# Correlation and Path Analysis Studies of Stalk Lodging Resistance, Grain Yield and Related Agronomic Traits in Different Maize Varieties

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## Abstract

*Twelve maize varieties of different years of release were grown at Bako in a plot size of 15.3 $m^2$ using the RCBD design under rain fed condition at Bako. The objectives were to assess the degree of variation of maize genotypes for stalk lodging resistance and to estimate correlation among stalk lodging, grain yield, and yield related traits. There were significant differences among genotypes for stalk lodging (P<0.01). Even though there were significant difference (P<0.01) for grain yield among genotypes most of the genotypes performed below their potential, except BH-541 due to the late onset of rainfall and terminal drought stress, which disfavours the full expression of genetic potential. A relatively high value of phenotypic coefficients of variation was observed for stalk water content, grain moister content, ear height, and stalk lodging percentage. The correlation values though high, were non-significant for most of genotypes due to the small number of experimental material tested. The dependent characters yield and stalk lodging correlated negatively at phenotypic and environmental level. Both grain yield and stalk lodging showed positive direct effect with grain moisture content (1.3817, 1.7844), ear height (6.9566, 8.9841), major stalk diameter (0.4912, 0.6344), minor stalk diameter (0.0912, 0.1178), ear length (0.4152, 0.5362) and stalk water content (0.4386, 0.5664) at phenotypic level. Correlations of grain yield with major stalk diameter (rp=0.7056) and with ear length (rp=0.5999) was positive and in a desirable direction, while Correlations of stalk lodging with major stalk diameter (rp=-0.3713) and with ear length (rp=-0.4332) was negative and in a desirable direction, so improving these traits directly improved grain yield and decrease stalk lodging but restricted simultaneous selection of other indirect traits would be important especially when we practice direct selection through major stalk diameter and ear length; hence, the positive contributor traits grain moister content, ear height, minor stalk diameter, stalk water content ignored while plant height, ear height to plant height ratio should be considered. Among the genotypes, BH-541 was found to be ideal since it has the highest values for both major stalk diameter and ear length.*

**Keywords:** Maize, Stalk lodging, Correlation, Path analysis, Yield

# Introduction

Maize (*Zea mays* L.) is one of the most important cereal crops in terms of production and productivity in Ethiopia. It stands first in total production and productivity and, second in area coverage (20.27%) next to tef [*Eragrostis tef* (Zucc) Trotter] (30.66%) of all cereal crops cultivated in Ethiopia (Mosisa et al., 2012; FAOSTAT, 2015). Ethiopia currently produces more maize than any other crop (Abate *et al.,* 2015; FAOSTAT, 2015). It grows on 2.1 million hectares of land with total production of 7.2 million tonnes annually with the national average productivity of 3.42 tonnes per hectare (CSA, 2015). Increased yields are in part due to improved agronomic practices and increased inputs, but increased yields could not have been realized without genetic improvements (Abate et al., 2015). However, the current national productivity average per hectare (3.42 tons ha-1) (FAOSTAT, 2015), is considerably low as compared to developed countries.

Tesfa *et al.*, 2004, summarized the predominant abiotic stress; drought, nutrient deficiencies and lodging are the major abiotic constraints that limit maize productivity in Ethiopia. The complex interrelationships of several factors affecting stalk lodging include stalk rot, other diseases, yield level, cultural practices, maturity, weather, nutrient balance and insects. These factors have made the stalk-lodging problem an endless task to the maize breeders (Zuber and Loesch, 1962). High yielding cultivars, increased plant densities, and improvement in soil fertility are generally accepted to have also contributed to increased stalk lodging (Sherry et al., 2003). Direct selection for stalk lodging resistance, while sometimes effective (Thompson, 1982; Albrecht and Dudley, 1987), can be unreliable because of dependency on environmental conditions that allow differentiation among genotypes. Stalk strength, which has high heritability and is controlled by additive gene action, has been proposed as an indirect means of selection because it is correlated with stalk resistance (Thompson, 1963; Sleper and Russell, 1970; Arnoled and Josephson, 1975).

Direct selection for yield is often deceptive as it is highly influenced by fluctuating environmental components (Talebi *et al*., 2007). The maize yield character is influenced by several genes which also interact with various environmental conditions (Bocanski et al., 2009). This is because a genotype could be selected based on the phenotype given that the environmental effect is separated from the total variability (Bello et al., 2012). The phenotypic variance explicates the total variance among phenotypes tested in different environments of interest to the plant breeder while the total genotypic variance explains the portion of phenotypic variance attributable to the failure of homogeneity among genotypes in different environments (Sujiprihati et al., 2003).

Correlation studies provide better understanding of yield component which helps the plant breeder during selection (Robinson *et al*., 1951 and Johnson *et al*., 1955). The coefficient of correlations helps to measure the level of relationships between the traits and establish the level at which these traits are mutually different (Bocanski et al., 2009; Nagabhushan *et al*., 2011). By utilizing genetic correlations between traits, secondary traits can be used to improve primary ones that have low heritability or are difficult to measure (Malosetti *et al*., 2008). The correlations also give reliable and useful information on nature, extent and direction of selection (Zeeshan et al., 2013). The correlation coefficient analysis is useful in the selection of several traits simultaneously influencing yield (Menkir, 2008). The appropriate knowledge of such interrelationships between grain yield and its contributing components can significantly improve the efficiency of breeding programmes using appropriate selection indices (Mohammadia *et al*., 2003).

In Ethiopia, the information on lodging and related traits is lacking; hence, detailed knowledge of association of lodging with other traits is important in a maize improvement program, especially to set up selection criterion for lodging resistance without affecting the grain yield. Hence, the present study was initiated with the objectives to assess the degree of variation among maize genotypes for stalk lodging resistance and to estimate correlation among stalk lodging, grain yield and yield related traits. The knowledge obtained will be useful for developing novel breeding strategies to enhance maize resistance to stalk lodging thereby improving crop yield.

# Materials and Methods

## Description of Experimental Site

This study was conducted at Bako Agricultural Research Center located in East Wollega Zone of the Oromia Regional State, western Ethiopia at an altitude of 1650 meters above sea level (m.a.s.l). Bako lies at $9^0$6' north latitude and $37^0$09' east longitude in the sub-humid ecology of the country 260km west of Addis Ababa. Average annual rainfall at this location is 1237mm. The rainy season covers April to October and maximum rain is received in the months of July to August. The mean minimum, mean maximum and average air temperatures are $13.3^0$c, $27.9^0$c and $20.6^0$c, respectively. The mean soil temperature at 0, 5, 10, 20, 50, and 100cm depths are $25.4^0$c, $25.3^0$c, $23.8^0$c, $23.4^0$c, $23.2^0$c and $24.1^0$c, respectively. Sixty percent of the soil (1400 ha), in Bako Research center is reddish brown in color and clay and loam in texture (Wakene, 2001). According to USDA soil classification, the soil is alfisols developed from basaltic parent materials, and is deeply weathered, and slightly acidic in reaction (Wakene, 2001).

## Experimental Design, and Management

The experiment was arranged in randomized complete block design with 3 replications. The planting was made following the onset of rain. Each plot consisted of 4 rows, each 5.1m long and spaced 0.75m apart. A plot size was 15.3 $m^2$. The spacing between plants was 0.3 m, Fertilizers were applied at the rate of 69/92 Kg/ha $P_2O_5$ / N i.e 150 kg/ha DAP and 150 kg/ha urea. Nitrogen was applied in split (half at planting and the rest 37 days after emergence). In order to ensure a healthy crop, agronomic practices including weeding, hoeing, field pest control and other practices were done as per research recommendation. The central two rows were used for data collection.

## Experimental Materials

The experimental materials for this study consisted of 12 released maize varieties obtained from Bako Agricultural Research Centre and Alemaya University of which seven of them were hybrids and the rest were composites. Detailed description of the 12 varieties is given in Table 1.

**Table 1** Description of Experimental Materials

| Type | Variety | Year of release | Altitude (msl) | Rain fall (cm) | Plant Height (cm) | Days to maturity | Ear placement (cm) | Seed color | Yield(Kg/ha) | | Gray Leaf Spot | Turcicum Leaf Blight | Common Leaf Rust |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | on station | on farm | | | |
| Hybrid | BH-140 | 1996 | 1000-1800 | 1000-1200 | 240-255 | 145 | 105-120 | White | 80-90 | 47-60 | MT | MT | MT |
| | BH-530 | 1988 | 1000-1800 | 1000-1200 | 200-230 | 140 | 110-120 | White | 80-90 | 50-60 | MT | MT | MT |
| | BH 540 | 1995 | 1000-2000 | 1000-1200 | 230-260 | 145 | 110-120 | White | 80-100 | 50-65 | MT | MT | MT |
| | BH 541 | 2001 | 1000-1300 | 1000-1200 | 245-260 | 135-145 | 130-140 | White | 80 | 60-70 | MR | MR | MR |
| | BHQP 542 | 2001 | 1000-1300 | 1000-1200 | 220-250 | 135 -145 | 100-120 | White | 80 | 60-70 | MR | MR | MR |
| | BH 660 | 1993 | 1600-2200 | 1000-1500 | 255-290 | 160 | 145-165 | White | 90-120 | 60-80 | T | T | T |
| | BH-670 | 2001 | 1700-2400 | 1000-1500 | 260-295 | 165 | 150-160 | White | 91-120 | | | | |
| Composite | Alemaya composite | 1975 | 1600-2200 | 1000-1200 | 280-300 | 163 | 160-190 | White | 50-70 | 38-42 | T | T | T |
| | Gambela composite | 2001 | 500-1000 | 1000-1200 | 210-230 | 110 | 120-140 | White | 60-70 | 40-45 | MT | T | T |
| | Gibe composite1 | 2000 | Low to mid altitude | 1000-1700 | 240-260 | 145 | 130-140 | White | 60-70 | 40-45 | MT | T | T |
| | Kuleni | 1995 | 1700-2200 | 1000-1200 | 240-265 | 150 | 130-145 | White | 60-70 | 40-45 | T | T | T |
| | Rare-1 | 1997 | 1600-2200 | 900-1200 | 250-270 | 163 | 130-150 | White | 60-80 | 40-45 | T | T | T |

Source: (Mosisa *et al*., 2002), T=Tolerant MT= Moderately Tolerant MR= Moderately Resistant (Roelfs *et al.*, 1992)

## Data collection

Data were collected on: Plant height (cm), Ear height (cm), Ear height to plant height ratio, Internode length, Major stalk diameter (cm). Minor stalk diameter (cm), Ear length (cm), Ear diameter (cm),Stalk Lodging, Number of ears per plant, Stalk water content, Grain moisture content, Grain yield, Weather data and Disease record.

## Statistical Analysis

### Analysis of variance

The data for stalk lodging, rust, gray leaf spot and blight were transformed with the arc sin of the percentage data. The analysis of variance (ANOVA) for RCBD was conducted as suggested by Gomez and Gomez (1984). Regarding ANOVA models, all dependent variables and genotype were fixed effects while replications were considered random effect.

Phenotypic coefficients of variation (PCV) was calculated according to Burton and Devane (1953) as:

$PCV = \frac{\sqrt{\sigma^2_p}}{\bar{X}} X100$, Where $\sigma^2_p$ is the phenotypic standard devotion and $\bar{X}$ is the grand mean.

### Correlation coefficient

The analysis of phenotypic, genotypic and environmental correlations was computed using Spar software. The phenotypic and genotypic variation and coefficient of variation were calculated following the formulae suggested by Singh and Chaundhary (1979). Phenotypic, genotypic and environmental variances were computed from the respective mean squares as indicated below. Correlation coefficients between the parameters were calculated from the variance and covariance components using the formula;

$$r_{(xy)} = Cov_{(xy)} / \sqrt{\sigma^2_x \sigma^2_y}$$

Where:

r (x, y) is the phenotypic correlation between variables x and y.

Cov (x, y) is the genotypic or phenotypic covariances between the two variables, which are expressed by the formulae $Cov_{gxy} = (M_g - M_e)/r$

where:

$\sigma_x^2$ is the phenotypic variance of the variable x, and $\sigma_y^2$ is the phenotypic variance of the variance of the variable y.

### Path coefficient analysis

The analysis for path coefficient was done using Indostate software. Path coefficient analysis was carried out using phenotypic correlation values to determine the direct and indirect effects of the yield components and other morphological characters on seed yield per plot using the general formula of Dewey and Lu (1959).

$r_{ij} = P_{ij} + \sum r_{ik} P_{jk}$:

Where:

$r_{ij}$ is the mutual association between the independent character (i) and dependent character (j);

$P_{ij}$ is the direct effect of independent character (i) on the dependent variable (j); and

$\sum r_{ik} P_{jk}$ is summation of components of indirect effects of a given independent character (i) on a given dependent character (j) via other independent characters (k).

To determine $P_{ij}$ values, square matrices of phenotypic correlation coefficients between independent characters in all possible pairs were inverted and then multiplied by the correlation coefficient between the independent and dependent characters following complete descriptions of the method in Singh and Chaudhary (1979). Residual effects were estimated using the formula:

$$P_{R1}^{2} = 1 - \sum P_{yi} r_{yi}$$

Where, $P_{R11}^{2}$ is the residual effect and $p_{yi} r_{yi}$ is the product of direct effect of any variable and its correlation coefficient with the dependant character.

# Results and Discussions

## Analysis of variance

The results of analysis of variance for yield and yield related traits are presented in Table 2. Highly significant variations ($p \leq 0.01$) were observed among genotypes for all traits except for stalk lodging, internodes length, plant height and rust where the difference were significant at ($p \leq 0.05$). Non-significant variations were observed among the genotypes for number of ears per plant, gray leaf spot and blight. The significant differences recorded for the different traits among the genotypes studied implied that the maize genotypes included in this study had diverse genetic backgrounds. Our finding is in line with previous studies by vashistha *et al*., 2013 and Reddy *et al*., 2012.

**Table 2.** Mean squares of yield and yield related traits.

| Characters | Mean squares | | |
|---|---|---|---|
| | Replication (df=2) | Genotypes (df=11) | Error (df=22) |
| Plant height | 5546.528** | 1373.422* | 461.679 |
| Ear height | 3325.69** | 1368.876** | 257.513 |
| Ear height to plant height ratio | 0.006* | 0.007** | 0.001 |
| Internod length | 10.33** | 6.311* | 2.394 |
| Major stalk diameter | 0.069 | 0.087** | 0.024 |
| Minor stalk diameter | 0.003 | 0.038** | 0.007 |
| Ear length | 16.675** | 5.879** | 1.284 |
| Ear diameter | 0.098 | 0.105** | 0.032 |
| Stalk lodging | 17.400 | 36.65* | 16.120 |
| Number of ears per plant | 0.015 | 0.084$^{ns}$ | 0.054 |
| Stalk water content | 252.127 | 4501.74** | 212.192 |
| Grain moisture content | 1.890 | 21.82** | 3.080 |
| Adjusted yield | 508.126** | 464.303** | 73.970 |
| Leaf Blight | 2.8$^{ns}$ | 12.35$^{ns}$ | 6.8 |
| Leaf Rust | 25.9* | 17.1* | 5.7 |
| Gray leaf spot | 216.5** | 16.8$^{ns}$ | 16.1 |

** Significant at 0.01 level of probability, * significant at 0.05 level of probability, ns non-sign.

Mean value of the 17 characters were computed and presented in Table 3. Grain yield ranged from 32.49 qt/ha for Alemaya Composite to 80.59 qt/ha for BH-541. Plant height ranged from 206.67 cm for BHQP-542 and Gambela Composite to 271.67 cm for Alemaya Composite, while the highest ear height of 168.3 cm was recorded for BH-670 and the lowest 98.3 cm for BHQP-542. The ratio of ear height to plant height ranged from 0.47 for BHQP 542 to 0.58 for Alemaya composite. The highest internode length was recorded for Alemaya Composite and BH-541 20 and 20.3 cm respectively while the lowest 15.62 cm was recorded for BH-140. BH-541 has the highest major stalk diameter, (2.52 cm) and has one of highest minor stack diameter (1.97 cm) even though the highest minor stalk diameter was (2.18) for Kuleni. A wide variation was observed for ear length, which ranged from 12.54 for Gambela Composite to 17.44 cm for BH-541. BH-541 has also the highest ear diameter. Wide variations among the genotypes were observed for stalk water content, the highest was recorded for Gibe Composite (144.8 g/300g) and the lowest (43.85 g/300g) for BH-140.

The percentage of stalk lodging is greater than root lodging. The highest stalk lodging was recorded for BH-660 and Alemaya composite due to their long height and the lowest was recorded for BHQP-542. The highest root lodging was recorded for BH-540 and no root lodging were recorded for BHQP-542 perhaps due to the shortest plant height and ear height making it the least susceptible among the genotypes tested. Relatively high stalk lodging percentage was recorded for BH-660, Alemaya composite, Rara-1, BH-540, BH-670 Kuleni, Gambela composite, Gibe composite in their decreasing order. High stalk lodging percentage coupled with late onset and terminal drought stress contributed for the low yield of the genotypes. The disease intensity was low for the three diseases, namely, gray leaf spot, blight, and rust during 2003 growing season (Table 3). All genotypes had disease score of 3 or lower, which can be categorized as resistant to moderately resistant. The low disease incidence might be due to short rainy season, the resultant dry condition being not favourable for the development of pathogens.

Table 3. Mean values of the studied characters

| Genotype | Plant height (cm) | Ear height (cm) | Plant height to Ear height ratio | Internodes length (cm) | Major stalk diameter (cm) | Minor stalk diameter (cm) | Ear length (cm) | | |
|---|---|---|---|---|---|---|---|---|---|
| BH-660 | 266.67AB | 153.30ABC | 0.57BC | 17.30BC | 2.12BCD | 1.84BC | 15.59AB | | |
| BH-670 | 260.00ABC | 168.30A | 0.57A | 16.00C | 2.28ABC | 1.98B | 15.80AB | | |
| BH-540 | 220.00CD | 108.30DE | 0.49EF | 18.00ABC | 2.13BCD | 1.90B | 14.47BCD | | |
| BH-541 | 241.67ABCD | 138.30BCD | 0.57BC | 20.30A | 2.52A | 1.97B | 17.44A | | |
| BHQP-542 | 206.67D | 98.30E | 0.47F | 16.67C | 1.93D | 1.70C | 13.12CD | | |
| BH-530 | 238.30ABCD | 121.67DE | 0.51DEF | 17.00C | 2.25ABC | 1.96B | 16.31AB | | |
| BH-140 | 223.30CD | 121.67DE | 0.54BCDE | 15.67C | 2.21BCD | 1.93B | 16.48AB | | |
| Kuleni | 231.67ABCD | 131.67BCD | 0.57BCD | 16.67C | 2.40AB | 2.18A | 14.83BC | | |
| Gibe Composite-1 | 230.00BCD | 125.00CDE | 0.54BCDE | 17.30BC | 2.26ABC | 1.85B | 15.05BC | | |
| Gambela Composite | 206.67D | 108.30DE | 0.52CDEF | 16.30C | 1.94D | 1.89B | 12.54D | | |
| Alemaya Composite | 271.67A | 158.30AB | 0.58B | 20.00AB | 2.15BCD | 1.92B | 15.83AB | | |
| Rare-1 | 231.67ABCD | 125.00CDE | 0.53BCDE | 17.67ABC | 2.09CD | 1.99B | 14.36ACD | | |
| Grand mean | 235.69 | 129.86 | 0.55 | 17.40 | 2.19 | 1.93B | 15.15 | | |
| CV% | 9.12 | 12.36 | 6.93 | 8.88 | 7.07 | 4.34 | 7.48 | | |
| LSD (0.05) | 36.38 | 27.17 | 0.06 | 2.62 | 0.26 | 0.14 | 1.92 | | |
| BH-660 | 4.50ABC | 22.30A | 0.88 | 134.30A | 19.26A | 50.43BC | 37.14 | 39.2 | 43.1B |
| BH-670 | 4.43BC | 16.67AB | 0.84 | 77.00B | 17.73A | 50.71BC | 37.14 | 43.1 | 43.1B |
| BH-540 | 4.70AD | 16.90AB | 1.00 | 125.07A | 14.33BC | 58.81B | 39.15 | 39.2 | 43.1B |
| BH-541 | 4.79A | 8.83BC | 1.16 | 138.07A | 16.86AB | 80.59A | 39.14 | 39.2 | 41.2BC |
| BHQP-542 | 4.59AB | 6.87C | 1.00 | 49.10D | 10.56E | 47.74BCD | 37.14 | 43.1 | 45AB |
| BH-530 | 4.42BC | 9.60BC | 1.46 | 80.63B | 12.30CD | 59.77B | 41.1 | 43.1 | 48.8A |
| BH-140 | 4.50ABC | 10.80BC | 0.98 | 43.85D | 12.30CD | 52.94B | 37.23 | 41.2 | 46.9AB |
| Kuleni | 4.49ABC | 15.67AB | 1.02 | 51.00CD | 15.36ABC | 54.90B | 43.1 | 43.1 | 43.1B |
| Gibe composite-1 | 4.79A | 14.70B | 0.86 | 144.80A | 14.10BC | 46.60BCD | 37.14 | 41.2 | 45AB |
| Gambela composite | 4.49ABC | 14.70B | 1.07 | 75.50BC | 12.56CD | 35.50CD | 43.1 | 45 | 48.8A |
| Alemaya composite | 4.79A | 20.83A | 0.91 | 136.70A | 16.73AB | 32.49D | 41.1 | 39.2 | 45AB |
| Rare-1 | 4.18C | 18.50AB | 0.98 | 117.47A | 11.96D | 43.34BCD | 37.25 | 43.1 | 45AB |
| Grand mean | 4.56 | 18.53 | 1.01 | 97.79 | 14.50 | 51.16 | 39.13 | 41.64 | 44.8 |
| CV% | 3.91 | 18.60 | 22.86 | 14.90 | 12.10 | 16.81 | 10.26 | 6.27 | 5.3 |
| LSD (0.05) | 0.30 | 5.81 | 0.39 | 24.67 | 2.97 | 14.56 | 6.79 | 4.42 | 4.1 |

NB: CV%, LSD, gray leaf spot (%), blight (%), rust (%) are transformed values

## Association among morphological characters

### Phenotypic correlations

The correlation values though higher were non-significant for most of the trait combinations due to the size of material tested (Table 4). Grain yield manifested significant strong positive association with major stalk diameter (r=0.7056), ear length, (r=0.5991) but it showed a non-significant medium negative association with stalk lodging (r=-0.4995). A strong and negative correlation was observed between stem lodging and grain yield (Nzuve etal, 2014). Similar results have been reported in other studies (Djordjevic and Ivanovic, 1996). It also showed non-significant and positive association with internodes length (r=0.2583), minor stalk diameter (r=0.2402), ear diameter (0.1918) and weak and positive association with ear height to plant height ratio (r=0.0226) and stalk water content (0.0717) at phenotypic level. Whereas significant positive correlation of major and minor stalk diameter with grain yield results have been reported in other studies (Djordjevic and Ivanovic, 1996). According to Mandefro (1999), grain yield significantly associated with number of kernels per row, ear height, plant height, days to tasselling, silking and maturity. According to Blum (1988), significant strong and positive association between grain yield and major stalk diameter, grain yield and ear length provides an opportunity to improve grain yield simultaneously with major stalk diameter and ear length. Yield related traits, which have strong association with yield have been emphasized as a selection criterion to increase grain yield in crops.

Stalk Lodging manifested non-significant positive and medium association with grain moisture content (r=0.3477), but negative and medium association with major stalk diameter (r=-0.3713), ear length (r=-0.4332), ear diameter (r=-0.3304). It showed a non -significant weak positive association with plant height (r=0.1794), ear height (r=0.2161), ear height to plant height ratio (r=0.189) and stalk water content (r=0.2648) but it showed a non-significant negative and weak association with minor stalk diameter (r=0.0749) at phenotypic level. Similarly, it was reported that significant phenotypic associations was not observed between stalk lodging and other morphological plant traits namely plant height, ear height, stalk inter nod length, major and minor stalk diameter (Djordjevic and Ivanovic 1996). Inconsistent relationship between stalk lodging and plant height was also reported for r values ranged from ( -0.02 to -0.32) (Albrecht and Dudley 1987). The lack of association indicated that selection for morphological traits alone would not improve stalk quality; concluded that such findings, however, allow us to use morphological traits in breeding for adaptability to high plant density and intensive use of N fertilizers without significant changes in stalk

lodging resistance (Djordjevic and Ivanovic, 1996).
Grain moisture showed a strong significant positive association with plant height (r=0.8255) ear height (r=0.8537) and ear height to plant height ratio (r=0.7744). There was a negative and significant correlation between moisture content and ear and plant height, grain yield and field weight (Nzuve et al, 2014). Plant height showed a strong significant positive association with ear height (r=0.9417), ear height to plant height ratio (r=0.763). According to Mandefro (1999) plant height showed strong association with ear height, number of kernels per row and grain yield. Yield also showed a significant medium positive association with ear length (r=0.6182. Ear height showed significant positive and strong association with ear height to plant height ratio (r=0.9339), However, it showed significant medium and positive association with ear length (r=0.5809) so we can improve simultaneously ear height, ear height to plant height ratio and ear length. Internodes length showed a significant strong positive association with stalk water content (r=0.7421). Major stalk diameter manifested a significant strong positive association with ear length (r=0.788) and it showed a significant medium positive association with minor stalk diameter (r=0.6502) so we can improve major stalk diameter, ear length and minor stalk diameter simultaneously. An increase in those traits which show positive and significant correlations could lead to enhanced grain yield (Akinwale et al., 2011). Similar relationships have been reported in previous studies (Kabdal et al., 2003; Shakoor et al., 2007). On the other hand, low phenotypic correlation coefficients could arise due to the modifying effect of environment on the association character at genetic level (Alake et al., 2008).

## Environmental correlations

Environmental correlations indicate the magnitude of environmental effects on a pair of traits. Direct selection for yield is often deceptive as it is highly influenced by fluctuating environmental components (Talebi *et al*., 2007). The maize yield character is influenced by several genes which also interact with various environmental conditions (Bocanski et al., 2009). Grain yield manifested strong positive and significant association with plant height (r=0.5578) and ear height(r=0.4565) this indicates that any environment, which is favourable for grain yield, is also favourable for plant height and ear height. It showed non-significant positive association with ear height to plant height ratio, internod length, major and minor stalk diameter and ear length, however, it showed low negative association with stalk water content, stalk lodging percentage at environmental level (Table 5).

Stalk lodging percentage manifested a non-significant positive association with minor stalk diameter, ear length, and internode length but non-significant negative association with plant height, major stalk diameter and ear diameter at environmental level, such non-significant negative environmental correlations indicating that there was no environmental elements which favours stalk lodging and disfavours the other trait.

Plant height showed significant strong positive association with ear height (r= 0.8649) and inter node length (r=0.5515) such significant positive environmental correlations indicating that any environment which is favourable for plant height is also favourable for ear height and inter node length. Ear height showed significant positive association with ear height to plant height ratio (r=0.6885) and with inter node length (r=0.4912) such significant positive environmental correlations indicating that any environment which is favourable Ear height is also favourable for ear height to plant height ratio. Minor stalk diameter showed strong significant positive association with stalk lodging percentage at environmental level such significant positive environmental correlations indicating that any environment which is favourable Minor stalk diameter is also favourable for stalk lodging. Low phenotypic correlation coefficients could arise due to the modifying effect of environment on the association character at genetic level (Alake *et al*., 2008).

**Table 4.** The estimates of phenotypic correlation coefficients among 12 traits

| Character | M% | Ayld | PH | EH | EH:PH | IL | MSD | msd | EL | ED | SWC | SL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Grain Moisture Content (M%) | | 0.1829 | 0.8255** | 0.8537** | 0.7744** | 0.3755 | 0.4585 | 0.2491 | 0.4937 | 0.2854 | 0.4928 | 0.3477 |
| Adjusted yield (Ayld) | | | -0.0182 | -0.019 | 0.0226 | 0.2583 | 0.7056* | 0.2402 | 0.5991* | 0.1918 | 0.0717 | -0.4945 |
| Plant height (PH) | | | | 0.9417** | 0.763** | 0.4113 | 0.3729 | 0.2265 | 0.6182** | 0.0993 | 0.4783 | 0.1794 |
| Ear height (EH) | | | | | 0.9339** | 0.2694 | 0.448 | 0.3391 | 0.5809* | 0.0397 | 0.3414 | 0.2161 |
| Ear height to plant height ratio (EH:PH) | | | | | | 0.1115 | 0.5347 | 0.4598 | 0.5205 | -0.0024 | 0.1687 | 0.189 |
| Internode length (IL) | | | | | | | 0.3388 | 0.0315 | 0.3889 | 0.5675 | 0.7421** | -0.1986 |
| Major stalk diameter (MSD) | | | | | | | | 0.6592** | 0.788** | 0.255 | 0.1738 | -0.3713 |
| Minor stalk diameter (msd) | | | | | | | | | 0.3383 | -0.2895 | -0.132 | 0.0749 |
| Ear length (EL) | | | | | | | | | | 0.2256 | 0.2755 | -0.4332 |
| Ear diameter (ED) | | | | | | | | | | | 0.4387 | -0.3304 |
| Stalk water content (SWC) | | | | | | | | | | | | 0.2648 |
| Stalk lodging (SL) | | | | | | | | | | | | |

*, **- Significant at P=0.05 and 0.01, respectively

**Table 5.** The estimates of environmental correlation coefficients among 12 traits

| Character | M% | Ayld | PH | EH | EH:PH | IL | MSD | msd | EL | ED | SWC | SL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Grain Moisture Content (M%) | | -0.1118 | 0.1595 | 0.0148 | -0.114 | 0.1947 | 0.008 | 0.0364 | 0.0605 | -0.0477 | 0.3451 | -0.1937 |
| Adjusted yield (Ayld) | | | 0.5578** | 0.4565* | 0.1429 | 0.2254 | 0.1654 | 0.1959 | 0.2434 | 0.0034 | -0.0257 | -0.0891 |
| Plant height (PH) | | | | 0.8649** | 0.2536 | 0.5515** | 0.0509 | -0.1166 | -0.1356 | 0.1901 | 0.2006 | -0.2099 |
| Ear height (EH) | | | | | 0.6885** | 0.4912* | 0.1042 | -0.0147 | -0.1713 | 0.1635 | 0.1929 | -0.0661 |
| Ear height to plant height ratio (EH:PH) | | | | | | 0.0425 | 0.2055 | 0.1812 | -0.169 | 0.0373 | 0.1624 | 0.0169 |
| Internode length (IL) | | | | | | | -0.0822 | -0.1575 | 0.3557 | -0.055 | -0.0705 | 0.2345 |
| Major stalk diameter (MSD) | | | | | | | | 0.3793 | 0.1942 | 0.1423 | 0.0544 | -0.1906 |
| Minor stalk diameter (msd) | | | | | | | | | 0.3103 | 0.0056 | 0.1048 | 0.4487* |
| Ear length (EL) | | | | | | | | | | -0.1457 | -0.3832 | 0.3159 |
| Ear diameter (ED) | | | | | | | | | | | 0.3291 | -0.1192 |
| Stalk water content (SWC) | | | | | | | | | | | | -0.379 |
| Stalk lodging (SL) | | | | | | | | | | | | |

Key: *, **= Significant at P=0.05 and 0.01, respectively

## Path Analysis

It is necessary to analyze the cause and effect relationship between dependent and independent variables to entangle the nature of relationship between the variables (Sidramappa et al., 2008). Path coefficient analysis (Dewey and Lu, 1959) was therefore used to elicit the nature of relationship of dependent variable (yield) with closely associated independent variables.

## Phenotypic path analysis for yield

The phenotypic direct (bold) and indirect effects of different traits on grain yield per hectare are presented in Table 6. Ear height exerted the highest positive direct effect and negative association with grain yield due to its negative indirect effect through plant height, ear height to plant height ratio and stalk lodging. Under such circumstances, a restricted simultaneous selection model is to be followed, i.e. restrictions are to be imposed to nullify the undesirable indirect effects to make use of the direct effect i.e. traits, which contribute positively to the direct effect, should be considered (Singh and Kakar 1977). In the present case grain moister, major stalk diameter, ear length and stalk water content contributed positively so we must consider these traits when we use ear height for direct selection.

Grain moisture content exerted the second highest positive direct effect next to ear height, positive association with grain yield. This is due to its negative indirect effects through plant height, ear height to plant height ratio and stalk lodging. Under such circumstances, a restricted simultaneous selection model is to be followed (Singh and Kakar 1977), i.e. restrictions are to be imposed to nullify the undesirable indirect effects to make use of the direct effect *i.e.* traits, which contribute positively to the direct effect, should be considered.
Plant height exerted the highest negative direct effect on grain yield (-0.018) . It is because its high negative direct effect was cancelled by positive indirect effect through grain moister content, major stalk diameter, ear height, and ear length and stalk water content. Trait with high negative direct effect and negative or negligible association with the economic yield such as grain yield should be deselected when selection is for high yield (Singh and Chaudhary 1977).

Ear height to plant height ratio exerted the highest negative direct effect on grain yield next to plant height but this trait had negligible rather no association (0.023) with yield. It is because its high negative direct effect was cancelled by positive indirect effect through grain moister content, ear height, major stalk diameter, ear height, and ear length and stalk water Trait with high negative direct effect and negative or negligible association with the economic yield such as grain yield should be deselected when selection is for high yield (Singh and Chaudhary 1977).

Inter node length exerted the negative direct effect and positive association with grain yield due to positive indirect effect through grain moister, major stalk diameter, ear height, ear length, stalk water content and stalk lodging. In this case, indirect factors are to be considered for selection. Major stalk diameter and Ear length exerted positive direct effect and almost equal positive significant association with grain yield. It is because the balanced negative and positive indirect effect of all traits. Direct selection through this trait will be effective.

Stalk water content exerted positive direct effect and weak non-significant positive association with grain yield. This is due to the negative indirect effect via plant height, ear height to plant height ratio, inter node length and ear diameter. Under such circumstances, a restricted simultaneous selection model is to be followed, i.e. restrictions are to be imposed to nullify the undesirable indirect effects to make use of the direct effect (Singh and Kakar 1977) *i.e.* traits, which contribute positively to the direct effect, should be considered. It was reported the undesirable effect of stalk water content on grain yield (-0.751) indicating that the selection for high stalk water content to improve stalk lodging resistance could reduce grain yield (Djordjevic and Ivanovic 1996). This agrees with the statement that significant improvements in stalk quality may lead to competition between the stalk and ear for photosynthate (Beak *et al.*, 1988), which could contribute to grain yield reduction.

Ear diameter exert medium negative direct effect and positive association with grain yield due to its positive indirect effect through grain moister content, major stalk diameter, ear height, stalk water content and stalk lodging. So, considering indirect characters for selection are important. The residual effect was almost zero ($R^2$= 0.0006) indicating that all the traits supposed to influence grain yield per hectare are included in the analysis.

**Table 6.** Phenotypic path analysis of the direct (bold) and indirect effects of eleven characters on grain yield

| | M% | PH | EH | EH:PH | IL | MSD | msd | EL | ED | SWC | SL | rp |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Grain moisture content (M %) | **1.382** | -4.029 | 5.939 | -3.294 | -0.054 | 0.225 | 0.023 | 0.205 | -0.161 | 0.216 | -0.269 | 0.183 |
| Plant height (PH) | 1.141 | **-4.881** | 6.551 | -3.245 | -0.059 | 0.183 | 0.021 | 0.257 | -0.056 | 0.21 | -0.139 | -0.018 |
| Ear height (EH) | 1.18 | -4.597 | **6.957** | -3.972 | -0.038 | 0.22 | 0.031 | 0.241 | -0.022 | 0.15 | -0.167 | -0.019 |
| Ear height to plant height ratio (EH: PH) | 1.07 | -3.724 | 6.497 | **-4.254** | -0.016 | 0.263 | 0.042 | 0.216 | 0.001 | 0.074 | -0.146 | 0.023 |
| Inter nod length (IL) | 0.519 | -2.008 | 1.874 | -0.474 | **-0.143** | 0.166 | 0.003 | 0.162 | -0.32 | 0.326 | 0.154 | 0.258 |
| Major stalk diameter (MSD) | 0.634 | -1.82 | 3.117 | -2.274 | -0.048 | **0.491** | 0.06 | 0.327 | -0.144 | 0.076 | 0.288 | 0.706* |
| Minor stalk diameter (msd) | 0.344 | -1.106 | 2.359 | -1.956 | -0.005 | 0.324 | **0.091** | 0.141 | 0.164 | -0.058 | -0.058 | 0.24 |
| Ear length (EL) | 0.682 | -3.017 | 4.041 | -2.214 | -0.056 | 0.387 | 0.031 | **0.415** | -0.127 | 0.121 | 0.335 | 0.599* |
| Ear diameter (ED) | 0.394 | -0.485 | 0.276 | 0.01 | -0.081 | 0.125 | -0.026 | 0.094 | **-0.564** | 0.192 | 0.256 | 0.192 |
| Stalk water content (SWC) | 0.681 | -2.335 | 2.375 | -0.718 | -0.106 | 0.085 | -0.012 | 0.114 | -0.247 | **0.439** | -0.205 | 0.072 |
| Stalk lodging (SL) | 0.48 | -0.876 | 1.503 | -0.804 | 0.028 | -0.182 | 0.007 | -0.18 | 0.186 | 0.116 | **-0.774** | -0.495 |

$R^2$=0.0007, rp- phenotypic correlation

## Phenotypic path analysis for stalk lodging

The phenotypic direct (bold) and indirect effects of different traits on stalk lodging percentage are presented in Table 7. Ear height and grain moisture content exerted the first and the second highest positive direct effect. Both the traits did not possess significant positive association with stalk lodging percentage. This was due to their negative indirect effect via plant height, ear height to plant height ratio, inter node length and ear diameter. Therefore, direct selection of these characters is advantageous. According to Singh and Choudhary (1977) direct selection through these traits will be effective to increase stalk lodging, but it is in the undesirable direction. Therefore, selection against these traits might be effective.

Plant height and ear height to plant height ratio exerted the first and second highest negative direct effect and positive association with stalk lodging percentage respectively due to their positive indirect effect with grain moister content, ear height, major and minor stalk diameter, ear length and stalk water content. According to Singh and Choudhary (1977) indirect characters seems to be the cause of correlation that is in the undesirable direction in increasing stalk lodging, so to improve stalk lodging we must consider plant height and ear height to plant height ratio.

Major stalk diameter and ear length exerted medium positive direct effect and negative association with stalk lodging percentage due to their negative indirect effect through plant height, ear height to plant height ratio, inter node length and grain yield. Under such circumstances, a restricted simultaneous selection model is to be followed (Singh and Kakar 1977), i.e. restrictions are to be imposed to nullify the undesirable indirect effects to make use of the direct effect, so in this study we should not consider in our selection ear height, minor stalk diameter, grain moister content and stalk water content because all contribute in positive direction which results in the stalk lodging increase which is undesirable.

Minor stalk diameter and stalk water content exerted low to medium positive direct effect and positive association with stalk lodging percentage due to their negative indirect effect through plant height, ear height to plant height ratio, inter node length and grain yield. Direct selection through these traits will be effective but it is in the undesirable direction (Singh and Chaudhary 1977) i.e. improving these traits will increase lodging so in our case to improve lodging we should not consider this trait. In the contrary it was reported that path analysis has negative direct effect of stalk water content with stalk lodging (Djordjevic and Ivanovic 1996). Stalk water content, could be an indicator for stay-green. Stay green is characterized by increased photosynthetic activity in older vegetative growth, increased resistance to diseases and pests, lower percentage of plant lodging, and increased tolerance to drought (Howared and Smart, 1993). Duvick (1984) showed that improved stay-green could provide an alternative strategy for improving stalk quality and increasing grain yield without changing maturity, plant height, or leaf area index. Stay-green type plants are usually more disease resistant and have less stalk rot and lodging (Berzonsky and Hawk 1986). Usually as soluble stalk solids increase, stalk lodging decrease due to a lower incidence of pith cell death (Craig and Hooker, 1961).

Grain yield exerted the third highest negative direct effect and negative association with stalk lodging percentage due to its positive indirect effect through grain moister, plant height, major and minor stalk diameter, ear length and stalk water content. Singh and Chaudhary (1977) reported that trait with high negative direct effect and negative association with the economic yield such as grain yield should be deselected when selection is for high yield. In this study the important character is stalk lodging which we want to decrease so direct selection of direct effect i.e. grain yield is advantageous to decrease lodging.

Internodes length and ear diameter exerted low to high negative direct effect and negative association with stalk lodging percentage due to their positive indirect effect through grain moister, ear height, major and minor stalk diameter, ear length and stalk water content. Singh and Chaudhary (1977) reported that trait with high negative direct effect and negative association with the economic yield such as grain yield should be deselected when selection is for high yield. In this study the important character is lodging which we want to decrease so direct selection of inter nod length and ear diameter is advantageous. Similarly, Djordjevic and Ivanovic (1996) reported that subsequent path coefficient analysis showed that no single morphological trait (plant and ear height, stalk inter nod length, major and minor stalk diameter) was significantly associated with stalk lodging. The residual effect is negligible ($R^2$=0.0007) as in the case of phenotypic path coefficient analysis indicating that all the traits supposed to influence stalk lodging percentage were considered in the analysis.

**Table 7.** Phenotypic path analysis of the direct (bold) and indirect effects of eleven characters on stalk lodging

| | M% | Ayld | PH | EH | EH:PH | IL | MSD | msd | EL | ED | SWC | rp |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Grain moisture content (M%) | **1.784** | -0.236 | -5.204 | 7.67 | -4.254 | -0.069 | 0.291 | 0.029 | 0.265 | -0.208 | 0.279 | 0.348 |
| Adjusted yield (Ayld) | 0.326 | **-1.291** | 0.115 | -0.17 | -0.124 | -0.048 | 0.448 | 0.028 | 0.321 | -0.14 | 0.041 | -0.495 |
| Plant height (PH) | 1.473 | 0.024 | **-6.304** | 8.46 | -4.191 | -0.076 | 0.237 | 0.027 | 0.331 | -0.072 | 0.271 | 0.179 |
| Ear height (EH) | 1.523 | 0.025 | -5.936 | **8.984** | -5.13 | -0.05 | 0.284 | 0.04 | 0.312 | -0.029 | 0.193 | 0.216 |
| Ear height to plant height ratio (EH: PH) | 1.382 | -0.029 | -4.81 | 8.39 | **-5.493** | -0.021 | 0.339 | 0.054 | 0.279 | 0.002 | 0.096 | 0.189 |
| Inter nod length (IL) | 0.67 | -0.334 | -2.593 | 2.42 | -0.612 | **-0.184** | 0.215 | 0.004 | 0.209 | -0.413 | 0.42 | -0.198 |
| Major stalk diameter (MSD) | 0.818 | -0.911 | -2.351 | 4.025 | -2.937 | -0.062 | **0.634** | 0.078 | 0.042 | 0.186 | 0.098 | -0.371 |
| Minor stalk diameter (msd) | 0.444 | -0.31 | -1.428 | 3.047 | -2.526 | -0.006 | 0.418 | **0.118** | 0.181 | 0.211 | -0.075 | 0.075 |
| Ear length (EL) | 0.881 | -0.774 | -3.102 | 5.219 | -2.859 | -0.072 | -0.5 | 0.04 | **0.536** | -0.164 | 0.156 | -0.433 |
| Ear diameter (ED) | 0.509 | -0.248 | -0.626 | 0.357 | 0.013 | -0.105 | 0.162 | -0.034 | 0.121 | **-0.729** | 0.249 | -0.33 |
| Stalk water content (SWC) | 0.879 | -0.093 | -3.015 | 3.067 | -0.927 | -0.137 | 0.11 | -0.016 | 0.148 | -0.32 | **0.566** | 0.265 |

$R^2$=0.0006, rp-phenotypic correlation

# Conclusion

Both grain yield and stalk lodging showed positive direct effect with grain moisture content, ear height, major stalk diameter, minor stalk diameter, ear length and stalk water content at phenotypic level. Although the direct effect was positive which is undesirable to fulfil our objective; therefore, restricted simultaneous selection of other indirect traits would be important especially when we practice direct selection through major stalk diameter and ear length. Hence, the positive contributor traits grain moister content, ear height, minor stalk diameter, stalk water content ignored while plant height, ear height to plant height ratio should be considered. We should rank the genotypes based on major stalk diameter and ear length. Among the genotypes BH-541 is ideal because it has the highest desirable values for both major stalk diameter and ear length. The other genotypes worth considering are Kuleni, BH-670, BH-530 and Gibe composite since they have relatively high major stalk diameter and ear length as compared to the other genotypes. For further improvement genotypes with below average grain yield and below average stalk lodging resistance should be discarded. Most genotypes gave grain yield below their potential except BH-541. This was due to the late onset of rainfall and terminal drought stress, which disfavoured the full expression of the genetic potential of the genotypes, the only exceptional case, was BH-541, which might be due to its relatively early maturing genotypes as compared to other genotypes. The same experiment should be repeated across years and locations to get more robust data to effectively select useful attributes for maize breeding.

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