.908
EA	-0.076	-0.062	-0.057	0.047	0.075	**-0.183**	-0.008	-0.067	-0.016	-0.348	-0.165
ASI	0.000	-0.001	-0.002	-0.002	-0.003	-0.001	**-0.031**	-0.003	0.012	-0.031	0.001
PA	-0.075	-0.077	-0.028	0.067	0.058	-0.063	-0.015	**-0.172**	-0.022	-0.326	-0.155
DTA	-0.019	-0.003	-0.041	0.013	0.008	-0.006	0.024	-0.008	**-0.065**	-0.096	-0.032

Note: WAP: Weeks after planting.

Traits like ear aspect (EA) and stay-green rating (SGR) at eight weeks are easily assessed and can be utilized for selecting maize genotypes with improved yield under low nitrogen.

3.5. Principal Component Analysis of the Traits Studied Under Low N Condition

The principal component analysis (PCA) results showed that the first three component axes had Eigenvalues exceeding one and accounted for 98.9% of the overall variation (Table 5). The Eigenvalues for PC1, PC2, and PC3 were 218.41, 4.24, and 1.21, respectively, with corresponding contributions of 96.5%, 1.87%, and 0.53%. Plant height was the main variable that PC1 alone explained, accounting for 96.5% of the variance. All the three PCs had good loadings, with PC2 being related to days to 50% silking and PC3 being related to plant aspect. The PCA findings indicate that the main factors influencing the observed variation were plant aspect, days to 50% silking, and plant height, highlighting the significance of these factors in selection efforts. The dominant role of plant height in PC1 further highlights its significance in selection under low nitrogen conditions.

Badu-Apraku, et al. [46] used genotype × trait biplot analysis and identified days to anthesis and silking, stay-green characteristic, ASI, plant height, EPP, and plant and ear aspects as traits strongly correlated with yield. . Their study highlighted ASI, EPP, and plant and ear aspects as the most reliable indicators for selecting early-maturing maize inbred lines under low nitrogen conditions. Additionally, path-coefficient and GGE biplot analyses identified ear height, plant aspect, ear aspect, and stay-green traits as useful markers for selecting nitrogen-tolerant extra-early maize lines [47]. A stepwise regression by Talabi, et al. [48] further emphasized ear aspect, plant aspect, EPP, stay-green traits, days to silking, and stalk lodging as important factors for improving yield in low-nitrogen environments.

Table 5. Principal component, Eigenvalues, and percentage variation of the traits studied under low N conditions across the locations in 2021.

Traits	PC1	PC2	PC3
Stay green ability 8WAP (1-9)	-0.03	0.13	0.34
Stay green ability 10WAP (1-9)	-0.02	0.07	0.37
Grain yield (t/ha)	0.02	-0.10	-0.28
Anthesis-Silking Interval (ASI)	0.01	0.10	0.52
Days to 50% silking	-0.07	0.97*	-0.19
Plant height (cm)	1.00*	0.08	0.03
Ears per plant	0.01	-0.03	-0.09
Plant aspect (1-9)	-0.03	0.05	0.59*
Ear aspect (1-9)	0.00	0.09	0.01
Eigenvalue	218.41	4.24	1.21
% variation	96.50	1.87	0.53
Cumulative	96.50	98.37	98.90

Note: *Component contributors; PC: Principal component.
(1-9): 1 for excellent, 9 for poor; cm: centimeter.

Bhadmus, et al. [49] found that plant and ear aspect significantly influenced grain yield, accounting for nearly 73% of the overall variation in their genetic study on 96 early white quality protein maize hybrids evaluated in low nitrogen environments. These results highlight the need to determine the most important qualities for different maize population, as the main attributes for yield prediction may differ with population. From the results presented in this study, it becomes evident that ear aspect, ear per plant (EPP), the capacity for stay-green, and plant height are important traits for selection in the improvement of QPM for tolerance to low soil nitrogen. These traits also exhibit high heritability in environments characterized by nitrogen scarcity.

4. CONCLUSION

The study discovered the key traits with moderate to high heritability that contribute to the QPM's grain production. These traits include the number of ears per plant, ear aspect, plant height, and stay-green ability at 8

WAP. Thus, the traits may serve as selection criteria for enhancing Quality Protein Maize's resilience to low soil nitrogen conditions, thereby accelerating the pace of breeding advancements. However, plant height should be pegged to a certain level in the index because tall plants lodge easily under intense wind, and this could indirectly reduce yield.

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REFERENCES

[1] A. Shaibu, S. Yusuf, and A. Adnan, "Phenotyping and prediction of Maize (Zea mays L.) yield using physiological traits," *Journal of Dryland Agriculture*, vol. 3, no. 1, pp. 28-35, 2017.

[2] FAOSTAT, "Statistical database of the food and agriculture of the United Nations," Retrieved: http://www.fao.org. [Accessed 2014.

[3] Amanullah, "Rate and timing of nitrogen application influence partial factor productivity and agronomic NUE of maize (Zea mays L) planted at low and high densities on calcareous soil in northwest Pakistan," *Journal of Plant Nutrition*, vol. 39, no. 5, pp. 683-690, 2016. https://doi.org/10.1080/01904167.2015.1087031

[4] C. Guo, P. Li, J. Lu, T. Ren, R. Cong, and X. Li, "Application of controlled-release urea in rice: Reducing environmental risk while increasing grain yield and improving nitrogen use efficiency," *Communications in Soil Science and Plant Analysis*, vol. 47, no. 9, pp. 1176-1183, 2016. https://doi.org/10.1080/00103624.2016.1166235

[5] D. Ogunniyan, C. Alake, F. Anjorin, and S. Makinde, "Agronomic performance of hybrids of white low-nitrogen maize (Zea mays L.) inbred lines under managed nitrogen environments," *Tropical Agriculture*, vol. 95, no. 1, p. 18-30, 2018.

[6] A. E. Asibi, Q. Chai, and J. A. Coulter, "Mechanisms of nitrogen use in maize," *Agronomy*, vol. 9, no. 12, p. 775, 2019. https://doi.org/10.3390/agronomy9120775

[7] J. Kogbe and J. Adediran, "Influence of nitrogen, phosphorus and potassium application on the yield of maize in the savanna zone of Nigeria," *African Journal of Biotechnology*, vol. 2, no. 10, pp. 345-349, 2003. https://doi.org/10.5897/ajb2003.000-1071

[8] J. Pavlov, N. Delić, K. Marković, M. Crevar, Z. Čamdžija, and M. Stevanović, "Path analysis for morphological traits in maize (Zea mays L.)," *Genetika*, vol. 47, no. 1, pp. 295-301, 2015. https://doi.org/10.2298/gensr1501295p

[9] R. Talebi, F. Fayaz, and N. A. B. Jeloder, "Correlation and path coefficient analysis of yield and yield components of chickpea (Cicer arietinum L.) under dry condition in the west of Iran," *Asian Journal of Plant Science*, vol. 6, p. 1151–1154, 2007. https://doi.org/10.3923/ajps.2007.1151.1154

[10] A. Menkir, "Genetic variation for grain mineral content in tropical-adapted maize inbred lines," *Food Chemistry*, vol. 110, no. 2, pp. 454-464, 2008. https://doi.org/10.1016/j.foodchem.2008.02.025

[11] Y. Muhammad and S. Muhammad, "Correlation analysis of S1 families of maize for grain yield and its components," *International Journal of Agriculture and Biology*, vol. 3, p. 387-388, 2001.

[12] S. Wright, "Correlation and causation," *Journal of Agricultural Research*, vol. 20, p. 557-585, 1921.

[13] V. Sellam and E. Poovammal, "Prediction of crop yield using regression analysis," *Indian Journal of Science and Technology*, vol. 9, no. 38, pp. 1-5, 2016. https://doi.org/10.17485/ijst/2016/v9i38/91714

[14] R. Bernardo, "Predictive breeding in maize during the last 90 years," *Crop Science*, vol. 61, no. 5, pp. 2872-2881, 2021. https://doi.org/10.1002/csc2.20529

[15] M. Bänziger, G. O. Edmeades, D. Beck, and M. Bellon, *Breeding for drought and nitrogen stress tolerance in maize: From theory to practice*. Mexico D.F: CIMMYT, 2000.

[16] G. O. Edmeades, J. Bolanos, A. Elings, J. M. Ribaut, M. Bänziger, and M. E. Westgate, "The role and regulation of the anthesis-silking interval in maize," in Physiology and modeling kernel set in maize, M. E. Westgate and K. J. Boote, Eds." Wisconsin: CSSA Special Publication, 2000, p. 43-73.

[17] B. Badu-Apraku, R. Akinwale, S. Ajala, A. Menkir, M. Fakorede, and M. Oyekunle, "Relationships among traits of tropical early maize cultivars in contrasting environments," *Agronomy Journal*, vol. 103, no. 3, pp. 717-729, 2011. https://doi.org/10.2134/agronj2010.0484

[18] S. Ajala, J. Kling, and A. Menkir, "Full-sib family selection in maize populations for tolerance to low soil nitrogen," *Journal of Crop Improvement*, vol. 26, no. 5, pp. 581-598, 2012. https://doi.org/10.1080/15427528.2012.662206

[19] B. Badu-Apraku, R. Akinwale, J. Franco, and M. Oyekunle, "Assessment of reliability of secondary traits in selecting for improved grain yield in drought and low-nitrogen environments," *Crop Science*, vol. 52, no. 5, pp. 2050-2062, 2012. https://doi.org/10.2135/cropsci2011.12.0629

[20] S. O. Ajala, A. B. Olaniyan, M. O. Olayiwola, and A. O. Job, "Yield improvement in maize for tolerance to low soil nitrogen," *Plant Breeding*, vol. 137, no. 2, pp. 118-126, 2018. https://doi.org/10.1111/pbr.12568

[21] X. Li *et al.*, "Kernel number as a positive target trait for prediction of hybrid performance under low-nitrogen stress as revealed by diallel analysis under contrasting nitrogen conditions," *Breeding Science*, vol. 64, no. 4, pp. 389-398, 2014. https://doi.org/doi:10.1270/jsbbs.64.389

[22] SAS Statistical Analysis System, *Version 9.0*. NC: SAS Institute Inc Cary, 2002.

[23] I. Matus, M. I. González, and A. Del Pozo, "Evaluation of phenotypic variation in a Chilean collection of garlic (Allium sativum L.) clones using multivariate analysis," *Plant Genetic Resources Newsletter*, vol. 120, pp. 31-36, 1999.

[24] B. Badu-Apraku *et al.*, "Gains in grain yield of early maize cultivars developed during three breeding eras under multiple environments," *Crop Science*, vol. 55, no. 2, pp. 527-539, 2015. https://doi:10.2135/cropsci2013.11.0783.

[25] S. Olakojo and G. Olaoye, "Correlation and heritability estimates of maize agronomic traits for yield improvement and Striga asiatica (L.) kuntze tolerance," *African Journal of Plant science*, vol. 5, no. 6, pp. 365-369, 2011.

[26] A. Menkir and S. Meseka, "Genetic improvement in resistance to Striga in tropical maize hybrids," *Crop Science*, vol. 59, no. 6, pp. 2484-2497, 2019. https://doi.org/10.2135/cropsci2018.12.0749

[27] B. Badu-Apraku *et al.*, "Genetic enhancement of early and extra-early maturing maize for tolerance to low-soil nitrogen in sub-Saharan Africa," *Crop Breeding, Genetics and Genomics*, vol. 5, no. 1, p. 1-44, 2023.

[28] D. S. Falconer, *Introduction to quantitative genetics*. Edinburgh: Oliver and Boyd Ltd, 1960.

[29] J. Bolaños and G. Edmeades, "Eight cycles of selection for drought tolerance in lowland tropical maize. I. Responses in grain yield, biomass, and radiation utilization," *Field Crops Research*, vol. 31, no. 3-4, pp. 233-252, 1993. https://doi.org/10.1016/0378-4290(93)90064-T

[30] M. S. Oladipo, G. Olaoye, M. Oyekunle, A. Atanda, and F. Bankole, "Yield potential of sub-tropical maize hybrids of different maturity groups across Nigeria Guinea Savanna," *Applied Tropical Agriculture*, vol. 26, no. 2, p. 144-154, 2021.

[31] F. B. Anjorin, A. Adebayo, T. Omodele, A. Adetayo, and J. Adediran, "Effects of soil nutrient amendments on growth and grain yield performances of quality protein maize grown under water deficit stress in Ibadan, Nigeria," *Acta agriculturae Slovenica*, vol. 117, no. 4, pp. 1-14, 2021. https://doi.org/10.14720/aas.2021.117.4.1887

[32] F. Chen *et al.*, "Evaluation of the yield and nitrogen use efficiency of the dominant maize hybrids grown in North and Northeast China," *Science China Life Sciences*, vol. 56, pp. 552-560, 2013. https://doi.org/10.1007/s11427-013-4462-8

[33] Z. Liu *et al.*, "Nitrogen allocation and remobilization contributing to low-nitrogen tolerance in stay-green maize," *Field Crops Research*, vol. 263, p. 108078, 2021. https://doi.org/10.1016/j.fcr.2021.108078

[34] E. Jandong, M. Uguru, and E. Okechukwu, "Genotype-by-environment interaction and stability analysis of soybean genotypes for yield and yield components across two locations in Nigeria," *African Journal of Agricultural Research*, vol. 14, no. 34, pp. 1943-1949, 2019. https://doi.org/10.5897/ajar2019.14251

[35] G. V. Emmanuel, J. Ndebeh, R. Akromah, and K. P. Obeng-Antwi, "Evaluation of maize top-cross hybrids for grain yield and associated traits in three agro-ecological zones in Ghana," *International Journal of Environment Agriculture and Biotechnology*, vol. 2, no. 4, p. 2076-2087, 2017. https://doi.org/10.22161/ijeab/2.4.66

[36] A. Adewumi, M. Oladipo, P. Ukachukwu, and O. Aluko, "Agronomic performance of some white hybrid maize evaluated in Savanna agroecologies," *Nigerian Journal of Basic and Applied Sciences*, vol. 31, no. 2, pp. 31-38, 2023.

[37] N. R. Inamullah, N. H. Shah, M. Arif, M. Siddiq, and I. A. Mian, "Correlations among grain yield and yield attributes in maize hybrids at various nitrogen levels," *Sarhad Journal of Agriculture*, vol. 27, no. 4, pp. 531-538, 2011.

[38] A. Al-Naggar, A. Abdalla, A. Gohar, and E. Hafez, "Heritability, genetic advance and correlations in 254 maize doubled haploid lines× tester crosses under drought conditions," *Archives of Current Research International*, vol. 6, no. 1, pp. 1-15, 2016. https://doi.org/10.9734/ACRI/2016/29523

[39] E. F. Udo, S. O. Ajala, and A. B. Olaniyan, "Physiological and morphological changes associated with recurrent selection for low nitrogen tolerance in maize," *Euphytica*, vol. 213, pp. 1-13, 2017. https://doi.org/10.1007/s10681-017-1928-y

[40] R. Akinwale, M. Fakorede, B. Badu-Apraku, and A. Oluwaranti, "Assessing the usefulness of GGE biplot as a statistical tool for plant breeders and agronomists," *Cereal Research Communications*, vol. 42, no. 3, pp. 534-546, 2014. https://doi.org/10.1556/CRC.42.2014.3.16

[41] M. J. Kearsey and H. S. Pooni, "Genotype by environment interaction," in The genetical analysis of quantitative traits," Chapman & Hall, 1996, p. 241–265.

[42] I. K. Amegbor, A. Abe, J. Adjebeng-Danquah, and G. B. Adu, "Genetic analysis and yield assessment of maize hybrids under low and optimal nitrogen environments," *Heliyon*, vol. 8, no. 3, p. e09052, 2022. https://doi.org/10.1016/j.heliyon.2022.e09052

[43] R. Akinwale, B. Badu-Apraku, and M. Fakorede, "Evaluation of striga-resistant early maize hybrids and test locations under striga-infested and striga-free environments," *African Crop Science Journal*, vol. 21, no. 1, pp. 1-19, 2013. https://doi.org/10.1016/j.fcr.2010.12.011

[44] R. Hay and J. Porter, *The physiology of crop yield*, 2nd ed. Oxford: Blackwell Publishing, 2006.

[45] M. Tollenaar, S. Nissanka, A. Aguilera, S. Weise, and C. Swanton, "Effect of weed interference and soil nitrogen on four maize hybrids," *Agronomy Journal*, vol. 86, no. 4, pp. 596-601, 1994. https://doi.org/10.2134/agronj1994.00021962008600040004x

[46] B. Badu-Apraku *et al.*, "Gains in grain yield of extra-early maize during three breeding periods under drought and rainfed conditions," *Crop Science*, vol. 58, no. 6, pp. 2399-2412, 2018. https://doi.org/10.2135/cropsci2018.03.0168

[47] B. Badu-Apraku and R. Akinwale, "Cultivar evaluation and trait analysis of tropical early maturing maize under Striga-infested and Striga-free environments," *Field Crops Research*, vol. 121, no. 1, pp. 186-194, 2011. https://doi.org/10.1016/j.fcr.2010.12.011

[48] A. Talabi, B. Badu-Apraku, and M. Fakorede, "Genetic variances and relationship among traits of an early maturing maize population under drought-stress and low nitrogen environments," *Crop Science*, vol. 57, no. 2, pp. 681-692, 2017. https://doi.org/10.2135/cropsci2016.03.0177

[49] O. A. Bhadmus, B. Badu-Apraku, O. A. Adeyemo, and A. L. Ogunkanmi, "Genetic analysis of early white quality protein maize inbreds and derived hybrids under low-nitrogen and combined drought and heat stress environments," *Plants*, vol. 10, no. 12, p. 2596, 2021. https://doi.org/10.3390/plants10122596