

PERFORMANCE OF MAIZE INBRED LINES OF DIFFERENT MATURITY GROUPS UNDER DIFFERENT SOIL NITROGEN LEVELS

Olawale Serifdeen Aboderin^{1,2}, Folusho Anuoluwapo Bankole^{1*}, Muhyideen Oyekunle²,
Gbadebo Olaoye¹ and Zakariya Saminu²

¹Department of Agronomy, University of Ilorin, Ilorin, Nigeria

²Institute for Agricultural Research, Ahmadu Bello University, Zaria PMB 1044, Nigeria;

*Corresponding Author: Email address: bankole.fa@unilorin.edu.ng

Phone number: - 08053282109, P.M.B 1515, Ilorin, Nigeria.

ABSTRACT

Evaluation of Per Se performance of inbred lines is crucial for assessing their inherent genetic potential and their prospective utility in population improvement and hybrid development. This study assessed 79 newly introduced maize inbred lines over two consecutive years (2018 and 2019) in Zaria, focusing on yield performance and low-nitrogen (N) tolerance under varying soil N conditions and N-fertilizer application rates. The results emphasized the substantial impact of nitrogen availability on various agronomic traits, including significant reductions in grain yield (35-95%), prolonged anthesis-silking intervals, and decreased plant and ear height, adversely affecting plant and ear morphology. Twelve screening indices were computed for each inbred line, revealing variations in the identification of tolerant lines, though some indices agreed on classifying certain lines as tolerant. The study identified 35 inbred lines as low-N tolerant, with consistent classification for SMLW5, SMLW156, and SMLW159 across multiple screening indices. Line SMLW156 and SMLW5 recorded the highest yield under low-N, with a yield advantage of 71% and 48.5%, respectively, over the best check. The highest-yielding inbred lines under optimum-N conditions were SMLW156 and SMLW21, with yield advantages of 40% and 39.2%, respectively, over the best check. These identified lines hold promise as parents for population improvement and high-yielding low-N tolerant hybrids. Correlation results and GenotypexTrait Biplot analyses underscored the significance of ear aspect, stay-green characteristics, plant height, and ear height in achieving high grain yield under low-N conditions.

Key words: *Per se* performance, traits correlation, GGE biplot analysis, Selection indices, Indirect selection.

INTRODUCTION

Maize (*Zea mays* L.) stands as a cornerstone in Nigeria's agricultural landscape, playing a vital role in ensuring food security and sustaining agriculture across diverse agro-ecological zones (Bankole *et al.*, 2023). Despite its significance, maize productivity faces persistent challenges in the resource-poor farming systems of the Northern Guinea Savanna (NGS) ecology of Nigeria, including

environmental variability, pests, diseases, and nutrient limitations, particularly low soil nitrogen (N) conditions (Badu-Apraku *et al.*, 2015). The optimization of maize cultivation in these regions with nitrogen-deficient soils remains a formidable challenge. Maize, being a C4 plant with high photosynthetic efficiency, heavily relies on nitrogen availability for substantial biomass support (Trachsel *et al.*, 2016). To address this challenge and enhance

maize productivity sustainably, the development of maize hybrids with low-N tolerance through genetic approaches emerges as a promising solution. This not only meets global demand but also reduces production costs and minimizes the environmental impact associated with fertilizer application.

In response to the rising global population and the growing need for crops with improved nutritional content, the Institute for Agricultural Research (IAR), Zaria, in collaboration with global partners, has undertaken extensive research for the development of maize varieties tailored to meet the needs of the ever-increasing population. As part of these efforts, a new set of inbred lines has recently been developed to serve as breeding resources for the development of hybrids with enhanced nitrogen use efficiency compared to existing varieties. However, before these inbred lines can be effectively utilized for hybrid development, a thorough *per se* performance evaluation is deemed essential.

Per se performance evaluation, a critical initial breeding step, provides insights into the inherent genetic potential of new lines. This allows breeders to compare their performance with existing ones, aiding in the selection of parental lines with the most desirable traits (Betran *et al.*, 2003; Meseka *et al.*, 2006). While *per se* performance alone may not predict hybrid performance in a stressed environment, it lays the foundation for selecting promising parental lines, contributing to the development of high-performing hybrids (Meeks *et al.*, 2012; Oyekunle and Badu-Apraku, 2013).

Recognizing the inefficiency of direct selection based solely on grain yield performance under low-N conditions, plant breeders often opt for indirect selection using selection indices (Badu-Apraku *et al.*, 2023). A selection index, a statistical method in plant breeding, combines information from multiple traits into a single value, facilitating the ranking and selection of

desirable genotypes for further breeding (Batista *et al.*, 2021). Yield performance under stress and normal conditions is a primary criterion for identifying desirable maize genotypes, but due to the quantitative nature and low heritability of grain yield, reliance solely on this trait often leads to limited improvements. Indirect selection, using secondary traits with high heritability and genetic correlations with grain yield as selection indices, has proven effective (Ribeiro *et al.*, 2020). IITA maize researchers identified flowering traits, stay-green traits, plant growth and development traits as crucial secondary traits for selecting superior maize genotypes under nitrogen stress. These traits are considered alongside genotype yield performance under low- and optimum-N environments (Monneveux, *et al.*, 2006; Badu-Apraku *et al.*, 2011; Oyekunle and Badu-Apraku, 2013).

Furthermore, the introduction of the genotype-by-trait (GxT) biplot analysis by Yan and Kang (2003) has provided a powerful statistical tool for efficiently visualizing and interpreting complex interactions between genotypes and multiple traits simultaneously. In this biplot, each trait is represented as a vector in a multidimensional space, with genotypes plotted in relation to these trait vectors. Interpreting a biplot involves analyzing the spatial relationships between genotypes and trait vectors. The angle and length of the vectors convey the direction and strength of the correlation between traits, offering valuable insights into how genotypes express multiple traits concurrently. This analytical approach enables researchers to identify patterns and trends in trait expressions across genotypes, facilitating the recognition of genotypes with desirable trait combinations and those requiring further improvement. Genotypes aligned with a specific trait vector express that trait more strongly, whereas those positioned away from the vector exhibit lower expression of that

particular trait. The biplot also aids in discerning whether certain traits are positively or negatively correlated, providing crucial information for breeders seeking to achieve specific trait combinations in their breeding programs (Yan and Kang, 2003).

Studies by several authors (Badu-Apraku *et al.*, 2011; Talabi *et al.*, 2017; Ribeiro *et al.*, 2020; Adu *et al.*, 2021) using GxT biplot analysis have revealed conflicting findings concerning significant trait associations under different nitrogen conditions. A critical review of these conflicting results underscores that trait associations are determined by the germplasm used in studies and the level of improvement already achieved in the desired germplasm. Each set of breeding lines may display distinct trait associations, highlighting the necessity to recognize and understand these unique associations for effective plant breeding practices. The study was therefore carried out to identify superior inbred lines with improved nitrogen use efficiency for population improvement and development of high yielding hybrids.

MATERIALS AND METHODS

Eighty-one maize inbred lines, including 79 newly introduced lines by IAR maize scientists and 2 inbred checks, constituted the experimental materials used for the study (Table 1). The evaluation took place at IAR experimental fields in Zaria, situated at Latitude 12°N, Longitude 8° 22' E, with an elevation of 640 m and an annual rainfall of 1200 mm. Zaria is located in the Northern Guinea Savanna ecology of Nigeria. The study was conducted under low- and optimum-N conditions over two successive years (2018 and 2019). The nitrogen level in the low-N field was maintained at 1.1g/kg. This level was achieved through continuous maize planting over several years without the application of fertilizers. As part of the standard procedure, all plants were

thoroughly removed from the fields during harvest each year to prevent the undesired release of nitrogen into the soil from the decomposition of organic matter.

The trial followed a 9 x 9 lattice design with two replications. Each plot consisted of a single row measuring 4 meters in length, with inter-row spacing set at 0.75 meters and 0.4 meters between individual plant hills. Nitrogen fertilizer was applied at two rates: 30kg/ha for low N and 90kg/ha for optimum N. For the low N treatment, urea (30kg/ha) was applied evenly in two split doses at two and five weeks after sowing (WAS), along with muriate of potash (MOP) and single superphosphate (SSP), both at a rate of 60kg/ha at 2WAS. Optimum N treatment involved NPK 15:15:15 (60 kg N ha⁻¹) at 2WAS, followed by an additional top dressing of 30kg/ha of urea at 4 WAS. Weeds were managed in the field through the application of herbicides (Primextra and Paraquat at 5 L/ha) during the early phases of maize growth. Subsequent manual weeding was performed when necessary to maintain a weed-free experimental field throughout the growing season.

Data Collection and Analyses

Agronomic data were recorded for each line on a plot or sampled plant basis under both low and optimum-N condition. Flowering traits were recorded in days, growth traits were measured based on the average measurements of five randomly selected plants in a plot, and aspect ratings were assessed visually on a phenotypic scale ranging from 1 to 10. Leaf senescence, characterized by the stay green trait, was assessed by visually evaluating the condition of the leaves, including color, overall appearance, and visible signs of aging for each plot in the low-N field. Leaf senescence data were collected 70 days after planting to capture the progression of this trait over time. To standardize this assessment, a visual scale was

designed to quantify leaf senescence. This involved assigning numerical values from 1 to 10 to represent different stages of senescence, with 1 indicating a healthy, green leaf and higher numbers representing decreasing degrees of senescence. For low-N trial, the harvested ears of each inbred line per plot were shelled, weighed, and recorded in grams before converting them to kilograms. Moisture content was also determined from the shelled grain. The values were then used to estimate the grain yield of the line in kilograms per hectare, adjusted to 15% moisture content. Under optimum-N conditions, the harvested ears per plot of each inbred line were weighed and recorded in kilograms. A sample size was taken among the harvested ears, which were then shelled to determine their moisture content. The ear weight was later converted to kilograms per hectare using a shelling coefficient of 80% and adjusted to 15% moisture content, similar to the procedure followed in the low-N trials

The analysis of variance using SAS software was conducted on the agronomic data collected (SAS Institute, version 9.2, 2008). Means of traits for which the maize inbred lines differed significantly were separated using the least significant difference (Steel and Torrie 1980). GEA- R software was used to investigate the stability of the selected low-N tolerant inbred lines (best 15 and worst 10), using their mean grain yield (Pacheco *et al.*, 2016). The same software was used to examine the relationships between grain yield and all the measured traits in the study, using their standardized values.

The format of ANOVA model used for each environment can be expressed as follows:

$$Y_{gjk} = \mu + G_g + R_j + B_k + \epsilon_{gjk}$$

Where μ = the population mean; R_j = the effect of replicate j ;

G_g = the effect of the g th genotype; B_k = the block effect within the j th replication;

ϵ_{gjk} = the residual variation contributed by the j th replication for the g th genotype

The tolerance level to low soil-N of each inbred line was assessed using twelve different indices, viz: Tolerance index (TOL), Mean Productivity (MP), Geometric Mean Productivity (GMP); Harmonic Mean (HM), Stress Susceptibility Index (SSI), Stress Tolerance Index (STI), Yield Index (YI), Yield Stability Index (YSI), Percentage Yield Reduction (RC), Relative Stress Index (RSI), Low-N Tolerance index (LNTI) and Base Index (BI). All the screening indices were estimated using iPASTIC software (Pour-Aboughadareh *et al.*, 2019), except for LNTI and BI, which were computed using the grain yield (GY) of the lines and their agronomic trait performance under low-N conditions.

$$\text{Base Index (BI)} = 5 * \text{GY (Low-N)} + 2\text{EPP} - 2\text{STGR} - \text{ASI} \quad (\text{Bänziger } et al., 2000)$$

$$\text{Low N tolerance Index (LNTI)} = 2 * \text{GY (Low-N)} + \text{GY (optimum)} + \text{EPP} - \text{ASI} - \text{PA} - \text{EA} - \text{STGR} \quad (\text{Oyekunle \& Badu-Apraku, 2013}).$$

RESULTS

The genotypic effect (G) as well as the interactive effect of genotype and environment (GxE) were significant ($p \leq 0.01$ or $p \leq 0.05$) for all measured or estimated traits under both growing conditions except for plant height (G) and ear height (GxE) under optimum-N condition. (Table 2). The environmental main effect was significant ($p \leq 0.05$) for only grain yield under low-N, while the environmental factors had a significant effect ($p \leq 0.01$) on days to anthesis, plant aspect and ear aspect under optimum-N condition. The inbred lines exhibited highly significant differences ($p \leq 0.01$) for all the screening indices.

Mean performance for grain yield and other agronomic characters of maize inbred lines

The overall mean grain yield (GY) of the lines under low-N was 344 kg/ha, whereas under optimum-N conditions, it was 1,803 kg/ha.

Grain yield varied from 132 kg/ha (SMLW58) to 1280 kg/ha (SMLW156) under low-N, and it ranged from 532 kg/ha (SMLW53) to 4142 kg/ha (SMLW156) under optimum-N conditions. SMLW156 emerged as the top yielder, exceeding 1,000 kg/ha, followed by SMLW5 and SMLW21, both with yields exceeding 650 kg/ha in low-N environments (Table 3). In the optimum-N environment, SMLW156, SMLW21, and SMLW167 were the highest yielders, with yields surpassing 3,500 kg/ha, representing a yield advantage of over 40% compared to the best check. All the inbred lines had approximately one ear per plant. Concerning flowering days, the inbred lines took fewer days to anthesis (DP) under optimum-N conditions (63) compared to low-N conditions (67 days). Similarly, the inbred lines reached silking (DS) earlier under optimum-N conditions (66) compared to low-N conditions (70). A significant reduction was observed in the anthesis-silking interval (ASI) under optimum-N conditions (2.4) compared to low-N conditions (3.4). The inbred line's mean plant height (PHT) increased from 87cm under low-N to 121cm under optimum-N, and ear height (EHT) exhibited a substantial increase from 36cm under low-N to 56cm under optimum-N. Plant aspect (PA) and ear aspect (EA) ratings improved under optimum-N (3.3 and 3.1, respectively) compared to under low-N (4.5 and 4.4, respectively) (Fig. 1). For stay green characteristics rating (STGR), inbred line SMLW37 recorded the highest score of 7.4, while SMLW156 had the lowest score of 3.9. The reduction in yield (percentage) varied from 34.9% (SMLW5) to 95.1% (SMLW58).

Screening of Inbred Lines for Low -N tolerance

Inbred lines SMLW5, SMLW147, SMLW53, SMLW3, SMLW75, and SMLW5 exhibited the least values for the TOL index. SMLW156, SMLW21, and SML159 had the highest values

for STI, HM, MP, and GMP. SMLW156, SMLW5, and SMLW21 exhibited the highest value for YI. Based on YSI and RSI, inbred lines SMLW5, SMLW25, and SMLW147 displayed the highest values. Considering SSI, SMLW5, SMLW25, and SMLW147 had the least values. Inbred lines SMLW156, SMLW159, and SMLW10 had the highest positive values for LNTI, while SMLW156, SMLW5, and SMLW99 had the highest positive values for BI. Considering the average of all the selection indices, inbred lines SMLW5, SMLW156, SMLW21, SMLW146, SMLW86, and SMLW10 were the top-ranking (Table 3).

Performance and Stability of Inbred lines across environments

Figures 2 and 3 show the polygon view of the GGE biplot, illustrating the grain yield performance across four environments in Zaria for the top 15 and bottom 10 low-N tolerant inbred lines. The biplot explained 94.8% of the total variation for grain yield, with 17.02% attributed to principal component axis 1 (PC1) and 77.78% attributed to Principal component 2 (PC2). Figure 2 shows the “which-won-where/what” polygon view that enabled the identification of vertex lines, i.e., genotypes positioned at one of the vertices (corners) of the biplot polygon. SMLW21(13) was identified as the vertex inbred in two environments Z21LN (Zaria low-N 2021) and Z21ON (Zaria optimum-N 2021). Similarly, inbred line 1 (SMLW156) exhibited the highest grain yield at environments Z20LN (Zaria low-N 2020) and Z20ON (Zaria optimum 2020).

Figure 3 shows the “mean vs stability” view for the identification of low N tolerant lines with high grain yield and stability across the 4 environments. The absolute length of each line's projection on the average tester axis represents its average yield performance, while its projection on the ATC y-axis measures its stability. Based on these criteria, SMLW21 (13),

SMLW156(1), SMLW159(5) and SMLW169(8) emerged as the highest yielding line across the four environments, while SMLW69 (84), SMLW75 (78) and SMLW140 (76) were identified as the lowest yielders. Lines SMLW156(1) and SMLW159(5) exhibited moderate stability with high yield while SMLW21 (13) recorded the highest yield, but it was highly unstable across the environments.

Correlation Results

Grain yield vs other traits

For grain yield under low-N conditions, positive correlations were observed with plant height ($r = 0.49^{**}$) and ear height ($r = 0.46^{**}$), while a weak and non-significant correlation was found with ears per plant ($r = 0.11$). In contrast, strong negative correlations were identified between GY and ear aspect ($r = -0.73^{**}$) as well as stay-green characteristics ($r = -0.61^{**}$). Moderate negative correlations were observed with days to anthesis ($r = -0.40^{**}$) and days to silking ($r = -0.31^{*}$). Anthesis-silking interval ($r = -0.02$) and plant aspect ($r = -0.16$) displayed weak and non-significant negative correlations with grain

yield (Table 4, Fig. 4). Under optimum-N conditions, GY exhibited positive correlations with plant height ($r = 0.32^{*}$) and ear height ($r = 0.41^{**}$), while displaying negative correlations with days to anthesis ($r = -0.45^{**}$) and ear aspect ($r = -0.73^{**}$). Weak and non-significant correlations were observed between grain yield and the other traits (Table 4, Fig. 5).

Grain yield vs screening indices

GY under low-N showed a positive correlation with various screening indices: BI ($r = 0.99^{**}$), YI ($r = 0.99^{**}$), HM ($r = 0.98^{**}$), LNTI ($r = 0.98^{**}$), STI ($r = 0.91^{**}$), GMP ($r = 0.84^{**}$), MP ($r = 0.56^{**}$), TOL ($r = 0.22^{**}$), RSI ($r = 0.34^{**}$), YSI ($r = 0.34^{**}$). However, it was negatively correlated with RC ($r = -0.34^{**}$) and SSI ($r = -0.34^{**}$). Under optimum-N conditions, GY showed positive correlations with BI ($r = 0.39^{**}$), YI ($r = 0.39^{**}$), HM ($r = 0.60^{**}$), LNTI ($r = 0.60^{**}$), STI ($r = 0.76^{**}$), GMP ($r = 0.84^{**}$), MP ($r = 0.98^{**}$), TOL ($r = 0.98^{**}$), RC ($r = 0.72^{**}$), and SSI ($r = 0.72^{**}$). However, GY was negatively correlated with YSI ($r = -0.26^{**}$), and RSI ($r = -0.26^{**}$) (Table 5, fig. 6).

DISCUSSION

The observed variations among the inbred lines for all traits underscore the inherent genetic variability within these lines, presenting opportunities for targeted breeding interventions. The significance of these observed differences implies that these lines possess distinct genetic traits influencing the expression of the measured agronomic characters. The significant impact of environmental factors on grain yield under low-N conditions emphasizes the sensitivity of yield to nutrient stress, indicating that consideration must not only be on the genetic potential of the lines but also on the dynamic interplay between these traits and the environmental conditions in which cultivation occurs. Conversely, the lack of a significant environmental effect under

optimum-N conditions suggests a certain level of resilience and stability in grain yield when nutrient requirements are adequately met. Under optimal nutrient conditions, maize plants are better equipped to maximize their genetic potential for yield, with external environmental factors playing a relatively minor role (Anas *et al.*, 2020; Yadav *et al.*, 2020). The interaction between the environment and the inbred lines significantly affected all characters except EHT under optimum-N conditions, providing evidence of the intricate relationship between genetic makeup and environmental factors. This implies that the same genetic makeup may result in different trait expressions under diverse environmental conditions, emphasizing the complexity of trait inheritance and the necessity for multilocal trials to assess the stability

of a genotype's performance across various environmental conditions (Badu-Apraku *et al.*, 2015; Abu *et al.*, 2021).

The observed reductions in grain yield, ranging from 35% to 95%, among inbreds under low-N conditions highlight the substantial impact of nitrogen stress on maize genotype performance. This aligns with established knowledge indicating that low nitrogen levels reduce a plant's ability to convert solar energy into carbohydrates, ultimately leading to reduced grain production (Bänziger *et al.*, 2000; Almeida *et al.*, 2018). Furthermore, nitrogen availability significantly influenced the timing of critical developmental stages in maize. Under optimum nitrogen conditions, inbred lines required fewer days to anthesis and silking compared to under low-N conditions. This acceleration in reproductive development under optimum-N conditions can be attributed to nitrogen's role in promoting the synthesis of proteins and enzymes involved in flowering, ultimately enhancing pollination and fertilization processes (Havlin *et al.*, 2014; Zuffo *et al.*, 2021). Additionally, the anthesis-silking interval was significantly higher under low-N compared to optimum-N conditions, indicating the substantial role of nitrogen deficiency in extending the time gap between anthesis and silking, thereby reducing the chances of successful pollination. Plant height and ear height were also significantly affected by nitrogen levels. Under optimum-N conditions, the inbred lines were taller compared to low-N conditions, highlighting nitrogen's role in promoting vigorous vegetative and reproductive growth. Plant aspect and ear aspect, indicators of plant and ear morphology, exhibited significant improvements under optimum nitrogen conditions. These changes suggest that nitrogen availability contributed to more robust and visually appealing plant and ear structures, reflecting the overall health and vigor of the lines.

Furthermore, this study utilized twelve screening indices to evaluate the tolerance of the inbred lines to low soil-N. The highly significant differences observed among the

inbred lines for each screening index underscore the relevance and effectiveness of these indices in discriminating between genotypes. These differences also indicate a diverse range of performances across the screening indices, providing a valuable advantage for identifying inbred lines with superior performance based on these indices. Each index produced different results regarding the identification of tolerant lines, although some indices showed agreement in classifying certain lines as tolerant. For instance, screening index TOL, used for identifying tolerant genotypes (Rosielle and Hamblin 1981), indicated that inbred lines SMLW5, SMLW147, SMLW53, SMLW3, and SMLW75 exhibited the least values and were thus identified as tolerant. Other screening indices, such as STI, MP, GMP, and HM, were useful for identifying inbred lines with excellent yield performance under both low- and optimum-N conditions (Pour-Aboughadareh, *et al.*, 2019). High values are desirable for these indices, and they identified SMLW156, SMLW21, and SMLW159 as the most tolerant. The SSI identified lines with minimal yield reductions under low-N compared to optimum-N conditions (Guttieri *et al.*, 2001). A value less than 1 for this index signifies tolerance to low-N stress, and based on this, SMLW5, SMLW25, and SMLW147 were identified as the most tolerant.

Screening indices YI, YSI and RSI are useful for identifying high-performing genotypes with consistent performance across a range of environments (Khalili *et al.*, 2016; Etminan *et al.*, 2019). These indices evaluate a genotype's ability to maintain yield potential in challenging environmental conditions, such as low-N stress in this study. Inbred lines (SMLW156, SMLW5, and SMLW21) with higher YI values are considered more productive and stable. YSI and RSI identified SMLW5, SMLW25, and SMLW147 as inbred lines with the highest stability in yield performance under both low- and optimum-N conditions. Inbred lines (SMLW156, SMLW159, and SMLW10) with the highest positive values for screening indices

LNTI and inbred lines (SMLW156, SMLW5, and SMLW99) with highest positive values for BI are considered the most tolerant to low-soil N (Bänziger *et al.*, 2000, Badu-Apraku and Oyekunle, 2012). Considering the inbred lines' performance across all selection indices, SMLW5, SMLW156, SMLW21, SMLW146, SMLW86, and SMLW10 were identified as the most tolerant to low soil-N.

Correlation analysis revealed that the indices HM, LNTI, STI, MP, and GMP exhibited similar and strong correlation patterns with grain yield under both low- and optimum-N conditions. This suggests that opting for any of these indices would be sufficient for the selection of low-N tolerant genotypes. These findings align with the observations of Badu-Apraku and Oyekunle, (2012), who identified LNTI as the most effective index for selecting low-N tolerant maize. Similarly, Khan and Mohammad (2016) and Aga *et al.* (2022) reported that STI, GMP, and MP were the most effective selection indices for identifying genotypes with low-N tolerance.

Additionally, the "which-won-where/what" biplot identified SMLW156 and SMLW21 as winning genotypes in two environments each. However, the "mean vs. stability" biplot revealed that SMLW156 not only had high yield but also exhibited moderate stability across different test environments, making it the closest to the ideal genotype in the study.

Correlation estimates and the genotype by traits provided insights into associations between grain yield and various agronomic traits under both low and optimum-N conditions. While correlation coefficients offer quantitative measures of relationships, biplots provide a visual representation that can aid in identifying patterns and trends in the data (Yan and Tinker, 2006). The convergence of both approaches on similar results enhances the depth of understanding trait relationships, facilitating more precise decision-making in crop improvement programs.

Under optimum-N conditions, grain yield showed a positive correlation with plant and ear height and displayed a significant negative

correlation with both ear aspect and plant aspect. The weak and non-significant correlation with other traits suggests that excellent overall phenotypic appeal, characterized by desirable plant and ear characteristics, increased plant height, and greater ear height, is advantageous for maximizing grain yield under optimum-N conditions. In low-N conditions, correlation results revealed that high-yielding inbred lines were associated with increased plant height, greater ear height, earlier maturity, and excellent ratings for stay-green characteristics and ear aspect. Moreover, the elongated vectors of EA, STGR, PHT and EHT on the biplot, indicate their high significance in the selection for achieving high grain yield under low-N conditions (Badu-Apraku and Akinwale, 2011; Talabi *et al.*, 2017, Ribeiro *et al.*, 2020). The perfect linear relationship observed between STGR and GY highlights the beneficial role of delayed senescence and prolonged photosynthesis in maize plants. Inbred lines with better stay-green attributes tend to maintain their greenness for a longer duration, allowing for extended photosynthetic activity and nutrient uptake during the grain-filling stage (Gallais and Coque, 2005; Kamal *et al.*, 2019). This prolonged photosynthesis resulted in increased grain yield due to enhanced assimilate production and grain-filling.

In conclusion, the inbred lines utilized in this study represent invaluable sources of genetic variability, offering potential for the development of new genotypes with enhanced grain yield and Low-N tolerance. The study underscored the crucial role of various selection indices in pinpointing low-N tolerant genotypes that consistently excel across diverse environments. Notably, selection indices such as HM, LNTI, STI, MP, and GMP emerged as particularly useful in identifying superior genotypes under low-N conditions.

Among the inbred lines assessed, SMLW5, SMLW156, and SMLW159 stood out as the most tolerant to low soil-N based on their robust performance across multiple selection indices. Specifically, SMLW156 demonstrated

excellent yield performance under both low- and optimum-N conditions, coupled with the added advantage of relatively high stability across various test environments

Correlation results and GxT Biplot analyses

unveiled the significance of certain traits, including ear aspect, stay-green characteristics, plant height, and ear height, in achieving high grain yield under low-N conditions.

REFERENCES

- Abu, P., Badu-Apraku, B., Tongoona, P., Ifie, B.E., Ribeiro, P.F., Obeng-Bio, E., and Offei, S.K. (2021). Genetics of Extra-early maturing yellow and orange quality protein maize inbreds and derived hybrids under low soil nitrogen and Striga infestation. *Crop Science*, 61(2): 1052-1072.
- Adu, G.B., Badu-Apraku, B., Akromah, R. (2021). Strategies for Selecting Early Maturing Maize Inbred Lines for Hybrid Production under Low Soil Nitrogen and Striga Infestation. *Agronomy* 11 (7) : 1 3 0 9 . . <https://doi.org/10.3390/agronomy11071309>
- Aga, T.G., Abera, F.A., Tufa, T.B., Abebe, K.A., Abeyo, B.G. and Ayana, N.G. (2022). Nitrogen deficiency tolerance and responsiveness of durum wheat genotypes in Ethiopia. *International Journal of Agronomy* 2022:9506078 <https://hdl.handle.net/10883/22403>
- Almeida V.C., Viana J.M.S., DeOliveira H.M., Risso L.A., Ribeiro A.F.S. and DeLima R.O. (2018). Genetic diversity and path analysis for nitrogen use efficiency of tropical popcorn (*Zea mays* ssp. everta) inbred lines in adult stage. *Plant Breed* 137:839–847.
- Anas, M., Liao, F., Verma, K.K. et al. (2020). Fate of nitrogen in agriculture and environment: agronomic, eco-physiological and molecular approaches to improve nitrogen use efficiency. *Biol Res* 53 , 4 7 <https://doi.org/10.1186/s40659-020-00312-4>
- Badu-Apraku, B. and Akinwale, R. (2011). Identification of early maturing maize inbred lines based on multiple traits under drought and low N environments for hybrid development and population improvement. *Canadian Journal of Plant Science*, 91 (5): 931-942
- Badu-Apraku, B., Akinwale, R., Ajala, S., Menkir, A., Fakorede, M. and Oyekunle, M. (2011). Relationships among Traits of Tropical Early Maize Cultivars in Contrasting Environments. *Agronomy Journal*. 103. 717–729.
- Badu-Apraku, B., and Oyekunle, M. (2012). Genetic analysis of grain yield and other traits of extra-early yellow maize inbreds and hybrid performance under contrasting environments. *Field Crops Res.* 129, 99–110.
- Badu-Apraku, B., Annor, B., Oyekunle, M., et al., (2015). Grouping of early maturing quality protein maize inbreds based on SNP markers and combining ability under multiple environments. *Field Crops Research*, 183, 169–183.
- Badu-Apraku B, Fakorede M.A.B., Annor, B., Adu, G.B., Obeng-Bio, E., Abu, P., et al. (2023). Genetic Enhancement of Early and Extra-Early Maturing Maize for Tolerance to Low-Soil Nitrogen in Sub-Saharan Africa. *Crop Breed Genet Genom* . 5 (1) : e 2 3 0 0 0 1 . <https://doi.org/10.20900/cbgg2023000>.
- Bankole, F. A., Olajide, O. O. and Olaoeye, G. (2023). Performance and yield stability of quality protein maize (*Zea mays* L.) hybrids under rainfed condition. *Agriculture (Poľnohospodárstvo)*, 69(2), 66–76
- Bänziger, M., Edmeades, G. O., Beck, D. and Bellon, M. (2000). Breeding for Drought and Nitrogen Stress Tolerance in Maize: From Theory to Practice. Mexico, D.F.: CIMMYT.
- Batista, L.G, Gaynor, R.C, Margarido, G.R.A, Byrne, T., and Amer, P. (2021) Long-term comparison between index selection and optimal independent culling in plant breeding programs with genomic prediction. *Plos One* 16(5): 0235554.

- Betràn, F. J., Beck, D., Bänziger, M. and Edmeades, G. O. (2003) Genetic Analysis of Inbred and Hybrid Grain Yield under Stress and Nonstress Environments in Tropical Maize. *Crop Science*, 43: 807-817.
- Etminan, A., Pour-Aboughadareh, A., Mohammadi R., Shoshtari, L., Yousefiazarkhanian, M., and Moradkhani, H. (2019). Determining the best drought tolerance indices using artificial neural network (ANN): Insight into application of intelligent agriculture in agronomy and plant breeding. *Cereal Research Communication* 47: 170–181.
- Gallais, A. and Coque, M. (2005). Genetic variation and selection for nitrogen use efficiency in maize: A synthesis. *Maydica* 50, 531–537
- Guttieri, M. J., Stark, J. C., Brien, K., and Souza, E. (2001). Relative sensitivity of spring wheat grain yield and quality parameters to moisture deficit. *Crop Science* 41: 327–335.
- Havlin, J.L., Beaton, J.D., Tisdale, S.L. and Nelson, W.L. (2014). *Soil Fertility and Fertilizers; An Introduction to Nutrient Management*. 6th Edition, Prentice Hall, Upper Saddle River, NJ.
- Kamal, N.M., Gorafi, Y.S.A., Abdelrahman, M., Abdellatef, E., Tsujimoto, H. (2019). Stay-Green Trait: A Prospective Approach for Yield Potential, and Drought and Heat Stress Adaptation in Globally Important Cereals. *International Journal of Molecular Sciences*. 20(23): 5837. <https://doi.org/10.3390/ijms20235837>
- Khalili, M., Pour-Aboughadareh, A. and Naghavi, M. R. (2016). Assessment of drought tolerance in barley: Integrated selection criterion and drought tolerance indices. *Environmental and Experimental Biology* 14: 33–41.
- Khan, F. U. and Mohammad, F. (2016). Application of stress selection indices for assessment of nitrogen tolerance in wheat (*Triticum aestivum* L.). *J. Anim. Plant Sci*, vol. 26(1)201-2016.
- Meeks, M., Murray, S. C., Hague, S., Hays, D., and Ibrahim, A.M.H. (2012). Genetic variation for maize epicuticular wax response to drought stress at flowering. *J. Agron. Crop Sci.* 198, 161–172.
- Meseka S.K., Menkir A., Ibrahim A.E.S., and Ajala S.O. (2006). Genetic analysis of performance of maize inbred lines selected for tolerance to drought under low nitrogen. *Maydica*, 2006, 51, 487-495.
- Monneveux, P.; Sanchez, C.; Beck, D.; Edmeades, G.O. (2006). Drought tolerance improvement in tropical maize source populations: Evidence of progress. *Crop Sci.*, 46, 180–19126.
- Oyekunle, M. and Badu-Apraku, B. (2013). Genetic Analysis of Grain Yield and Other Traits of Early-Maturing Maize Inbreds under Drought and Well-Watered Conditions. *Journal of Agronomy and Crop Science*. 200. 10.1111/jac.12049.
- Pacheco, A., Vargas, M., Alvarado, G., Rodríguez, F., Crossa, J. and Burgueño, J. (2016). GEA-R (genotype×environment analysis with R for Windows). Version 2.0. CIMMYT
- Pour-Aboughadareh, A., M. Yousefian, H. Moradkhani, M. Moghaddam Vahed, P. Pocza, and K. H. M. Siddique. 2019. iPASTIC: An online toolkit to estimate plant abiotic stress indices. *Applications in Plant Sciences* 7(7): e11278. doi:10.1002/aps3.11278
- Ribeiro, P.F., Badu Apraku, B., Gracen, V., Danquah, E.Y., Afriyie-Debrah, C., Obeng-Dankwa, K., and Toyinbo, J.O. (2020). Combining ability and testcross performance of low N tolerant intermediate maize inbred lines under low soil nitrogen and optimal environments. *The Journal of Agricultural Science* 1–20.
- Rosielle, A. A., and Hamblin, J. (1981). Theoretical aspects of selection for yield in stress and non-stress environments. *Crop Science* 21: 943–946.
- SAS Institute. (2008). SAS system for windows. Release 9.2. Cary, NC: SAS Institute.
- Steel, R. G. D., and Torrie, J. H. (1980). Principles and Procedures of statistics. New York: McGraw-Hill Books Co
- Talabi, A.O., Badu-Apraku, B., Fakorede, M.A.



- (2017) Genetic variances and relationship among traits of an early maturing maize population under drought-stress and low nitrogen environments. *Crop Sci.*;57(2:681-92
- Trachsel, S., Leyva, M., Lopez, M., Suarez, E.A., Mendoza, A., Montiel, N.G., Macias, M.S., and Burgueno, J. (2016). Identification of tropical maize germplasm with tolerance to drought, nitrogen deficiency, and combined heat and drought stresses. *Crop science*, 56: 3031 - 3045
- Yadav, S., Modi, P., Dave, A., Vijapura, A., Patel, D., & Patel, M. (2020). Effect of Abiotic Stress on Crops. IntechOpen. doi: 10.5772/intechopen.88434
- Yan, W. and Kang, M.S. (2003) GGE biplot analysis: A graphical tool for breeders. In Kang MS (ed.), *Geneticists and Agronomist*. Boca Raton, FL, USA: CRC Press, p. 271.
- Yan, W. and Tinker, N. A. (2006) Biplot analysis of multi-environment trial data: Principles and applications. *Canadian Journal of Plant Science*, 86: 623-645.
- Zuffo, L., Luz, L., Destro, V., Silva, M., Rodrigues, M., Lara, L., Faria, S. and DeLima, R. (2021). Assessing genotypic variation for nitrogen use efficiency and associated traits in Brazilian maize hybrids grown under low and high nitrogen inputs. *Euphytica*. 217(271).

Table 1: List of inbred lines used in the study and their pedigree information

INBRED	PEDIGREE	INBRED	PEDIGREE
SMLW - 3	SAM 18 S ₆ -4-5-1-2-3-2-1-2-1-1-4-4	SMLW - 93	SAM 18 S ₆ -3-5-2-2-1-1-1-2-1-1-1-2
SMLW - 4	SAM 16 S ₆ -3-6-1-2-2-3-1-2-1-1-1-2	SMLW - 96	SAM 15 S ₆ -4-6-1-2-1-1-1-2-1-1-1-1
SMLW - 5	SAM 18 S ₆ -4-5-1-2-1-2-1-2-1-1-3-3	SMLW - 99	SAM 16 S ₆ -2-6-1-2-3-3-1-2-1-1-1-1
SMLW - 6	SAM 18 S ₆ -2-3-2-2-1-1-1-2-1-1-1-1	SMLW - 100	TZEE-W S ₆ -2-3-1-2-1-2-1-2-1-1-1-1
SMLW - 7	SAM 15 S ₆ -1-6-1-2-1-1-2-2-1-2-1-1	SMLW - 101	TZE-W S ₆ -2-3-1-2-1-2-2-2-1-2-1-1
SMLW - 9	SAM 18 S ₆ -4-5-1-2-1-3-1-2-1-1-2-3	SMLW - 102	SAM 16 S ₆ -1-1-1-2-1-2-1-1-1-1-1-1
SMLW - 10	TZEE-W S ₆ -8-10-1-2-1-2-3-2-1-1-1-3	SMLW - 104	TZE-W S ₆ -6-10-1-2-2-2-2-2-1-1-1-1
SMLW - 11	TZEE-W S ₆ -8-10-1-2-1-2-3-2-1-1-3-3	SMLW - 105	SAM 18 S ₆ -1-5-2-2-1-2-2-2-2-2-1-1
SMLW - 14	SAM 18 S ₆ -4-3-1-2-3-2-1-2-1-1-4-5	SMLW - 106	SAM 15 S ₆ -3-6-1-1-1-1-2-2-1-1-1-1
SMLW - 16	SAM 18 S ₆ -4-3-1-2-3-2-1-2-1-1-1-5	SMLW - 107	SAM 16 S ₆ -3-6-1-2-3-2-2-2-1-1-1-1
SMLW - 17	SAM 16 S ₆ -5-5-1-2-2-2-2-2-1-2-1-4	SMLW - 108	SAM 15 S ₆ -2-6-1-2-1-1-2-2-2-2-1-1
SMLW - 19	SAM 16 S ₆ -5-5-1-2-2-2-2-2-1-2-3-4	SMLW - 119	TZE-W S ₆ -2-3-2-2-1-2-2-2-1-1-2-2
SMLW - 20	SAM 16 S ₆ -5-5-1-2-2-2-2-2-1-2-4-4	SMLW - 120	TZE-W S ₆ -2-3-2-2-1-2-2-2-1-1-1-2
SMLW - 21	SAM 16 S ₆ -3-16-3-3-2-2-1-1-1-1-1-3	SMLW - 121	SAM 16 S ₆ -2-6-1-2-1-3-1-2-1-1-1-2
SMLW - 22	SAM 26 S ₆ -3-16-3-3-2-2-1-1-1-1-3-3	SMLW - 122	SAM 16 S ₆ -2-6-1-2-1-3-1-2-1-1-2-2
SMLW - 23	SAM 26 S ₆ -3-16-3-3-2-2-1-1-1-1-2-3	SMLW - 127	SAM 20 S ₆ -5-5-1-2-2-2-1-2-1-3-1-1
SMLW - 24	SAM 26 S ₆ -3-16-3-3-2-2-1-1-1-1-1-3	SMLW - 134	TZE-W S ₅ -1-12-1-2-1-2-1-1-2-2
SMLW - 25	SAM 16 S ₆ -3-6-2-2-1-3-3-3-1-1-2-3	SMLW - 135	TZE-W S ₅ -3-3-1-2-2-2-1-2-1-1
SMLW - 26	SAM 16 S ₆ -3-6-2-2-1-3-3-3-1-1-3-3	SMLW - 140	2009 DTE S ₅ -8-10-1-2-1-2-1-1-2-2
SMLW - 27	SAM 16 S ₆ -3-6-2-2-2-3-1-2-1-1-3-3	SMLW - 143	TZE-W S ₅ -3-13-2-2-1-2-1-2-1-2
SMLW - 33	TZEE-W S ₆ -10-10-1-2-1-1-1-2-1-1-1-3	SMLW - 144	TZE-W S ₅ -5-13-3-6-1-2-1-3-2-2
SMLW - 34	TZEE-W S ₆ -10-10-1-2-1-1-1-2-1-1-2-3	SMLW - 145	TZE-W S ₅ -5-13-3-3-1-2-1-3-1-2
SMLW - 37	SAM 15 S ₆ -3-6-2-2-1-1-2-2-1-1-2-3	SMLW - 146	TZE-W S ₅ -3-13-2-2-1-2-2-2-1-2
SMLW - 43	SAM 16 S ₆ -4-6-2-2-2-2-2-2-1-1-1-3	SMLW - 147	TZE-W S ₅ -1-13-2-2-1-2-1-1-2-2
SMLW - 44	SAM 16 S ₆ -4-6-2-2-2-2-2-2-1-1-2-3	SMLW - 150	TZE-W S ₅ -3-13-1-2-2-2-2-2-3-3
SMLW - 48	SAM 20 S ₆ -4-5-1-2-1-1-1-2-1-1-1-3	SMLW - 155	SAM 26 S ₅ -4-6-2-2-2-2-1-1-3-3
SMLW - 50	SAM 20 S ₆ -4-5-1-2-1-1-1-2-1-1-3-3	SMLW - 156	SAM 26 S ₅ -4-6-2-2-2-2-1-1-2-3
SMLW - 51	TZE-W S ₆ -9-10-1-2-2-2-1-3-1-1-1-3	SMLW - 157	SAM 26 S ₅ -4-6-2-2-2-2-1-1-1-3
SMLW - 52	TZE-W S ₆ -9-10-1-2-2-2-1-3-1-1-2-3	SMLW - 158	SAM 26 S ₅ -1-12-2-2-2-2-1-1-2-2
SMLW - 53	SAM 18 S ₆ -4-5-1-2-1-2-2-2-1-1-2-2	SMLW - 159	SAM 26 S ₅ -1-12-2-2-2-2-1-1-1-2
SMLW - 57	TZE-W S ₆ -3-3-2-2-1-1-1-2-1-1-2-2	SMLW - 160	SAM 27 S ₅ -2-11-2-3-3-3-3-3-3-3
SMLW - 58	SAM 16 S ₆ -3-6-2-2-1-3-1-3-1-1-1-2	SMLW - 162	SAM 27 S ₅ -2-11-2-3-3-3-3-3-1-3
SMLW - 64	SAM 16 S ₆ -3-6-2-2-1-1-2-2-1-1-2-2	SMLW - 163	TZE-W S ₅ -5-13-1-3-1-1-2-2-2-2
SMLW - 69	TZEE-W S ₆ -2-3-1-2-1-2-1-2-1-1-1-2	SMLW - 165	TZE-W S ₅ -2-13-3-3-2-2-1-1-1-1
SMLW - 70	TZEE-W S ₆ -2-3-1-2-1-2-1-2-1-1-2-2	SMLW - 167	SAM 27 S ₅ -2-11-2-3-3-3-1-3-1-1
SMLW - 74	TZE-W S ₆ -2-11-1-2-2-2-2-2-1-1-2-2	SMLW - 169	TZE-W S ₅ -3-8-2-3-1-2-2-2-1-1
SMLW - 75	SAM 16 S ₆ -2-1-1-2-3-3-2-2-2-2-1-2	SMLW - 183	SAM 27 S ₅ -7-11-1-2-1-2-1-1-1-1
SMLW - 77	TZE-W S ₆ -1-3-1-2-1-2-1-2-1-1-2-2	SMLW - 86	SAM 15 S ₆ -2-6-2-2-1-2-1-2-1-1-2-2
SMLW - 78	TZE-W S ₆ -1-3-1-2-1-2-1-2-1-1-1-2	SMLW - 91	SAM 16 S ₆ -3-6-1-2-3-3-1-3-1-1-1-1
SMLW - 84	SAM 16 S ₆ -2-6-1-2-2-3-2-2-1-1-1-2		

Table 2: ANOVA Table showing the effect of Genotype, Environment, and Their Interactions on Trait Expression in Maize Inbred Lines evaluated under contrasting nitrogen levels at Zaria in 2020 and 2021

Source	df	Grain yield	Days to anthesis	Days to silking	Anthesis-silking interval	Plant height	Ear height	Ear per plant	Plant aspect	Ear aspect	Stay green characteristic
<i>Low N conditions</i>											
Environment, E	1	452096.13*	0.05	0.01	0.01	18.20	8.68	0.01	0.01	0.02	0.01
Rep (E)	2	53027.40	38.86**	228.43**	79.22**	735.40*	5.26	0.04	0.10	0.76	0.58
Block(E x Rep)	3	73612.54*	6.81*	5.38	1.21	479.03*	56.66	0.03	0.17	0.75	0.743*
Genotype, G	8	75853.07**	6.21*	10.68**	3.12*	654.60**	137.86**	0.03	0.27	0.97	1.43**
G x E	8	73323.80	8.50*	10.57**	1.95*	583.77**	104.50**	0.03	0.34	0.91	1.50**
Pooled Error	18	35473.64	3.76	4.16	1.01	229.60	46.91	0.02	0.12	0.32	0.44
<i>Optimum conditions</i>											
Environment, E	1	1630107.4	747.03**	750.01**	0.01	21.00	6.03	0.06	24.37	27.14**	
Rep (E)	2	2331488.9*	73.00*	77.90*	0.41	433.24	195.56	0.35	0.41	2.12	
Block(E x Rep)	3	992835.3	28.03*	30.00*	0.62	1042.78*	353.42	0.10	0.21	0.32	
Genotype, G	8	1949255.6**	38.50**	39.86**	1.04*	735.14	327.39*	0.10	0.39	1.02	
G x E	8	2097565.9**	31.00**	29.70**	0.82*	1027.96*	280.71	0.11	0.46	1.06	
Pooled Error	18	636235.3	14.20	15.13	0.49	586.10	238.29	0.04	0.17	0.24	

Screening Indices

Table 3: Grain yield and Screening index values of Maize Inbred lines (best 15 and worst 5) evaluated under low- and optimum-N conditions at Zaria in 2018 and 2019.

Lines	GY(kg/ha)		RC	TOL	MP	GMP	HM	SSI	STI	YI	YSI	RSI	LNTI	BI
	LN	OPT												
Top 15														
SMLW156	1280	4142	69.1	2862	2711	2302	1956	0.86	1.68	3.72	0.31	1.59	18.94	31.99
SMLW5	711	1091	34.9	381	901	881	861	0.43	0.25	2.06	0.65	3.36	7.97	16.25
SMLW21	654	4094	84.0	3440	2374	1637	1128	1.04	0.85	1.90	0.16	0.82	4.59	4.49
SMLW146	641	2028	68.4	1387	1334	1140	974	0.85	0.41	1.86	0.32	1.63	6.30	11.27
SMLW86	630	2138	70.5	1508	1384	1161	973	0.87	0.43	1.83	0.29	1.52	5.35	11.32
SMLW159	626	3344	81.3	2718	1985	1446	1054	1.01	0.66	1.82	0.19	0.97	8.09	9.32
SMLW10	600	2193	72.7	1593	1396	1147	942	0.90	0.42	1.74	0.27	1.41	8.09	11.24
SMLW99	568	2377	76.1	1808	1472	1162	917	0.94	0.43	1.65	0.24	1.23	7.52	14.12
SMLW169	515	2159	76.2	1645	1337	1054	832	0.94	0.35	1.50	0.24	1.23	3.65	7.59
SMLW24	488	2589	81.1	2101	1539	1124	822	1.01	0.40	1.42	0.19	0.97	1.81	2.13
SMLW96	462	1963	76.4	1500	1213	953	748	0.95	0.29	1.34	0.24	1.22	1.87	3.83
SMLW183	432	1168	63.0	736	800	710	630	0.78	0.16	1.25	0.37	1.91	0.07	-0.70
SMLW19	413	2044	79.8	1632	1228	918	686	0.99	0.27	1.20	0.20	1.04	0.46	0.22
SMLW78	399	1165	65.8	767	782	682	594	0.82	0.15	1.16	0.34	1.77	-0.24	2.62
SMLW157	398	1773	77.6	1375	1085	839	649	0.96	0.22	1.15	0.22	1.16	0.89	3.72
Bottom 5														
SMLW84	184	1419	87.0	1235	802	511	326	1.08	0.08	0.53	0.13	0.67	-3.87	-4.53
SMLW108	184	1247	85.3	1064	716	479	320	1.06	0.07	0.53	0.15	0.76	-2.89	-3.47
SMLW120	174	1112	84.3	938	643	440	301	1.05	0.06	0.51	0.16	0.81	-5.84	-9.86
SMLW160	170	2122	92.0	1952	1146	600	315	1.14	0.11	0.49	0.08	0.41	-1.64	-4.12
SMLW58	132	2692	95.1	2560	1412	597	252	1.18	0.11	0.38	0.05	0.25	-4.51	-11.3
Check 1	366	2489												
Check 2	349	1786												
Mean	344	1777	77.2	1432	1060	759	558	0.96	0.21	1.00	0.23	1.18	-0.35	-0.23
Minimum	132	532	34.9	237	383	347	252	0.43	0.04	0.38	0.05	0.25	-7.86	-11.3
Maximum	1280	4142	95.1	3440	2711	2302	1956	1.18	1.68	3.72	0.65	3.36	18.94	31.99

Table 4: Correlation coefficients between Grain yield of the Inbred lines and other agronomic traits under low- and optimum-N condition

	Grain Yield (Kg/ha)	
	Low N	Optimum-N
Days to anthesis	-0.40**	-0.11
Days to silking	-0.31*	-0.13
Anthesis silking interval	-0.02	-0.17
Plant height	0.49**	0.32*
Ear height	0.46**	0.41**
Ears per plant	0.11	-0.08
Plant aspect	-0.16	-0.46**
Ear aspect	-0.73**	-0.73**
Stay green characteristics	-0.61**	

*, **, Significant at 0.05 and 0.01 probability levels, respectively;

Table 5: Correlation coefficients between Grain yield of the Hybrids and their Screening Index Values

	Grain Yield (Kg/ha)	
	Low N	Optimum-N
Low N Tolerance Index	0.98**	0.60**
Base Index	0.99**	0.39**
Tolerance index	0.22**	0.98**
Mean Productivity	0.56**	0.98**
Geometric Mean Productivity	0.84**	0.84**
Harmonic Mean	0.98**	0.60**
Stress Susceptibility Index	-0.34**	0.72**
Stress Tolerance Index	0.91**	0.77**
Yield Index	0.99**	0.39**
Yield Stability Index	0.34**	-0.26**
Relative Stress Index	0.34**	-0.26**
Percentage Yield Reduction	0.90**	0.06

*, **, Significant at 0.05 and 0.01 probability levels, respectively;

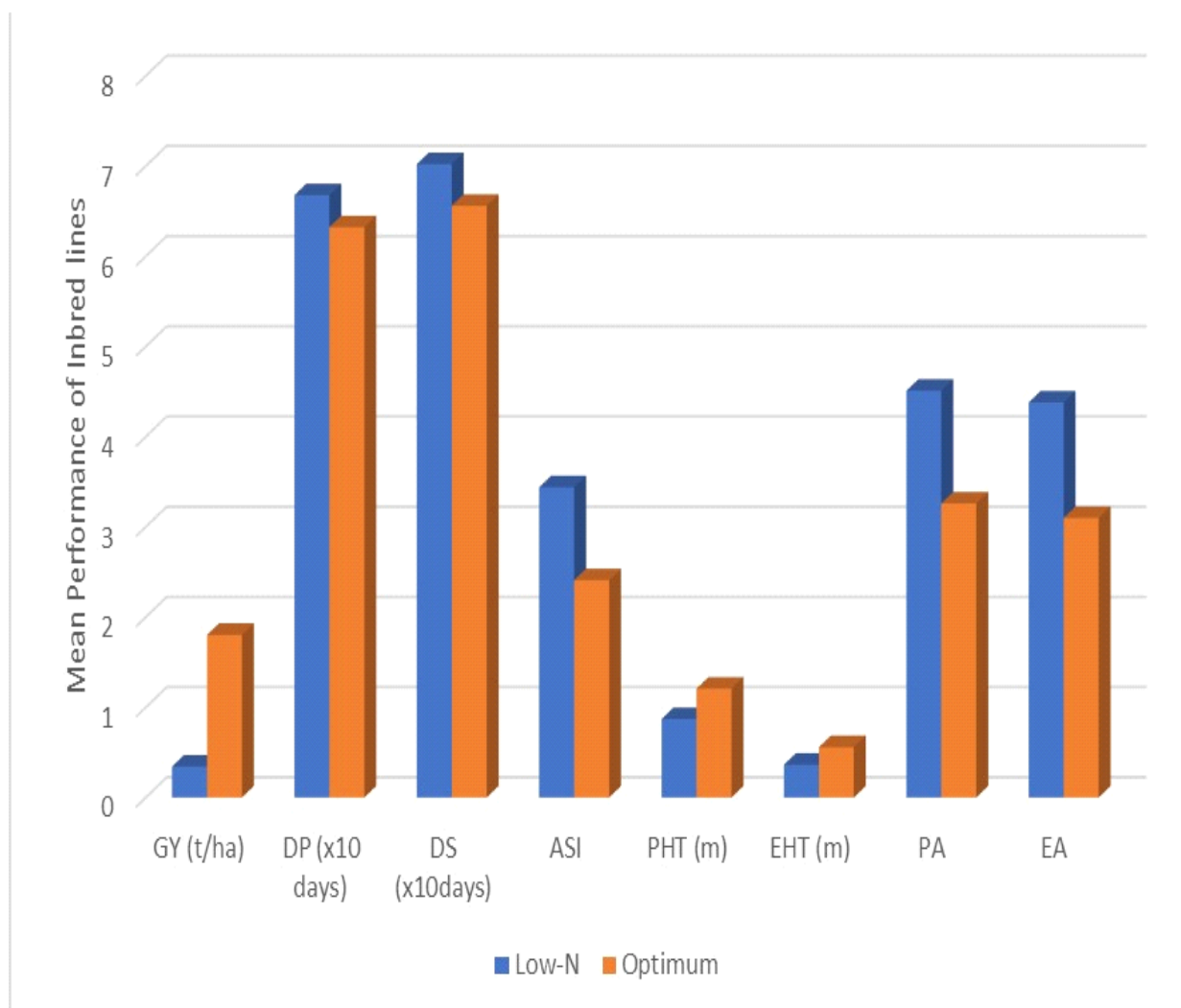
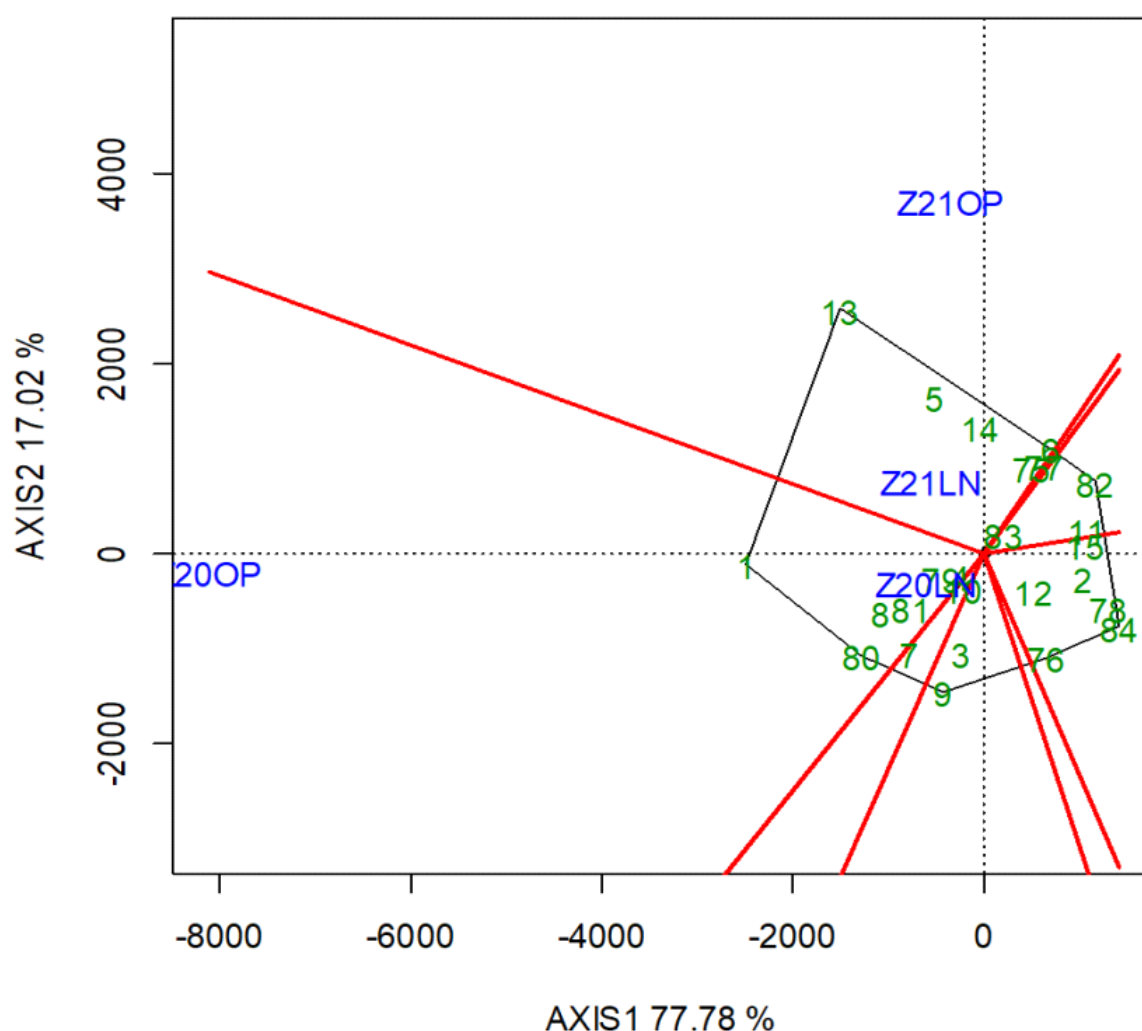
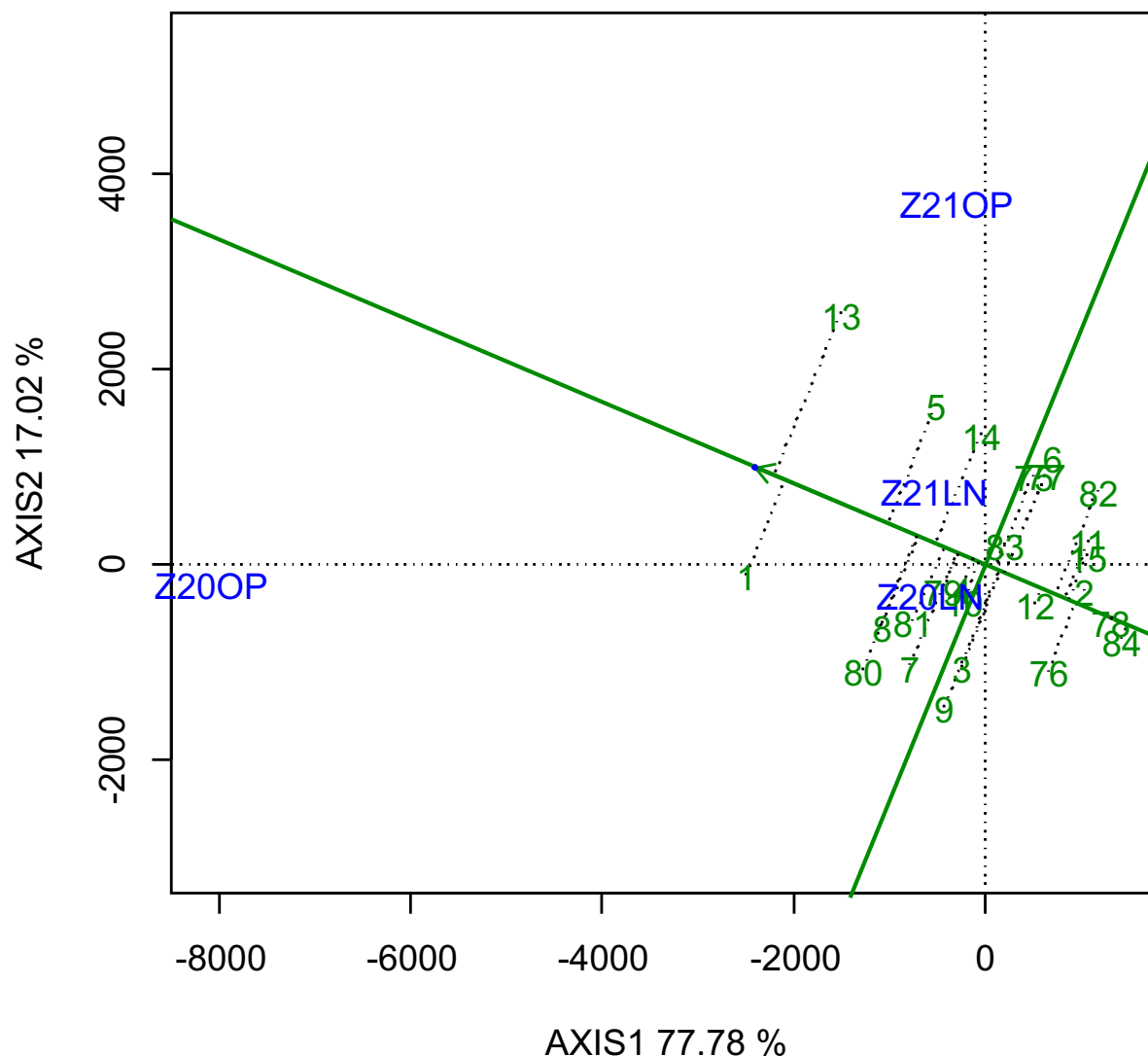


Figure 1: Mean grain yield and other agronomic Traits of the Inbred Lines evaluated under low-N and Optimum-N environments



Code	Environment	code	Hybrid	Code	Hybrid
Z20LN	Zaria low N 2020	1	SMLW - 156	14	SMLW - 107
Z21LN	Zaria Low N 2021	2	SMLW - 5	15	SMLW - 165
Z20OP	Zaria Optimum N 2020	3	SMLW - 10	76	SMLW - 140
Z21OP	Zaria Optimum N 2021	4	SMLW - 99	77	SMLW - 74
		5	SMLW - 159	78	SMLW - 75
		6	SMLW - 146	80	SMLW - 37
		7	SMLW - 86	81	SMLW - 58
		8	SMLW - 169	82	SMLW - 120
		9	SMLW - 51	83	SMLW - 20
		10	SMLW - 163	84	SMLW - 69
		11	SMLW - 183	79	SMLW - 22
		12	SMLW - 145	75	SMLW - 155
		13	SMLW - 21		

Figure 2: A 'which-won-where/what' genotype and genotype x environment (GGE) biplot of 20 (best 15 and worst 10) Low N tolerant inbred lines across four environments in Zaria during 2018 and 2019 growing season.



Code	Environment	code	Hybrid	Code	Hybrid
Z20LN	Zaria low N 2020	1	SMLW - 156	14	SMLW - 107
Z21LN	Zaria Low N 2021	2	SMLW - 5	15	SMLW - 165
Z20OP	Zaria Optimum N 2020	3	SMLW - 10	76	SMLW - 140
Z21OP	Zaria Optimum N 2021	4	SMLW - 99	77	SMLW - 74
		5	SMLW - 159	78	SMLW - 75
		6	SMLW - 146	80	SMLW - 37
		7	SMLW - 86	81	SMLW - 58
		8	SMLW - 169	82	SMLW - 120
		9	SMLW - 51	83	SMLW - 20
		10	SMLW - 163	84	SMLW - 69
		11	SMLW - 183	79	SMLW - 22
		12	SMLW - 145	75	SMLW - 155

13 SMLW - 21

Figure 3 An entry/tester genotype and genotype × environment (GGE) biplot of 20 (best 15 and worst 10) Low N tolerant inbred lines across four environments in Zaria during 2018 and 2019 growing season.

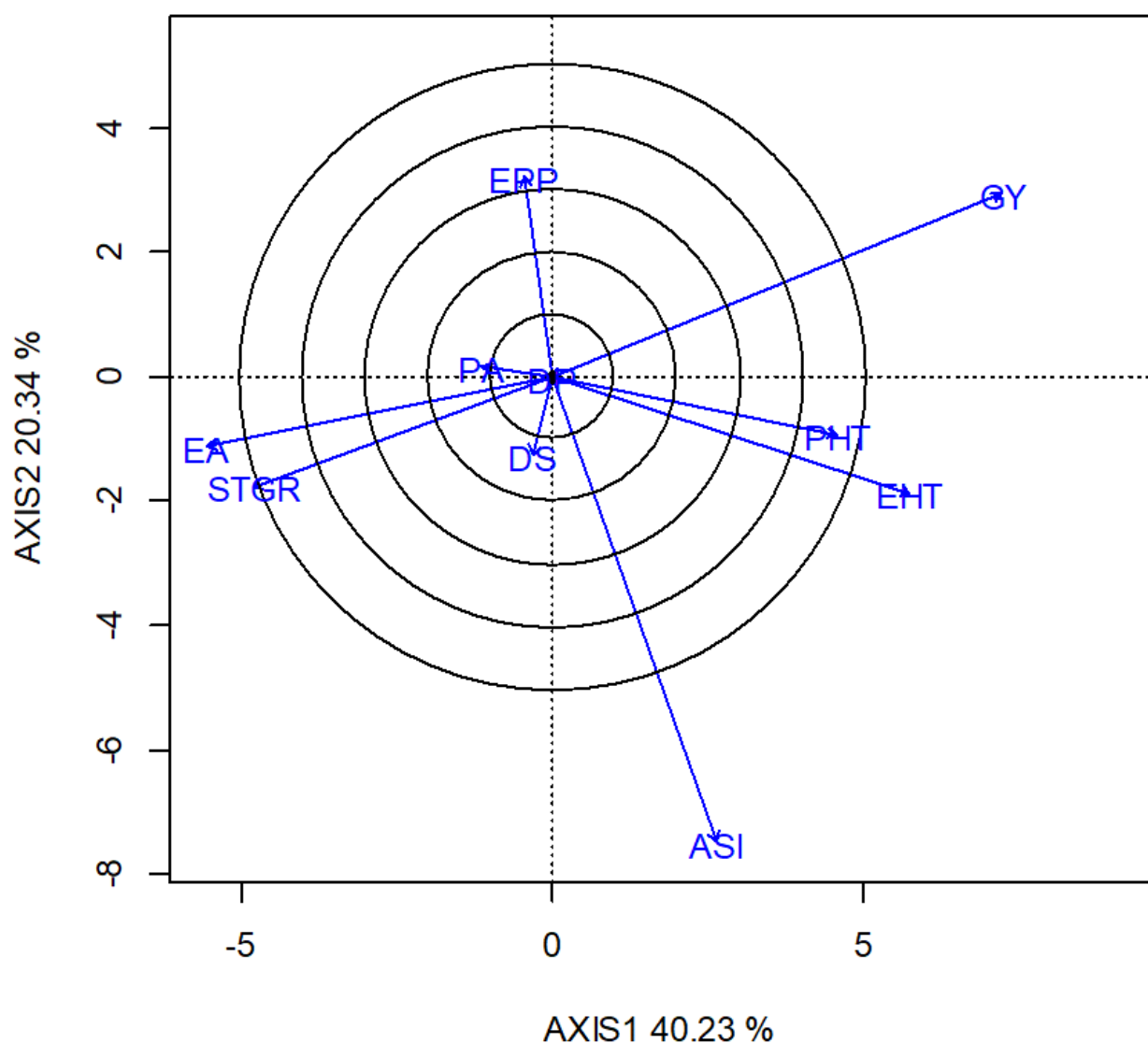


Figure 4: : A vector view of the genotype-by-trait biplot showing interrelationships among traits of 79 inbred lines evaluated under low-N conditions at Zaria in 2019 and 2020. (GY, grain yield; PHT, plant height; EHT, ear height; EPP, number of ears per plant; PA, plant aspect; EA, ear aspect; DP, days to anthesis; DS, days to silking; ASI, anthesis silking interval; STGR, stay green characteristics).

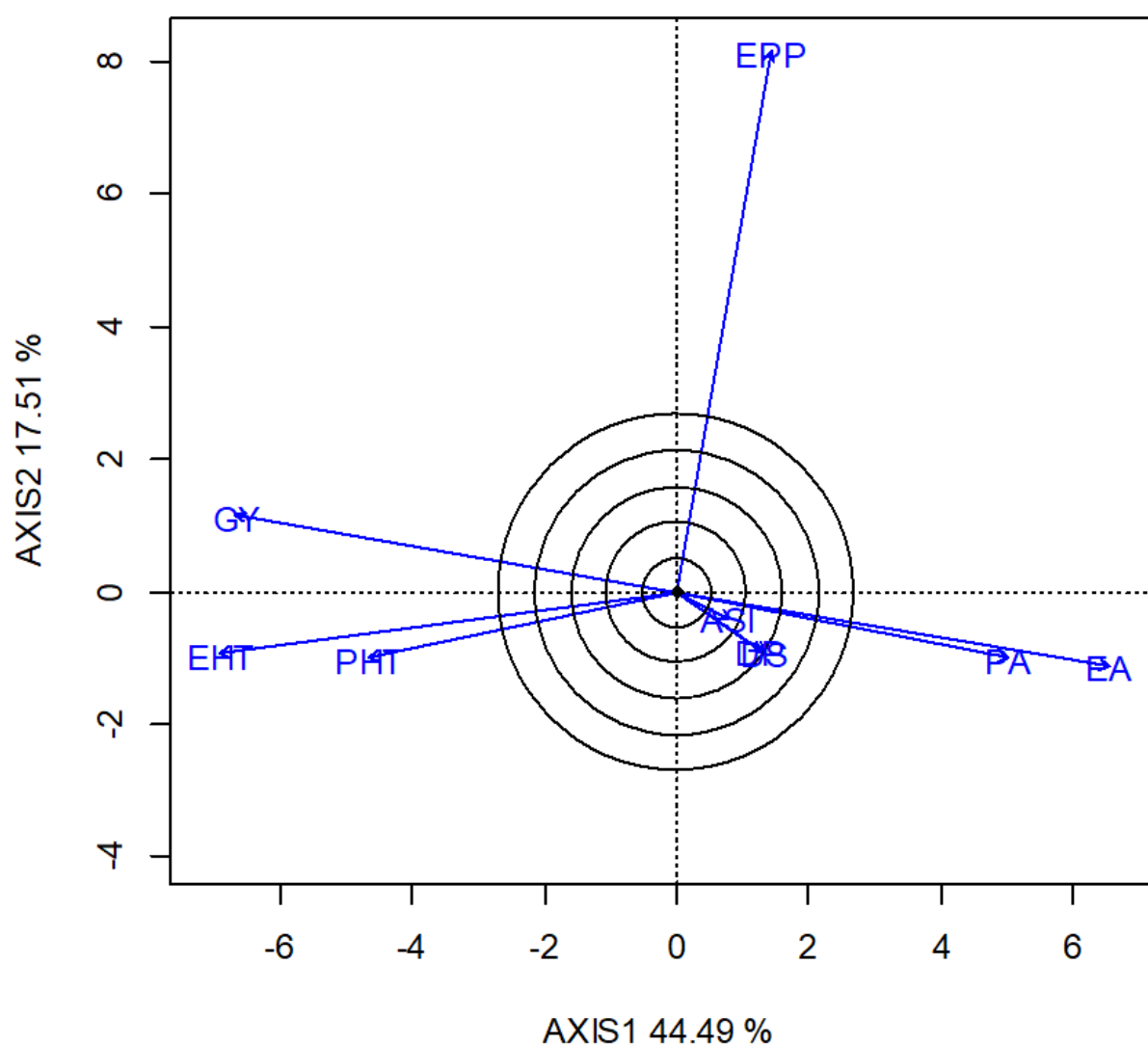


Figure 5: A vector view of the genotype-by-trait biplot showing interrelationships among traits of 79 inbred lines evaluated under optimum-N conditions at Zaria in 2019 and 2020. (GY, grain yield; PHT, plant height; EHT, ear height; EPP, number of ears per plant; PA, plant aspect; EA, ear aspect; DP, days to anthesis; DS, days to silking; ASI, anthesis silking interval)

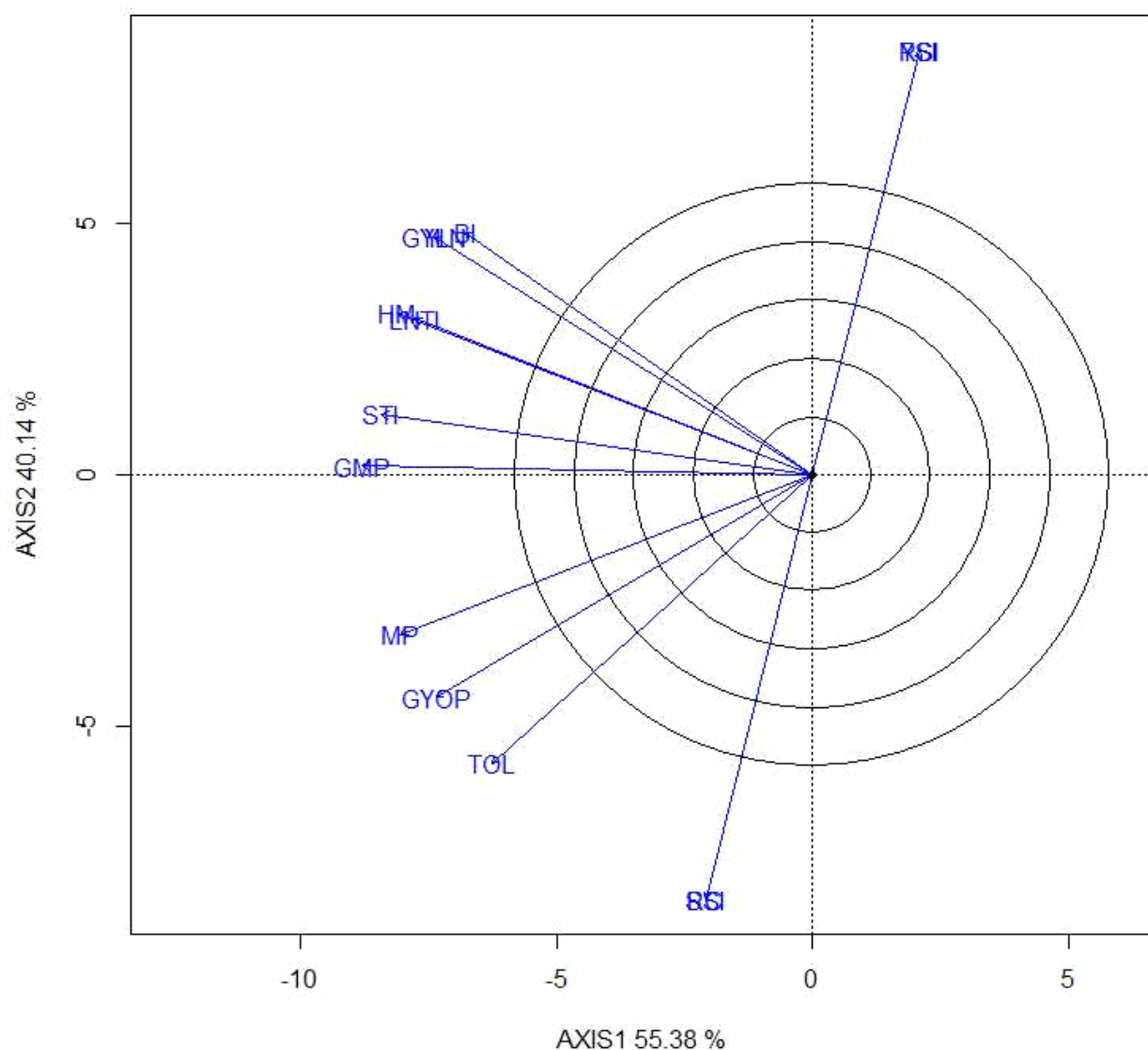


Figure 6: A vector view of the genotype-by-trait biplot showing the relationship between grain yield and the screening indices (LNTI=Low N Tolerance Index; BI=IITA Base Index; TOL= Tolerance index; MP= Mean Productivity; GMP = Geometric Mean Productivity; HM = Harmonic Mean; SSI = Stress Susceptibility Index; STI = Stress Tolerance Index; YI = Yield Index; YSI = Yield Stability Index; RS = Relative Stress Index; IN = Selection Index; GYOP = Grain yield under optimum-N; GYLN = Grain yield under low-N)