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Research article

Root Length and Diameter at Flag Leaf Stage Correlate with Important Yield Parameters in Corn (*Zea mays* L.) Grown in Alkaline Soil Under Drought Conditions

Noriel Jay A. Magsayo[1*], Elvira D. Jamio[2], Melissa I. Canunayon[3], Daniel B. Tangpos[4], Julius D. Caritan[5], and Pet Roey L. Pascual[6]

[1] Graduate School, Cebu Technological University – Barili Campus, Barili, 6306 Cebu, Philippines
[2] Graduate School, Cebu Technological University – Barili Campus, Barili, 6306 Cebu, Philippines
[3] Graduate School, Cebu Technological University – Barili Campus, Barili, 6306 Cebu, Philippines
[4] Graduate School, Cebu Technological University – Barili Campus, Barili, 6306 Cebu, Philippines
[5] Graduate School, Cebu Technological University – Barili Campus, Barili, 6306 Cebu, Philippines
[6] Food Science, Agribusiness, and Development Communication, Cebu Technological University – Barili Campus, Barili, 6306 Cebu, Philippines
* Correspondence: norieljaymagsayo@gmail.com

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Abstract: Root growth and development are critical in determining corn yield, with nutrient and energy demands at a higher level during flag leaf stage. To simulate common abiotic stresses, an experiment was conducted under alkaline and drought conditions, which often limit root and shoot growth, nutrient uptake, and productivity. A randomized complete block design was used to evaluate the relationship between root length, root diameter, shoot growth, and yield components at the flag leaf stage. The results showed that grain yield had no relationship with shoot development but showed a strong positive correlation with nodal root length and diameter. Ear height (EH), ear weight (EW), unshelled weight (UW), shelled weight (SW), ear length (ER), and computed yield (CY) are strongly correlated with root length at r = 0.741, r = 0.578, r = 0.591, r = 0.869, and r = 0.874, respectively. Moreover, ear height, ear weight, unshelled weight, shelled weight, ear length, and computed yield are strongly correlated positively with the root length at r = 0.725, r = 0.831, and r = 0.822, r = 0.625, r = 0.408, and r = 0.622, respectively. These results indicate that nodal root length and thickness at the flag leaf stage are major determinants of eventual corn yield. The study emphasizes the importance of improved management practices to enhance root and shoot development during the flag leaf stage. It further suggests that breeding programs should focus on nodal root length and diameter, particularly under alkaline soil and drought conditions.

Keywords: Root length; root diameter; stress; correlation; nodal root

1. Introduction

Corn is one of the most widely grown crops worldwide. Drought stress is one of the environmental factors that highly affects its productivity [1]. Similarly, for drought-tolerant corn breeding efforts in areas with limited water on alkaline soils, the link between root features and yield-related traits is also crucial. Several research articles have investigated the effects of drought on a range of plant physiological processes, such as root development [2]. The experiment was conducted in Barili, Cebu, where the soil is naturally alkaline and recent climatic conditions have resulted in prolonged drought periods. Measuring corn under these combined stress factors was necessary to simulate the actual field environment that local farmers face. Improving corn yields is a formidable challenge facing local farmers in Cebu, Philippines, which is characterized by alkaline soils and frequent droughts. Although geneticists and breeders have made significant advances in creating root traits that improve productivity in drought conditions, a deeper understanding of the correlation between whole-plant traits and root functional traits is necessary to enhance crop performance in these environments further [3]. Some root traits have been shown to enhance the potential for productivity among plants under drought stress, such as those that involve the formation of highly dense, densely branched root structures that effectively capture moisture supplies deep in soils [2,3]. Notably, studies have shown that improved drought tolerance is often correlated with increased root length, characterized by more branching with smaller diameters, higher specific root lengths, and higher root densities in various crop species, particularly in the deeper parts of the soil profile [3,4]. It is the most important factor allowing root access to subsurface water reserves that may persist into the critical reproductive and grain-filling stages. It has been identified as a key factor for plants to maintain optimal metabolic processes under conditions characterized by late-season water shortages.

Interestingly, previous studies suggest that water stress may not significantly impact the development of corn roots. In some instances, drought stress can even promote better root growth and extension [2, 5]. Physiologically, drought-tolerant genotypes often exhibit enhanced resilience by accumulating osmoregulatory molecules, such as proline and amino acids, which reduce cellular osmotic potential and maintain water absorption and cell turgor pressure under stress [6]. Improving water-use efficiency is critical in arid and semi-arid regions, where water scarcity limits crop yields. Therefore, drought tolerance should be a target for improvement under certain changing environmental conditions. This study aims to investigate the relationship between root length, root diameter, and shoot development at the flag leaf stage and important yield parameters in corn grown in alkaline soil under drought conditions, highlighting the key root traits that can be used to improve production and enhance corn's ability to withstand these stress conditions.

2. Materials and Methods

2.1 Preparation of Experimental Area

The research was conducted at the experimental and production farm of Cebu Technological University - Barili Campus (10°7'53" N, 123°32'45" E), covering a study area of 100 square meters. In terms of chemical characteristics, the soils have an alkaline pH of more than 7.5 [7]. The experimental area was plowed twice to improve soil aeration and drainage. The study utilized five top-performing varieties in alkaline soil, each replicated four times, resulting in a total of 20 experimental blocks. The plots were divided into furrows spaced 75 cm apart. Each treatment plot measured 5 meters in length, with a one-meter space allocated between blocks to facilitate data collection and regular inspection.

2.2 Climatic Conditions

The research was conducted from February to June 2024. Cebu, Philippines, was warm and humid during the period. Temperatures in March ranged from 25°C to 31°C, accompanied by moderate rainfall of approximately 103 mm over 8 days. In April, temperatures were slightly higher at 32°C, but rainfall was lower at approximately 81 mm over 7 days. May recorded the highest temperature at 33°C, but had more rainfall, with intervals of 127-147 mm within 8 to 9 days [8]. This study, however, coincides with a dry season due to the El Niño phenomenon [9]. Below-average precipitation has been documented, especially in April, when drought conditions prevailed [10].

2.3 Seed Preparation, Field Planting, and Experimental Design

Corn seeds were soaked in coconut water for twenty-four (24) hours to improve the germination rate and sown directly with two seeds per hill. The spacing between rows was 75 cm for all treatments, with 25 cm spacing between planting hills. This planting arrangement ensured proper spacing for each crop, allowing for accurate comparison across treatments. The field experiment was laid out in a

Randomized Complete Block Design (RCBD) having five treatments, which were hybrid and conventional corn varieties, with ten (10) samples per treatment, replicated four times with a spacing of 0.25m between hills and 0.75m between rows. The following were the treatments: T1 = WPS327, T2 = TCT1868, T3 = SAPT84HY, T4 = M22B-01, and T5 = GSI130YR.

2.4 Fertilization

To ensure soil productivity, 7 bags of organic fertilizer were applied as a basal application across the entire field, resulting in a fertilization rate of 17.5 tons/ha. The fertilization application rate was also given. There was a split application of NPK fertilizers, in particular, nitrogen (46-0-0), phosphorus (16-20-0), and potassium (0-0-60). The first application of nitrogen was made at 15 days after planting, followed by the second application of the mixture of nitrogen and potassium at 30 days after planting, while the third application of the combination of the three fertilizers was carried out at 45 days after planting. These applications of fertilizers helped provide steady nutrients for the crop throughout its sensitive growth periods, resulting in higher corn yields.

2.5 Thinning and Weeding

To ensure adequate spacing of the corn plants, thinning to one seedling per hill was done 14 days after sowing for all corn varieties. Followed by uniform hand weeding across all rows in each replication to manage weed pressure. Additionally, hill up was carried out 14 days after crop emergence to increase drainage, proper root aeration, and suppress weed growth. These crop management practices optimized root growth development by providing better soil stability, allowing each corn plant to absorb necessary nutrients and sunlight.

2.6 Water and Pest Management

Considering the lack of rainfall due to drought conditions during the vegetative stage, watering was done three times a week to maintain the soil moisture needed by the corn plants. Fall armyworms (FAW) and Asiatic corn borers (ACB) were observed, and synthetic insecticides were used during severe infestation.

2.7 Data Gathered

2.7.1 Agronomic Characteristics of Corn

Plant height (cm) was measured from the base of the plant to the base of the tassel using a measuring tape. Days to silking were determined by counting the number of days from planting to silk emergence. Root length (cm) was measured by measuring the length of the nodal root of the corn plant at the flag leaf stage using a ruler. Root diameter (mm) was determined by measuring the width of the nodal root at the flag leaf stage using a caliper. Ear height (cm) was measured at the maturity stage, from the ground to the base of the ear. Average ear weight (kg) was recorded by dividing the total weight of sample ears with husks by the number of samples using a digital weighing scale. Average ear length (cm) was measured by dividing the total length of the sample ears without husks by the number of samples using a tape measure. Shelled weight (g) was determined by shelling and weighing sample ears by the number of samples per treatment using a digital weighing scale. The average weight of unshelled ears (g) was determined by weighing all sample ears without husks and dividing by the total sample ears per treatment. Computed yield (kg). The total yield with 15% moisture content was computed using this formula:

$$Grain\ Yield\ (t/ha) = \frac{SW(g)\ x\ 55{,}000\ x\ (100 - MC)}{(100 - 18) x\ (1{,}000{,}000)}$$

Where:

SW = shelled weight (g)
55,000 = assumed plant population per hectare (constant)
MC = actual harvest moisture
15 = standard moisture basis used
1,000,000 = conversion factor from grams to metric tons

2.7.2 Chemical Composition of Corn

Total Soluble Solid (TSS). Twenty grams of kernels were blended and homogenized with 100 mL of distilled water to make corn juice. TSS in Brix was measured using a handheld refractometer (model HI-96801, Hanna Instruments Ltd., USA), calibrated with distilled water by placing 1-3 drops of juice on the instrument's prism and taking the reading. Titratable Acidity (%). Five milliliters (5 mL) of corn juice was taken and diluted with 45 mL of distilled water. The 50 mL extract (aliquot) was measured and transferred into an Erlenmeyer flask, to which two drops of 1% phenolphthalein indicator were added. This was then titrated with 0.1% NaOH until a pink color was achieved, using a Cordial 1642TF Glass burette, and the volume of NaOH was recorded. Titratable acidity was expressed as percent lactic acid equivalent, since lactic acid is the predominant organic acid in corn. TA was calculated using this formula.

$$TA\ (\%\ lactic\ acid) = \frac{V\ x\ N\ x\ 0.09}{Sample\ weight\ (g)}\ x\ 100$$

Where:

- V = volume of NaOH used in titration (mL)
- N = normality of NaOH (0.1 N)
- Milliequivalent weight of lactic acid = 0.09 (g/meq.)
- Sample weight (g) = weight/volume of extracted juice used in titration.

2.8 Data Analysis

This study performed a linear correlation analysis to evaluate the relationship between corn's root, shoot, and yield parameters. The Pearson correlation coefficient (r) was calculated to determine the strength and direction of the linear relationship between these variables using SPSS.

Table 1. Pearson correlation coefficient interpretation.

r	Interpretation
> 0.70	Very strong positive correlation
0.40 to 0.69	Strong positive correlation
0.30 to 0.39	Moderate positive correlation
0.20 to 0.29	Weak positive correlation
0.01 to 0.19	No relationship
-0.01 to -0.19	No relationship
-0.20 to -0.29	Weak negative correlation
-0.30 to -0.39	Moderate negative correlation
-0.40 to -0.69	Strong negative correlation
<-0.70	Very strong negative correlation

3. Results and Discussion

3.1 Relationship between Nodal root length at flag leaf stage and Yield components of corn

The relationship between the nodal root length during the flag leaf stage and various yield components of corn was assessed to understand the influence of root architecture on corn performance under drought and alkaline conditions. The primary functional roots during the flag leaf stage are nodal roots, which are known to be essential for nutrition uptake, hydraulic support, and soil exploration [11]. The analysis revealed varying degrees of correlation between nodal root length, days to silking, ear height, ear weight, unshelled and shelled weight, ear length, total soluble solids (TSS), Titratable acidity (TA), and computed yield per hectare. Figure 1b illustrates a strong negative correlation between nodal root length and days to silking (r = -0.505). This suggests that an increase in nodal root length may be associated with marginally earlier reproductive development, potentially due to enhanced early-stage water absorption. This result is consistent with Chaudhary [12], who reported that corn genotypes with deeper rooting systems exhibited shorter flowering times under saline stress. Similarly, Ju [13] demonstrated genetic linkages between root traits and phenology, indicating that enhanced root length contributes to reduced anthesis–silking interval (ASI), a well-known indicator of stress tolerance. Conversely, Figure 1g illustrates a moderate positive correlation between nodal root length and total soluble solids (TSS) with a correlation coefficient of r = 0.392. This suggests that corn with longer roots tends to have a higher soluble sugar content in its kernels. Longer root systems likely enhance nutrient and water uptake, which sustains photosynthetic activity and carbohydrate allocation to developing ears. This explains the positive but moderate relationship observed here. Similar findings were reported by Li [14], who showed that root length density correlated positively with sugar accumulation and yield under mulching conditions. However, compared with stronger correlations between nodal root length and physical traits such as ear height and grain weight, the relationship with TSS is weaker. This is consistent with the notion that sugar metabolism is influenced by multiple physiological pathways, not solely by root architecture. Wang [15] found that while crown root traits in corn influenced carbohydrate allocation, kernel sugar content was strongly affected by genotypic differences in starch biosynthesis pathways.

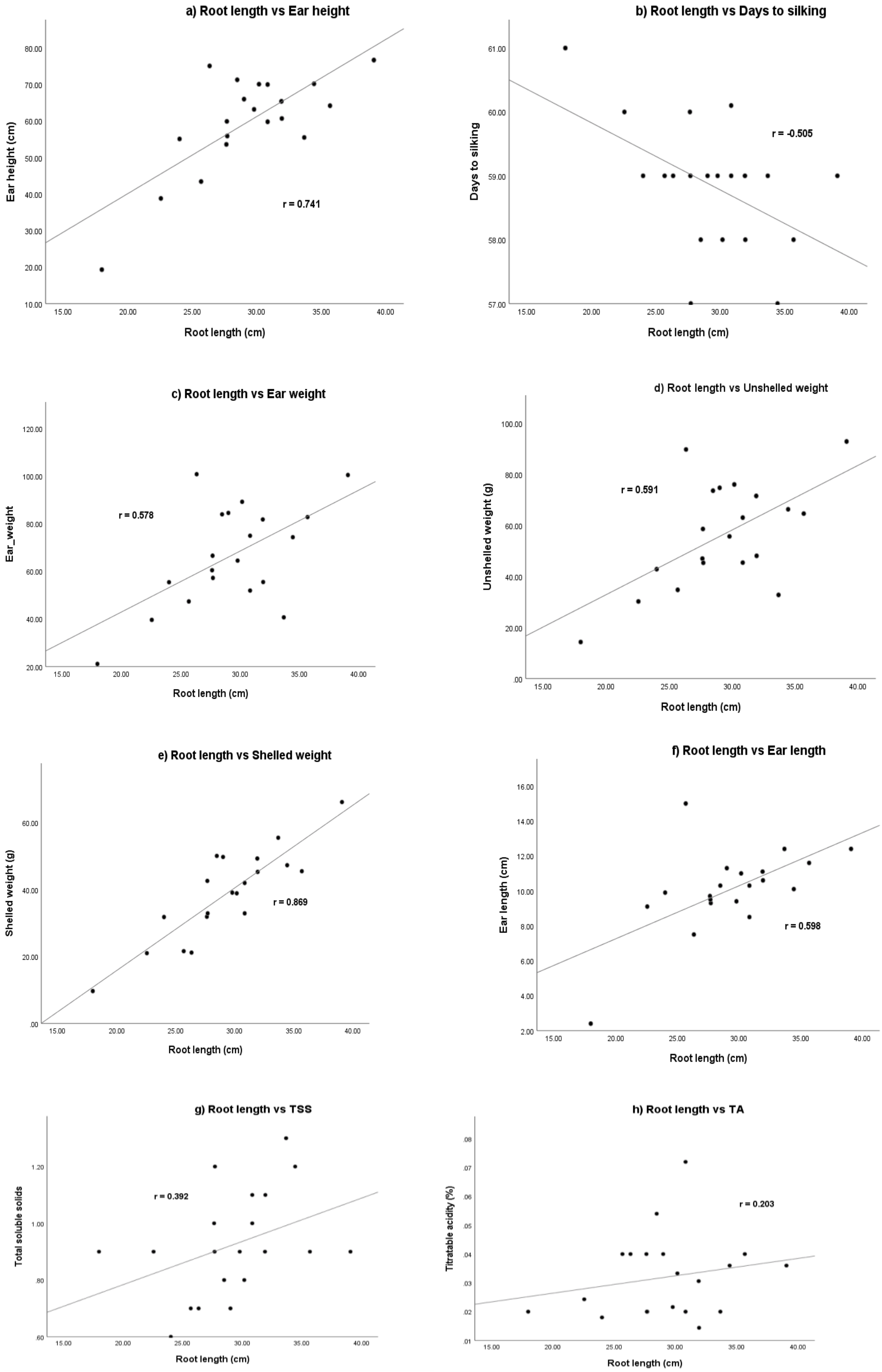
On the other hand, Figure 1h shows a weak positive correlation between nodal root length and titratable acidity (TA) with a correlation coefficient of r = 0.203. Suggesting that the relationship between root system development and kernel acidity is minor. Unlike yield-related traits, which strongly depend on root capacity for water and nutrient uptake, organic acid levels are more tightly regulated by genotype-specific biochemical processes and environmental factors such as light intensity, temperature, and post-harvest respiration [16]. A similar conclusion was drawn by Silva [17], who found that root traits and biochemical grain quality traits were weak compared to those with yield attributes. Notably, figures 1c, 1d, and 1f show a strong positive association. Ear weight, unshelled weight, and ear length are strongly correlated with the nodal root length at r = 0.578, r = 0.591, and r = 0.598, respectively. These relationships indicate that as the root system becomes longer, corn plants tend to produce larger and heavier ears. Longer root systems improved nutrient uptake and enhanced water availability, all of which contribute to kernel initiation and filling. A longer ear indicates improved sink capacity, while higher ear and unshelled weights suggest greater biomass partitioning into reproductive structures. These findings are consistent with the work of Silva and Nzuve [17,18] who showed that root vigor contributed significantly to ear development and grain filling under field and low-input conditions. Additionally, Figures 1a, 1e, and 1i revealed a very strong positive correlation between nodal root length and three key agronomic traits of corn: ear height (r = 0.741), shelled weight (r = 0.869), and computed yield (r = 0.874). These results indicate a robust association between underground and aboveground growth, where deeper root systems strongly support higher ear development and eventual yield performance. Higher ear placement tends to exhibit greater vigor and biomass accumulation, longer roots provide greater access to deep soil nitrogen and water, which are critical for maximizing kernel set and grain weight. Root system architecture plays a significant role in drought avoidance, nutrient acquisition, and photosynthate partitioning, all of which translate into higher yields [12, 17]. Ju [13] demonstrated that QTLs for root length often co-localized with yield-related QTLs, providing genomic evidence for these strong relationships. However, as ear height is also strongly correlated with nodal root length, care must be taken to avoid excessively tall plants that may increase the risk of lodging under high-density planting conditions.

3.2 Relationship between Nodal root diameter at flag leaf stage and yield components of corn

The correlations observed between nodal root diameter and key phenological and yield performance of corn reveal the significance of root morphology in regulating corn performance in alkaline and drought stress conditions. Figure 2g shows no relationship between nodal root diameter and total soluble solids. Nodal root diameter is primarily a structural trait that provides anchorage and lodging resistance, but it does not significantly improve nutrient acquisition [19]. Additionally, a strong negative correlation was observed in Figure 2 B between nodal root length and days to silking, with a correlation coefficient of r = -0.493. This indicates that corn plants with thicker nodal roots tend to silk earlier than those with thinner nodal roots. Thicker nodal roots improve a plant's hydraulic conductivity, enabling more efficient uptake and transport of water and nutrients [20]. Early silking is particularly advantageous under drought, as it reduces the anthesis-silking interval (ASI) and improves the likelihood of successful fertilization [21]. On the other hand, a moderate positive correlation was found between nodal root diameter and titratable acidity at Figure 2h with r = 0.363. This indicates that corn plants with thicker nodal roots tend to have kernels with slightly higher organic acid content. Thicker nodal roots with higher nutrient transport capacity, particularly for nitrogen and minerals such as potassium and magnesium [20]. These nutrients are closely involved in organic acid metabolism within kernels, including the citric acid and lactic acid pathways that determine TA [16]. By contrast, correlation of titratable acidity (TA) with nodal root diameter is generally weaker than that with yield-related parameters, as TA is more strongly determined by genotype-specific biochemical pathways and post-harvest physiological processes [17]. The moderate relationship observed suggests that nodal root diameter plays only an indirect role in modulating grain acidity. Additionally, figures 2e, 2f, and 2i showed a strong positive correlation between shelled weight, ear length, and computed yield with nodal root diameter at $r = 0.625$, $r = 0.408$, and $r = 0.622$, respectively. Suggesting that corn plants with thicker nodal roots tend to develop heavier shelled grain, longer ears, and eventual yield. This is due to the improved water and nutrient transport efficiency in thicker nodal roots, which supports ear elongation and kernel set [13, 20]. These strong correlations highlight nodal root diameter as a valuable indirect selection of traits for yield improvement. Moreover, figures 2a, 2c, and 2d showed a very strong positive relationship between nodal root diameter and ear height ($r = 0.725$), ear weight ($r = 0.831$), and unshelled weight ($r = 0.822$). These results indicate that plants with thicker nodal roots consistently produced taller shoots and larger, heavier ears. Similar findings were reported by Silva[17], who found that root structural traits made strong contributions to ear development and yield. The strong correlations confirm that nodal root diameter is a valuable indirect selection trait for yield improvement. In breeding programs, selecting for thicker nodal roots could simultaneously enhance plant vigor, ear size, and yield stability, particularly under stress conditions where efficient resource use and strong anchorage are essential.

3.3 Relationship between Plant height at flag leaf stage and yield components of corn

Plant height is a crucial agronomic trait in corn, often associated with vigor and yield potential. Taller plants generally capture more light and produce larger ears, although excessive height can increase the risk of lodging. Figures 3b and 3g showed weak negative correlations between plant height and days to silking (r =- 0.298) and total soluble solids (TSS) (r =- 0.258), respectively. Indicating that taller corn plants tend to flower slightly earlier and may allocate more assimilates to vegetative biomass rather than soluble sugar accumulation in kernels. This is consistent with earlier reports that kernel quality traits are less strongly associated with corn plant stature than yield-related parameters [17]. Early silking in taller plants may reflect more efficient growth and faster transition to reproductive development [21]. Figures 3e, 3f, and 3i showed that plant height has no relationship with shelled weight, ear length, and computed yield. This suggests that, unlike root traits, plant height is not a reliable predictor of ear size or grain yield, as kernel development and yield are more strongly controlled by root efficiency, source-sink balance, and genetic regulation of reproductive traits [17,18]. Additionally, a weak positive correlation was observed in Figure 3h between plant height and titratable acidity (TA). This relationship suggests that vegetative vigor may have a minor influence on organic acid accumulation, potentially due to increased photosynthetic activity and metabolic flux in taller plants. Similar findings have been reported in tomato by Kumar [22], where plant height was weakly associated with fruit quality traits, including titratable acidity. On the other hand, strong positive correlations were observed in Figures 3a, 3c, and 3d between plant height and key yield-related traits in corn, including ear height ($r = 0.586$), ear weight ($r = 0.692$), and unshelled weight ($r = 0.687$). These findings suggest that taller plants tend to exhibit greater ear development and higher biomass accumulation, supporting their positive contribution to overall yield performance. Taller plants generally exhibit greater vegetative vigor, with increased leaf area and photosynthetic capacity that enhance the supply of assimilates to reproductive organs. This results in higher ear placement and a larger ear mass. Similar findings were reported by Samskriti [23], who found that plant height was strongly associated with ear height and grain yield in promising hybrids. Mallhi [24] likewise observed that plant height enhanced ear height and ear size. Under drought stress, Tasnim [25] confirmed that plant height positively correlated with ear length, indicating its stability as a vigor trait across environments. Nutrient management further reinforces this relationship. Liu [26] demonstrated that plant and ear height were strongly correlated with yield under organic and inorganic fertilizer regimes. Similarly, Ayad [27] reported significant positive associations between plant height and ear weight across environments, showing that shoot vigor and reproductive sink capacity are closely linked. These results confirm that plant height can serve as an indirect indicator of ear development, particularly in genotypes where increased vegetative vigor translates into larger ears and greater ear size and weight.


a) Root length vs Ear height
Ear height (cm)
Root length (cm)
r = 0.741
b) Root length vs Days to silking
Days to silking
Root length (cm)
r = -0.505
c) Root length vs Ear weight
Ear_weight
Root length (cm)
r = 0.578
d) Root length vs Unshelled weight
Unshelled weight (g)
Root length (cm)
r = 0.591
e) Root length vs Shelled weight
Shelled weight (g)
Root length (cm)
r = 0.869
f) Root length vs Ear length
Ear length (cm)
Root length (cm)
r = 0.598
g) Root length vs TSS
Total soluble solids
Root length (cm)
r = 0.392
h) Root length vs TA
Titratable acidity (%)
Root length (cm)
r = 0.203

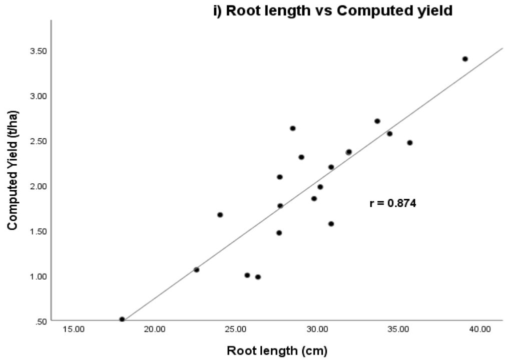
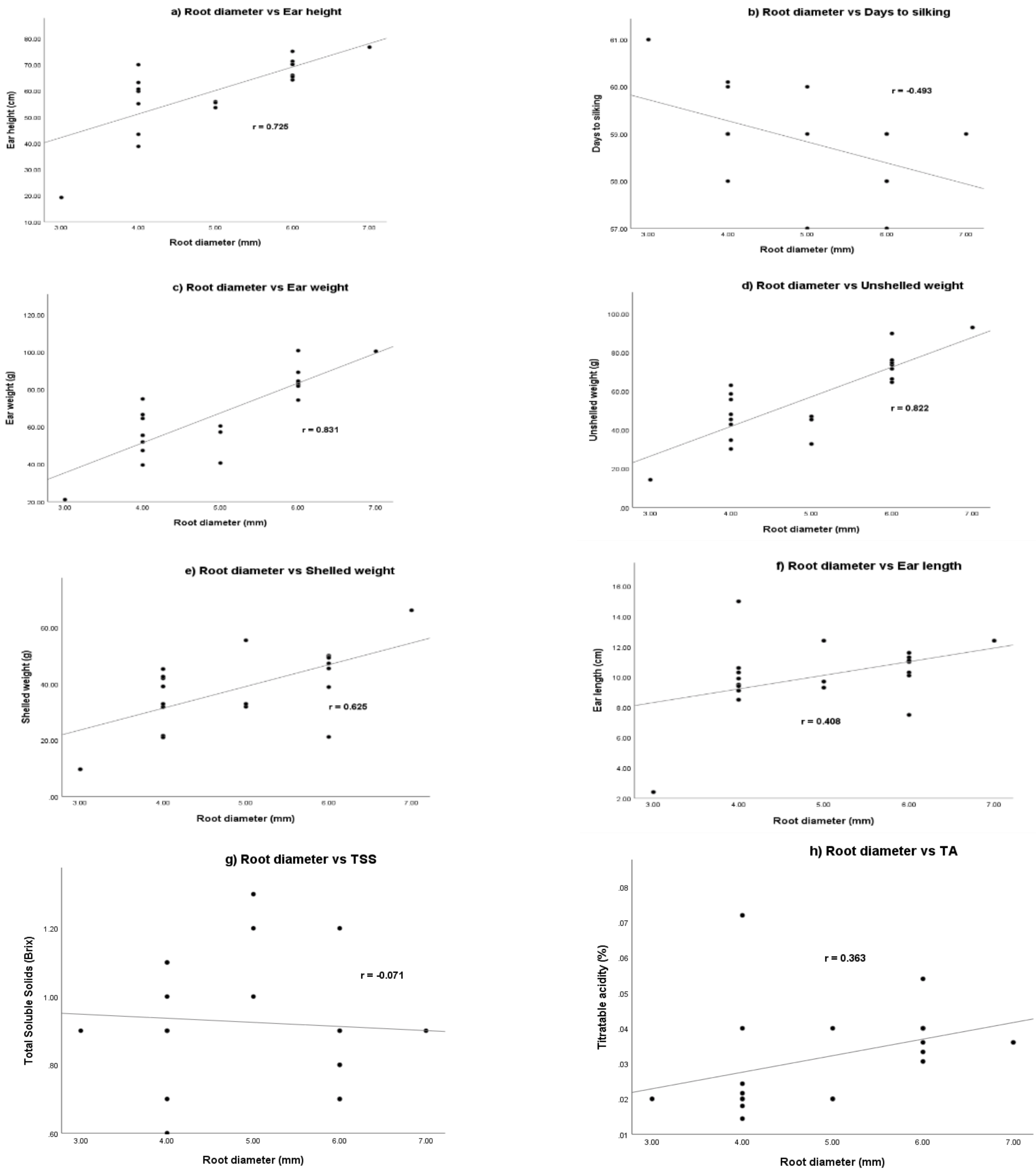


Figure 1. Relationship between Nodal root length and Yield parameters of corn



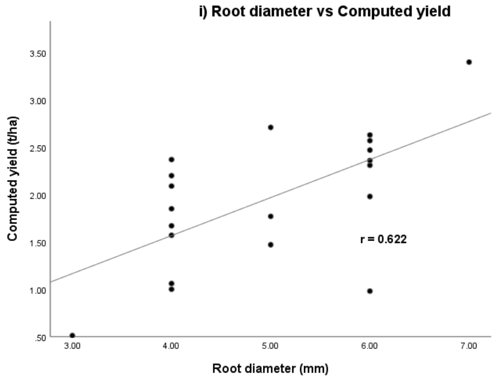
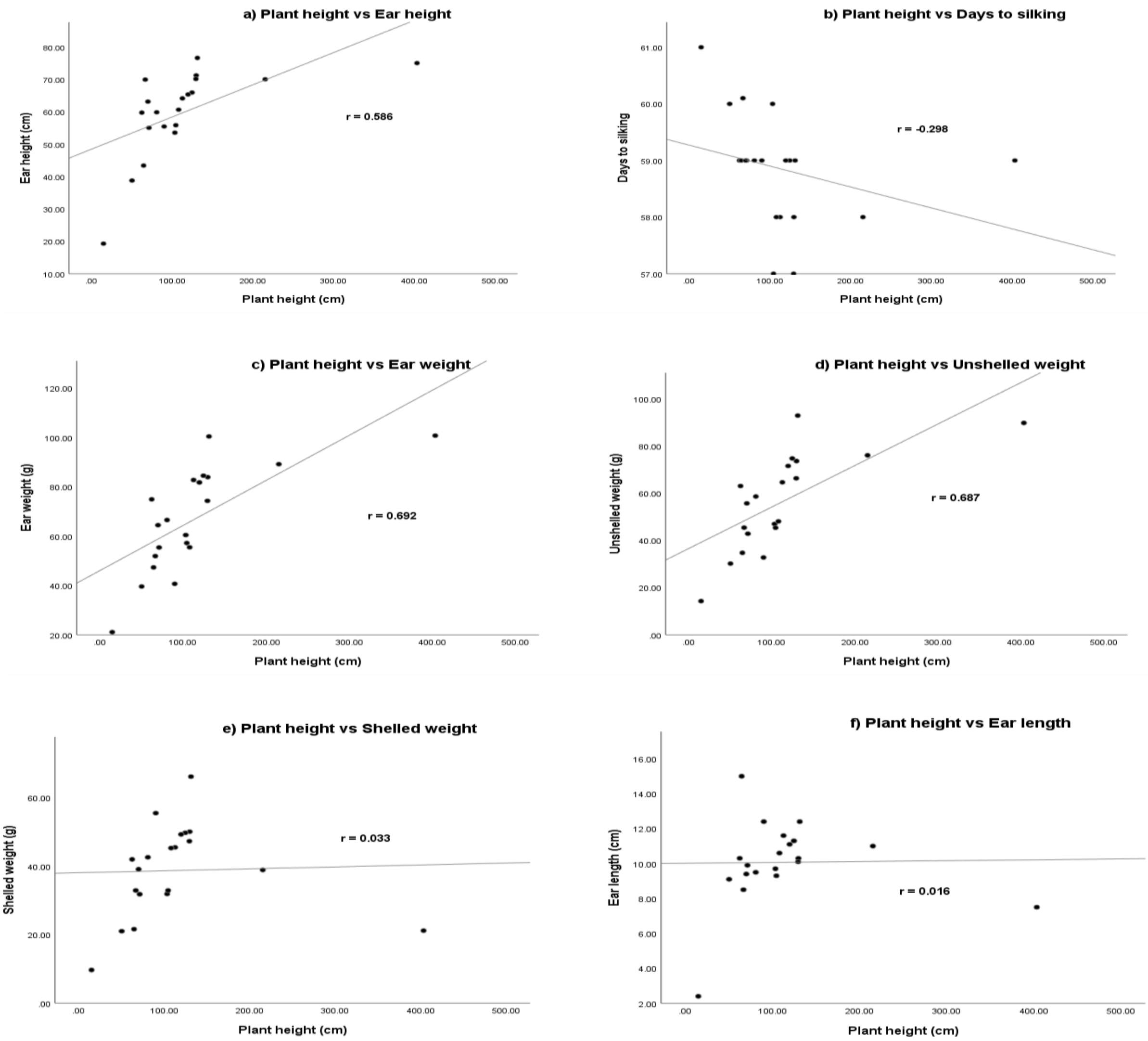


Figure 2. Relationship between Nodal root diameter and Yield parameters of corn



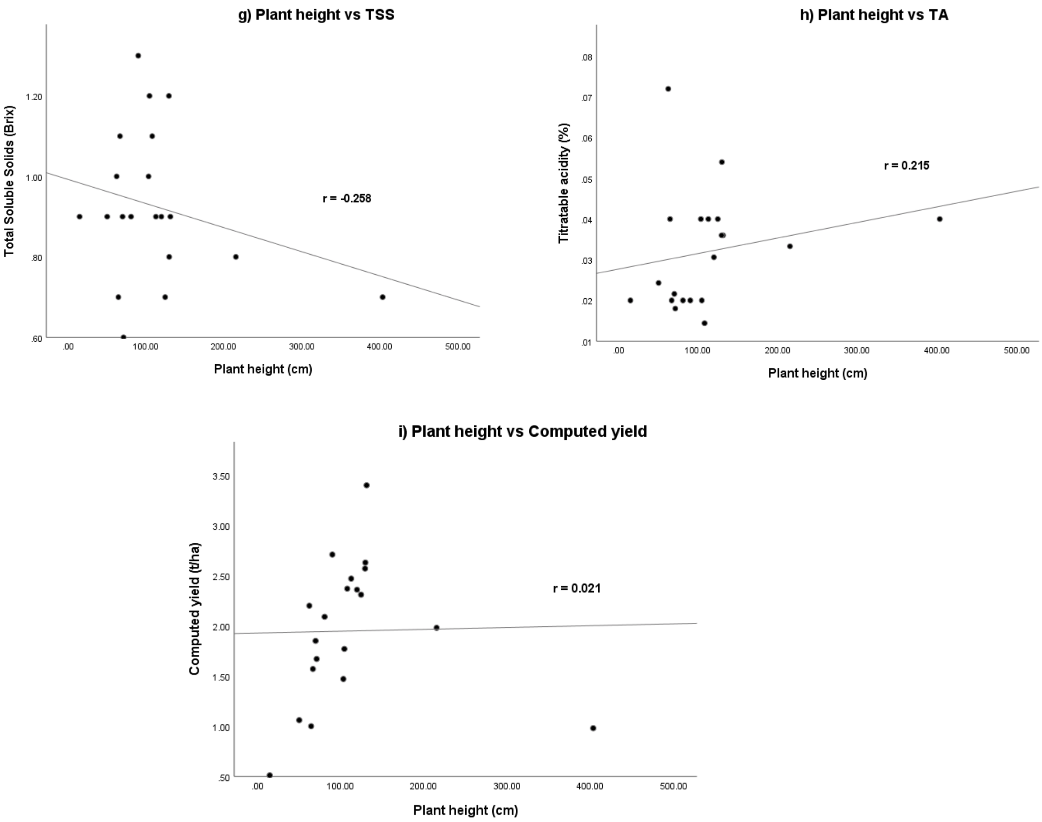


Figure 3. Relationship between plant height and yield and yield components

4. Conclusions

These collective findings highlight the crucial role of root traits and shoot development, specifically nodal root length and diameter at the flag leaf stage, in influencing various yield-related parameters in corn plants grown under alkaline and drought conditions. The correlations observed in the study, ranging from moderate to strong, highlight the complex interplay between root morphology, plant development, and yield potential. However, while beneficial for productivity, excessive height may increase susceptibility to lodging, suggesting that breeders should aim for balanced plant structure, combining moderate height with strong stalks and robust root systems

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