
Article AR2366

DOI: HTTPS://DOI.ORG/10.23910/1.2021.2366

*International Journal of Bio-resource and Stress Management*

Crossref

October 2021

Print ISSN 0976-3988
Online ISSN 0976-4038

*IJBSM* 2021, 12(5):594-602

**Research Article** *Natural Resource Management*

# Determination of Principal Yield Attributing Traits of Hybrid Maize (*Zea mays* L.) Using Multivariate Analysis

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***Citation:*** Rana et al., 2021. Determination of Principal Yield Attributing Traits of Hybrid Maize (*Zea mays* L.) Using Multivariate Analysis. International Journal of Bio-resource and Stress Management 2021, 12(5), 594-602. HTTPS://DOI.ORG/10.23910/1.2021.2366.



***Data Availability Statement:*** Legal restrictions are imposed on the public sharing of raw data. However, authors have full right to transfer or share the data in raw form upon request subject to either meeting the conditions of the original consents and the original research study. Further, access of data needs to meet whether the user complies with the ethical and legal obligations as data controllers to allow for secondary use of the data outside of the original study.

***Conflict of interests:*** The authors have declared that no conflict of interest exists.

***Funding:*** The work was supported by University Grants Commission, Ministry of Social Justice & Empowerment and Ministry of Tribal Affairs. Government of India in the form of Rajiv Gandhi National Fellowship to the leading author.

***Acknowledgement:*** The authors would like to thank Bidhan Chandra Krishi Viswavidyalaya (BCKV), West Bengal for providing necessary facilities during the course of experimentation.

## Abstract

The field experiments were conducted at farmer's field, Madandanga village under Chakdaha Block of Nadia district in West Bengal during *rabi* season 2014-15 and 2015-16. Treatments were distributed in split-factorial design, with three varieties (P '3533', P '3396', P '30V92') in the main plot and three planting density (55,555, 66,666, 83,333 plants $ha^{-1}$) × three sowing dates (November 20, November 30, December 10) combinations in the sub-plots, replicated thrice. Irrespective of planting density and sowing date, the variety 'P30V92' produced the highest yield, followed by 'P3396' and 'P3533'. The significantly highest grain and stover yield was obtained in high density planting (83,333 plants $ha^{-1}$), accounting 44.2 and 39.6% more than low planting density (55,555 plants $ha^{-1}$), respectively. The maximum grain and stover yields were obtained from Nov. 20 sown plants; being 7.71 and 11.95% more than the grain yield derived from late sown (Dec. 10) plants. A correlation study showed that among the growth and yield components, leaf area index (0.96) and shelling percentage (0.91) exhibited highly positive direct effects on the grain yield of hybrid maize. However, other growth attributes, namely P uptake (0.88), K uptake (0.86) and plant height (0.81) exerted comparatively low positive direct effects on the grain yield of hybrid maize. Further, the standard regression equation revealed a significant relationship of shelling percentage ($p \le 0.01$), leaf area index ($p \le 0.01$) and uptake of P ($p \le 0.05$) with grain yield.

***Keywords:*** Multivariate analysis, pearson correlation study, phenotypic traits

## 1. Introduction

Maize (*Zea mays* L.) is a major staple crop species and accounts for 60% of global human consumption, livestock feed and raw materials for industrial purposes (Gandhi and Zhou, 2014; Anonymous, 2020). Maize yield improvements have typically been achieved through genetic improvement, farmland management, and planting techniques (Qin et al., 2016; Jin et al., 2012; Li and Wang, 2009). Over the past few decades, the area under maize cultivation in West Bengal has been increased remarkably due to the growing demand of grains for human nutrition and livestock feeds. Presently, its cultivation has shifted from subsistence to commercial crop and is considered to be the best alternative to

**Article History**
RECEIVED on 17th May 2021 RECEIVED in revised form on 20th September 2021 ACCEPTED in final form on 30th October 2021

summer rice or wheat due to its high yield potential in the winter season under assured irrigated conditions (Ray et al., 2018). However, the agronomic management of the crop was neither up to the mark nor developed especially for single cross hybrids (SCH). Moreover, the present productivity of maize in West Bengal (4.92 t $ha^{-1}$) although comparatively higher than the national average (2.51 t $ha^{-1}$), but is markedly low with respect to world average productivity (5.11 t $ha^{-1}$) (Anonymous, 2018).

Successful maize production requires an understanding of various management practices as well as environmental conditions that affect crop performance. An important part of agricultural adaptation is the timing of crop sowing dates, affecting yields and the level of risk incurred during a particular season (Parker et al., 2016). Timely sowing is critical for maximizing yield for both grain and biomass in maize. When maize is planted prior to or later than this optimum window, a yield decline can be observed (Zhou et al., 2015). In West Bengal, winter (*rabi*) maize is normally sown during the second fortnight of November. Sometimes its sowing is delayed depending upon the withdrawal of monsoon and late harvest of preceding *kharif* crop (rice), which may lead to poor seed yield. Hence, maize crop (with suitable variety) must be grown on an optimum sowing date in order to best utilization of the moisture, nutrients and solar radiation. Delaying maize (*Zea mays* L.) sowing date can diminish grain yields through reductions in the number, size and activity of growing grains (sink strength) and/or reductions in the assimilate supply (source capacity) to grains during the grain filling period (Bonelli et al., 2016).

The increase in plant density has been one of the main managements contributed to maize grain yield improvements (Zhang et al., 2019; Wang et al., 2019) which remarkably increase resources use efficiency when combination with high density tolerance maize cultivars (Jia et al., 2018). Seed yield of hybrid maize, a complex dependent character, is contributed by a number of component characters. These components are related among themselves and also with yield either positively or negatively. Thus, direct selection of a cultivar for seed yield is often not very effective rather indirect selection based on some associated traits may be useful. Understanding the nature of associations among traits is important for direct or indirect selection and consequently to improve the efficiency of selection gains in plant breeding programs. Simple correlation analysis establishes the mutual associations of variables without regard to cause and effect. Path coefficient analysis is useful statistical procedures to estimate the magnitude and nature of associations between selection parameters. Correlation and path coefficient analysis were done with 3 maize cultivars over two seasons to find out association among characters and to assess the direct and indirect contribution of different characters on grain yield of hybrid maize along with their inter-relationships.

## 2. Materials and Methods

The field studies were conducted in farmer's field, Madandanga, Gayeshpur, Nadia, West Bengal during *rabi* season of 2014–15 and 2015–16 (24 months) situated at $23^{o}26.010'$ N latitude and $88^{o}22.221'$ E longitude and 12.0 meters above the mean sea level) under new alluvial agro-climatic condition. The maximum and minimum temperature fluctuated between 37.3°C and 24.8°C and 20.3 and 9.6°C in winter 2014–15, 35.1°C and 23.7°C and 21.8°C and 9.3°C in winter 2015–16. In general, there was a gradual drop in temperature from November to January, which favoured the growth and development of the crop. Relative humidity prevailed between 89% and 34% in winter 2014–15, and 97% and 34% in winter 2015-16. The rainfall during the experimental period (November to March) was recorded 24.2 (5 rainy days) and 112.3 mm (14 rainy days) in winter 2014-15 and winter 2015–16, respectively. Maximum bright sunshine was recorded 144.7 hours in winter 2014-15 and 113 hours in winter 2015-16. The soil was clay loam in texture having pH 7.30, organic carbon 0.42%, available N 104.0 kg $ha^{-1}$, available P 52.5 kg $ha^{-1}$ and available K 268.0 kg $ha^{-1}$.

The experiment was set up in a split factorial design. The main plot consisted of 3 maize hybrids (P'3533', P'3396' and P'30V92') and 9 treatment combinations (3 sowing date × 3 plant density) in the sub-plots. Therefore, each hybrid was tested under 3 sowing dates (November 20, November 30 and December 10) and three planting densities (55,555, 66,666 and 83,333 plants $ha^{-1}$). The total number of plots was 81 with 12 $m^2$ (4×3 $m^2$) of individual plot size. The recommended dose of fertilizer (RDF) i.e. 200: 60: 60 kg N, $P_2O_5$ and $K_2O$ $ha^{-1}$, respectively was given through urea (46% N), single super phosphate (16% $P_2O_5$), and muriate of potash (60% $K_2O$). All P and K fertilizers were applied to the soil prior to sowing in each plot. The N fertilizer was applied in three splits of 40% before sowing, 30% at 30 days after sowing (DAS) at knee height stage and the rest 30% at the pre-tasseling stage. The crop is grown under assured irrigation. Light irrigations were given at 5 days intervals within 12 DAS for good germination and better crop establishment. Then 3 irrigations were given at an interval of 7–8 days. Manual weeding was carried out twice at 30 and 60 DAS to promote early crop growth. Top-dressing of N followed by earthing up was done at 60 DAS and ridges were made by manual labour with the help of spade. Weeds, pests and diseases were intensively controlled by chemicals to avoid yield loss. Crops were harvested when husks turned yellow, silks got a brownish discolouration, and grains became hard. In each plot, the third row was marked for destructive sampling as well as for recording different biometrical observations. The middle two rows were marked for the determination of grain and stover yield.

The data obtained on different growth parameters, yield components and yield were analyzed statistically by the method of analysis of variance (ANOVA) as per the procedure outlined for split-factorial design (Jones and Nachtsheim, 2009). Statistical significance was tested by P-value at 0.05 level of probability and critical difference (CD) was worked out wherever the effects were significant. Pearson's correlation coefficients were calculated to describe the degree and pattern of associations of observed traits in hybrid maize. Direct and indirect path coefficients were calculated for quantitative traits using the software MS Excel. For path analysis of quantitative traits, grain yield (GY) was considered as a response variable, whereas all measured growth parameters and yield components were considered as causal variables. Multivariate data reduction technique like principal component analysis (PCA) based upon correlation matrix involving all measured parameters was used to diagnose the similarity among twenty seven (27) treatment combinations. Regression factor scores with respect to component loading for the first four components were calculated and a scatter diagram was drawn.

## 3. Results and Discussion

### *3.1. Growth attributes, yield components and yield of hybrid maize*

Irrespective of planting density and sowing date, tested cultivars exhibited non-significant ($p \geq 0.05$) variation among themselves in terms of plant height and the number of cobs plant$^{-1}$ (Table 1). At harvest, the LAI, DMA and CGR (91-120 DAS) of maize differed significantly ($p \leq 0.05$) among the varieties. The variety 'P30V92' produced the highest LAI, DMA and CGR (91-120 DAS), accounting 7.53, 7.62 and 19.55% more than the values obtained with 'P3533', respectively; being statistically at par with the values of 'P3396'. Planting density exerted a significant influence on all the measured growth attributes (Table 1). Plants with significantly ($p \leq 0.05$) highest height, LAI, DMA, CGR (91-120 DAS) and number of cobs/plant was observed in high density planting (83,333 plants ha$^{-1}$), accounting 8.64, 31.22, 8.7 and 40.5% more than low planting density (55,555 plants ha$^{-1}$), respectively. Whereas, plants under medium density (66,666 plants ha$^{-1}$) produced the maximum number of cobs/plant, accounting 18.44% more than low planting density (55,555 plants ha$^{-1}$). These findings supported by Hargilas (2015). In the present study, sowing date significantly ($p \leq 0.05$) influenced only plant height (Table 1). The tallest plants were found with early sowing (Nov. 20), accounting 4.54% more height than late sown (Dec. 10) plants. Maize is a summer crop and delay in sowing limits its

Table 1: Effect of variety, planting density, sowing date on growth attributes, yield components and yield of rabi maize (pooled data of two years)

| Treatments | PH | LAI | DMA | CGR | NCP | CL | CG | NGRC | NGR | GW | GY | SY |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Variety | | | | | | | | | | | | |
| P3533 | 257.6 | 5.65 | 224.3 | 22.14 | 1.30 | 18.75 | 14.60 | 14.59 | 37.73 | 312.2 | 11.23 | 10.60 |
| P3396 | 258.5 | 6.08 | 238.2 | 26.22 | 1.11 | 17.36 | 14.65 | 14.30 | 36.36 | 320.4 | 11.59 | 9.67 |
| P30V92 | 262.3 | 6.11 | 242.8 | 27.52 | 1.22 | 17.77 | 14.93 | 14.37 | 35.94 | 320.7 | 11.65 | 10.69 |
| SEm± | 1.77 | 0.08 | 3.88 | 0.96 | 0.06 | 0.32 | 0.16 | 0.28 | 1.09 | 4.53 | 0.27 | 0.35 |
| CD ($p$=0.05) | NS | 0.33 | 15.25 | 3.79 | NS | NS | NS | NS | NS | NS | NS | NS |
| Planting density | | | | | | | | | | | | |
| 55,555 plants ha$^{-1}$ | 247.3 | 4.89 | 223.5 | 19.36 | 1.15 | 17.95 | 14.69 | 14.41 | 36.55 | 319.3 | 8.36 | 7.84 |
| 66,666 plants ha$^{-1}$ | 260.4 | 5.85 | 237.1 | 23.99 | 1.41 | 18.60 | 15.26 | 14.85 | 37.99 | 327.0 | 11.11 | 10.13 |
| 83,333 plants ha$^{-1}$ | 270.7 | 7.11 | 244.8 | 32.54 | 1.07 | 17.32 | 14.23 | 14.00 | 35.49 | 307.0 | 15.00 | 12.99 |
| SEm± | 2.53 | 0.15 | 4.24 | 1.12 | 0.07 | 0.29 | 0.17 | 0.18 | 0.86 | 4.54 | 0.25 | 0.29 |
| CD ($p$=0.05) | 7.20 | 0.44 | 12.05 | 3.19 | 0.21 | 0.81 | 0.49 | 0.52 | NS | 12.91 | 0.71 | 0.84 |
| Sowing date | | | | | | | | | | | | |
| November 20 | 264.2 | 6.14 | 241.0 | 24.17 | 1.22 | 18.66 | 15.06 | 14.59 | 37.91 | 330.7 | 11.81 | 10.88 |
| November 30 | 262.0 | 6.04 | 235.1 | 25.46 | 1.19 | 18.04 | 14.67 | 14.56 | 36.35 | 322.2 | 11.76 | 10.50 |
| December 10 | 252.2 | 5.68 | 229.2 | 26.25 | 1.22 | 17.19 | 14.44 | 14.11 | 35.77 | 300.4 | 10.90 | 9.58 |
| SEm± | 2.53 | 0.15 | 4.24 | 1.12 | 0.07 | 0.29 | 0.17 | 0.18 | 0.86 | 4.54 | 0.25 | 0.29 |
| CD ($p$=0.05) | 7.20 | NS | NS | NS | NS | 0.81 | 0.49 | NS | NS | 12.91 | 0.71 | 0.84 |

PH: Plant height (cm) at harvest; LAI: leaf area index at harvest; DMA: Dry matter accumulation (g plant$^{-1}$) at harvest; CGR: Crop growth rate (g m$^{-2}$ day$^{-1}$) at 91-120 DAS; DAS: Days after sowing; NCP: No. of cobs plant$^{-1}$; CL: Cob length (cm); CG: Cob girth (cm); NGRC: No. of grain rows cob$^{-1}$; NGR: No. of grains row$^{-1}$; GW: 1000 grain weight (g); GY: Grain yield (kg ha$^{-1}$); SY: Stover yield (kg ha$^{-1}$); NS: Non-significant productivity due to limited time to complete life cycle (Akmal et al., 2014; Hanif and Ali., 2014). Late sowing of maize might have experienced the effect of uncongenial low and high temperature coincided with the growth and reproductive phases, respectively, and finally resulted in untimely and forced maturity realized lower growth attributes and Early sown crop availed more days of life cycle for vegetative development than late sown crop which are in agreement with the results obtained by other investigators (Jain et al., 2018).

Irrespective of planting density and sowing date, the variations in grain and stover yield among tested varieties were non-significant ($p\geq0.05$) (Table 1). Both grain and stover yield were significantly ($p\leq0.05$) affected by planting density. These findings are supported by Dar et al. (2014). The significantly highest grain and stover yield was obtained in high density planting (83,333 plants $ha^{-1}$), accounting 44.27 and 39.65% more than low planting density (55,555 plants $ha^{-1}$), respectively. This plant population represents the minimum stress condition, under which maximum yield is expected. In addition, parallel to the increasing plant density the individual production of plants decreases but the yield per unit area increases.Finally, advanced grain yield of maize under high plant density can be attributed to genetic improvement (Ci et al., 2012). In the present study, sowing date significantly ($p\leq0.05$) influenced grain and stover yields (Table 1). The maximum grain and stover yields were obtained from Nov. 20 sown plants; being 7.71 and 11.95% more than the grain yield derived from late sown (Dec. 10) plants. This result was achieved potentially because late sowing decreased the crop growth rate during grain filling because of low radiation-use efficiency and low incident radiation; moreover, the lower yield was largely attributed to the grain-filling phase coinciding with the diminishing temperature and radiation levels, thereby causing a decline in grain weight (Lu et al., 2017; Koca and Canavar., 2014). Previous studies also suggest that the productivity of winter maize for late sowing dates tend tobe lower than for early sowing (Madonni., 2012; Tsimba et al., 2013). In the present study, The interaction effects (variety × sowing date, variety × planting density, sowing date × planting density and variety × sowing date × planting density) were non-significant ($p\geq0.05$) on growth attributes, yield components, grain yields and stover yields of tested maize cultivars.

### *3.2. Pair-wise association between the assessed traits of tested cultivar through correlation study*

Pearson correlation coefficients showing pair-wise associations between the assessed traits of the tested hybrid maize varieties are presented in Table 2. Among the phenotypic traits evaluated, significant and positive correlation were observed between PH and LAI (r=0.74, $p\leq0.01$), DMA (r=0.41, $p\leq0.05$), SP (r=0.84, $p\leq0.01$), UN (r=0.50, $p\leq0.01$), UP (r=0.74, $p\leq0.01$) and UK (r=0.65, $p\leq0.01$). The LAI showed significant and positive correlation with DMA (r=0.77, $p\leq0.01$), SP (r=0.84, $p\leq0.01$), UN (r=0.50, $p\leq0.01$), UP (r=0.83, $p\leq0.01$) and UK (r=0.85, $p\leq0.01$). On the other hand, the LAI showed significant and negative correlation with NGPP (r=-0.51, $p\leq0.01$), AN (r=-0.40, $p\leq0.05$), AP (r=-0.67, $p\leq0.01$) and AK (r=-0.41, $p\leq0.05$). Significant ($p\leq0.01$) and positive correlations were also observed between DMA with SP (r=0.26), UP (r=0.27) and UK (r=0.25). While DMA had significant and negative correlations with NGPP (r=-0.45, $p\leq0.05$), CW (r=-0.42, $p\leq0.05$), AP (r=-0.56, $p\leq0.05$) and AK (r=-0.48, $p\leq0.05$). Similarly, NCPP was significantly and positively correlated with CL (r=0.50, $p\leq0.01$), CG (r=0.44, $p\leq0.05$), CW (r=0.59, $p\leq0.01$) and SY (r=0.55, $p\leq0.01$). Significant and positive correlation were observed between CL and CG (r=0.83, $p\leq0.01$), NGPR (r=0.72, $p\leq0.01$), CW (r=0.73,$p\leq0.01$), TGW (r=0.72, $p\leq0.01$), AN (r=0.43, $p\leq0.05$), AP (r=0.40, $p\leq0.05$) and AK (r=0.49, $p\leq0.05$) and UN (r=0.64, $p\leq0.01$). Also significant and positive correlation were detected between CG and NGPR (r=0.77, $p\leq0.01$), CW (r=0.61, $p\leq0.01$), TGW (r=0.81, $p\leq0.01$), AN (r=0.45, $p\leq0.05$) and UP (r=0.54, $p\leq0.01$).

The NGPR showed significant and positive correlation with NGPP (r =0.58, $p\leq0.01$), CW (r=0.61, $p\leq0.01$), TGW (r=0.49, $p\leq0.01$) and AP (r=0.41, $p\leq0.05$). On the other hand, the NGPR showed significant and negative correlation with SP (r=-0.52, $p\leq0.01$), UP (r=-0.42, $p\leq0.05$) and UK (r=-0.45, $p\leq0.05$). Significant ($p\leq0.01$) and positive correlation were also observed between NGRPP and CW (r=0.69), and NGRPP and TGW (r=0.67). Similarly, CW was significantly and positively correlated with TGW (r=0.60, $p\leq0.01$), AP (r=0.41, $p\leq0.05$) and AK (r=0.50, $p\leq0.01$).Significant and positive correlation were also observed between TGW and AN (r=0.55, $p\leq0.01$), and TGW and AK (r=0.41, $p\leq0.05$). The SP showed significant and positive correlation with UN (r=0.55, $p\leq0.01$), UP (r=0.80, $p\leq0.01$) and UK (r=0.77, $p\leq0.01$). On the other hand, the SP showed significant and negative correlation with AP (r=-0.38, $p\leq0.05$). Significant ($p\leq0.01$) and positive correlation were also observed between AN and AP (r=0.65, $p\leq0.01$), and AN and AK (r=0.48, $p\leq0.05$). The AP had significant and positive correlation with AK (r=0.50, $p\leq0.01$), while significant and negative correlation was found between AP and UP (r=-0.44, $p\leq0.05$), and AP and UK (r=-0.62, $p\leq0.01$). The AK had significant and negative correlation only with UK (r=-0.48, $p\leq0.05$). Significant ($p\leq0.01$) and positive correlations (were also observed between UN and UP (r=0.61). Finally, strong and significant ($p\leq0.01$) correlation was detected between UP and UK (r=0.75, $p\leq0.01$).

### *3.3. Correlation coefficient into direct and indirect influences of various traits of hybrid maize through path coefficient analysis*

With the aim of analyzing the genetic correlations further and splitting the correlation coefficient into direct and indirect influences of different attributes, the path coefficient technique was employed. It, therefore, warrants an acute study of attributes that affect a certain correlation and can be advantageous in preparing a competent selection approach. Results of the path coefficient with hybrid maize yield as the response variable are summarized in Table 3. Values of direct effects were <1, indicating that inflation due to multi-collinearity was low. Among the growth and yield

Table 2: Phenotypic correlation coefficients between yield and observed traits in hybrid maize (based on pooled data of two years)

| | LAI | DMA | NCPP | CL | CG | NGPP | NGPR | CW | TGW |
|---|---|---|---|---|---|---|---|---|---|
| PH | 0.739** | 0.409* | 0.107 | 0.187 | 0.052 | -0.216 | -0.065 | -0.053 | 0.001 |
| LAI | 1 | 0.772** | -0.232 | -0.045 | -0.082 | -0.512** | -0.245 | -0.344 | -0.135 |
| DMA | | 1 | -0.332 | -0.065 | 0.034 | -0.446* | -0.210 | -0.420* | 0.067 |
| NCPP | | | 1 | 0.503** | 0.438* | 0.346 | 0.380 | 0.590** | 0.549** |
| CL | | | | 1 | 0.832** | 0.298 | 0.722** | 0.733** | 0.722** |
| CG | | | | | 1 | 0.367 | 0.768** | 0.611** | 0.809** |
| NGPP | | | | | | 1 | 0.581** | 0.613** | 0.491** |
| NGPR | | | | | | | 1 | 0.684** | 0.671** |
| CW | | | | | | | | 1 | 0.596** |
| TGW | | | | | | | | | 1 |
| SP | | | | | | | | | |
| AN | | | | | | | | | |
| AP | | | | | | | | | |
| AK | | | | | | | | | |
| UN | | | | | | | | | |
| UP | | | | | | | | | |
| UK | | | | | | | | | |

Table 2: Continue...

| | SP | AN | AP | AK | UN | UP | UK | GY |
|---|---|---|---|---|---|---|---|---|
| PH | 0.840** | -0.173 | -0.306 | -0.038 | 0.498** | 0.739** | 0.645** | 0.808** |
| LAI | 0.845** | -0.439* | -0.671** | -0.409* | 0.497** | 0.833** | 0.845** | 0.960** |
| DMA | 0.586** | -0.042 | -0.560** | -0.477* | 0.298 | 0.653** | 0.772** | 0.708** |
| NCPP | -0.059 | 0.152 | 0.259 | 0.280 | 0.162 | -0.129 | -0.248 | -0.193 |
| CL | 0.135 | 0.426* | 0.403* | 0.486* | 0.636** | 0.157 | -0.006 | 0.050 |
| CG | 0.015 | 0.450* | 0.320 | 0.285 | 0.541** | 0.057 | 0.021 | -0.050 |
| NGPP | -0.515** | 0.242 | 0.411* | 0.281 | -0.322 | -0.417* | -0.449* | -0.482* |
| NGPR | -0.140 | 0.334 | 0.375 | 0.304 | 0.289 | -0.058 | -0.133 | -0.171 |
| CW | -0.213 | 0.179 | 0.412* | 0.503** | 0.211 | -0.228 | -0.318 | -0.265 |
| TGW | -0.060 | 0.554** | 0.308 | 0.406* | 0.321 | -0.028 | -0.109 | -0.100 |
| SP | 1 | -0.216 | -0.384* | -0.206 | 0.548** | 0.796** | 0.765** | 0.907** |
| AN | | 1 | 0.652** | 0.475* | 0.019 | -0.140 | -0.278 | -0.366 |
| AP | | | 1 | 0.500** | -0.095 | -0.437* | -0.615** | -0.618** |
| AK | | | | 1 | 0.267 | -0.153 | -0.482* | -0.322 |
| UN | | | | | 1 | 0.610** | 0.346 | 0.516** |
| UP | | | | | | 1 | 0.752** | 0.882** |
| UK | | | | | | | 1 | 0.861** |

LAI: leaf area index; DMA: dry matter accumulation; CGR: crop growth rate; DAS: days after sowing; NS: non-significant; PH: Plant height at harvest (cm), LAI: Leaf area index at harvest, DMA: Dry matter accumulation (g plant$^{-1}$), NCPP: No. of cobs plant$^{-1}$ at harvest, CL: Cob length(cm), CG: Cob girth (cm), NGPP: No. of grain rows plant$^{-1}$, NGPR: No. of grains row$^{-1}$, CW: Cob weight (g), TGW: 1000 grain weight (g), SP:Shelling percent, AN:Available nitrogen (kg ha$^{-1}$), AP:Available phosphorus (kg ha$^{-1}$), AK:Available potassium (kg ha$^{-1}$), UN: Uptake of nitrogen at harvest (%), UP: Uptake of phosphorus at harvest (%), UK: Uptake of potassium at harvest (%)

Table 3: Estimates of direct and alternate/indirect path coefficient values of different traits in maize hybrids (based on pooled data of two years)

| Variables | PH | LAI | DMA | NCPP | CL | CG | NGPP | NGPR | CW | TGW |
|---|---|---|---|---|---|---|---|---|---|---|
| PH | 0.208 | 0.263 | -0.072 | -0.023 | 0.046 | -0.005 | 0.035 | 0.001 | -0.002 | 0.000 |
| LAI | 0.154 | 0.355 | -0.137 | 0.049 | -0.011 | 0.008 | 0.082 | 0.005 | -0.015 | -0.035 |
| DMA | 0.085 | 0.274 | -0.177 | 0.070 | -0.016 | -0.003 | 0.072 | 0.004 | -0.018 | 0.017 |
| NCPP | 0.022 | -0.083 | 0.059 | -0.211 | 0.124 | -0.045 | -0.056 | -0.007 | 0.025 | 0.143 |
| CL | 0.039 | -0.016 | 0.011 | -0.106 | 0.247 | -0.086 | -0.048 | -0.014 | 0.032 | 0.188 |
| CG | 0.011 | -0.029 | -0.006 | -0.092 | 0.205 | -0.104 | -0.059 | -0.015 | 0.026 | 0.211 |
| NGPP | -0.045 | -0.182 | 0.079 | -0.073 | 0.073 | -0.038 | -0.160 | -0.011 | 0.026 | 0.128 |
| NGPR | -0.013 | -0.087 | 0.037 | -0.080 | 0.178 | -0.080 | -0.093 | -0.019 | 0.029 | 0.175 |
| CW | -0.011 | -0.122 | 0.074 | -0.124 | 0.181 | -0.063 | -0.098 | -0.013 | 0.043 | 0.156 |
| TGW | 0.000 | -0.048 | -0.012 | -0.116 | 0.178 | -0.084 | -0.079 | -0.013 | 0.026 | 0.261 |
| SP | 0.175 | 0.300 | -0.104 | 0.013 | 0.033 | -0.002 | 0.083 | 0.003 | -0.009 | -0.016 |
| AN | -0.036 | -0.156 | 0.007 | -0.032 | 0.105 | -0.047 | -0.039 | -0.006 | 0.008 | 0.144 |
| AP | -0.064 | -0.238 | 0.099 | -0.055 | 0.099 | -0.033 | -0.066 | -0.007 | 0.018 | 0.080 |
| AK | -0.008 | -0.145 | 0.084 | -0.059 | 0.120 | -0.029 | -0.045 | -0.006 | 0.022 | 0.106 |
| UN | 0.104 | 0.177 | -0.053 | -0.034 | 0.157 | -0.056 | 0.052 | -0.006 | 0.009 | 0.084 |
| UP | 0.154 | 0.296 | -0.116 | 0.027 | 0.039 | -0.006 | 0.067 | 0.001 | -0.010 | -0.007 |
| UK | 0.134 | 0.300 | -0.137 | 0.052 | -0.002 | -0.002 | 0.072 | 0.003 | -0.014 | -0.028 |

Table 3: Continue....

| Variables | SP | AN | AP | AK | UN | UP | UK | Total correlation with GY |
|---|---|---|---|---|---|---|---|---|
| PH | 0.168 | 0.011 | 0.051 | 0.004 | -0.097 | 0.221 | -0.001 | 0.808 |
| LAI | 0.169 | 0.029 | 0.112 | 0.044 | -0.097 | 0.249 | -0.001 | 0.960 |
| DMA | 0.117 | 0.003 | 0.093 | 0.051 | -0.058 | 0.195 | -0.001 | 0.708 |
| NCPP | -0.012 | -0.010 | -0.043 | -0.030 | -0.031 | -0.039 | 0.000 | -0.193 |
| CL | 0.027 | -0.028 | -0.067 | -0.052 | -0.124 | 0.047 | 0.000 | 0.050 |
| CG | 0.003 | -0.030 | -0.053 | -0.031 | -0.105 | 0.017 | 0.000 | -0.050 |
| NGPP | -0.103 | -0.016 | -0.068 | -0.030 | 0.063 | -0.124 | 0.001 | -0.482 |
| NGPR | -0.028 | -0.022 | -0.062 | -0.033 | -0.056 | -0.017 | 0.000 | -0.171 |
| CW | -0.043 | -0.012 | -0.069 | -0.054 | -0.041 | -0.068 | 0.000 | -0.265 |
| TGW | -0.012 | -0.037 | -0.051 | -0.044 | -0.062 | -0.008 | 0.000 | -0.101 |
| SP | 0.200 | 0.014 | 0.064 | 0.022 | -0.106 | 0.238 | -0.001 | 0.907 |
| AN | -0.043 | -0.066 | -0.109 | -0.051 | -0.004 | -0.042 | 0.000 | -0.366 |
| AP | -0.077 | -0.043 | -0.166 | -0.054 | 0.019 | -0.131 | 0.001 | -0.618 |
| AK | -0.041 | -0.031 | -0.083 | -0.108 | -0.052 | -0.046 | 0.001 | -0.322 |
| UN | 0.110 | -0.001 | 0.016 | -0.029 | -0.194 | 0.182 | -0.001 | 0.516 |
| UP | 0.159 | 0.009 | 0.073 | 0.016 | -0.118 | 0.299 | -0.001 | 0.882 |
| | 0.153 | 0.018 | 0.102 | 0.052 | -0.067 | 0.225 | -0.001 | 0.861 |

PH: Plant height at harvest (cm); LAI: Leaf area index at harvest; DMA: Dry matter accumulation (g plant$^{-1}$); NCPP: No. of cobs plant$^{-1}$ at harvest; CL: Cob length (cm); CG: Cob girth (cm); NGPP: No. of grain rows plant$^{-1}$; NGPR: No. of grains row$^{-1}$; CW: Cob weight (g); TGW: 1000 grain weight (g); SP: Shelling percent; AN: Available nitrogen (kg ha$^{-1}$); AP:Available phosphorus (kg ha$^{-1}$); AK: Available potassium (kg ha$^{-1}$); UN: Uptake of nitrogen at harvest (%); UP: Uptake of phosphorus at harvest (%); UK: Uptake of potassium at harvest (%); Residual effect:0.00972 components, LAI (0.960) and shelling percentage (0.907) exhibited highly positive direct effects on the grain yield of hybrid maize. The direct selection for these three characters could be beneficial for yield improvement of hybrid maize since these characters also showed a positive correlation with grain yield. However, other growth attributes, namely P uptake (0.882), K uptake (0.861) and plant height (0.808) exerted comparatively low positive direct effects on the grain yield of hybrid maize.

### *3.4. Principal component analysis (PCA)*

Principal component analysis, a type of factor analysis, was used to reduce a large number of variables to a smaller number of compounds or factors that capture most of the variance in the observed variables. Each component or factor was estimated as being a linear weighted combination of the observed variables (Table 4). Selected two components explained the greatest portion of the total variance (66.95%). The first component alone could explain 38.97% of the total variance. Here, all measured growth parameters and yield components are highly loaded. The second component could explain only 27.98% of variance further. The remaining components explained a very small portion of the total variance and hence they were discarded from the analysis.

Table 4: Component matrix

| Variables | Component | | | |
|---|---|---|---|---|
| Variables | 1 | 2 | 3 | 4 |
| PH | -.540 | .604 | -.078 | -.326 |
| LAI | -.856 | .453 | -.097 | .017 |
| DMA | -.702 | .354 | .186 | .502 |
| NCPP | .476 | .403 | -.371 | -.239 |
| CL | .473 | .818 | .044 | -.050 |
| CG | .478 | .751 | .006 | .290 |
| NGPP | .717 | .054 | -.391 | .215 |
| NGPR | .596 | .563 | -.201 | .247 |
| CW | .693 | .461 | -.367 | -.146 |
| TGW | .547 | .656 | .019 | .323 |
| SP | -.702 | .574 | .061 | -.201 |
| AN | .538 | .234 | .693 | .239 |
| AP | .757 | .014 | .391 | -.146 |
| AK | .598 | .249 | .331 | -.504 |
| UN | -.179 | .807 | .159 | -.254 |
| UP | -.653 | .632 | .067 | -.096 |
| UK | -.780 | .452 | -.066 | .197 |
| Eigen value | 6.626 | 4.756 | 1.299 | 1.221 |
| % of Variance | 38.975 | 27.979 | 7.639 | 7.181 |
| Cumulative % | 38.97 | 66.952 | 74.591 | 81.772 |

Extraction Method: Principal component analysis

From the scatter diagram the homogenous situations can be detected if any at two dimensional space (Figure 1). But considering components it can be concluded that treatment 111 and 121 are always beneficial for the growth and yield of hybrid maize, closely followed by 131, 333, 332 and 322 manifested the least expression for all the observed parameters.

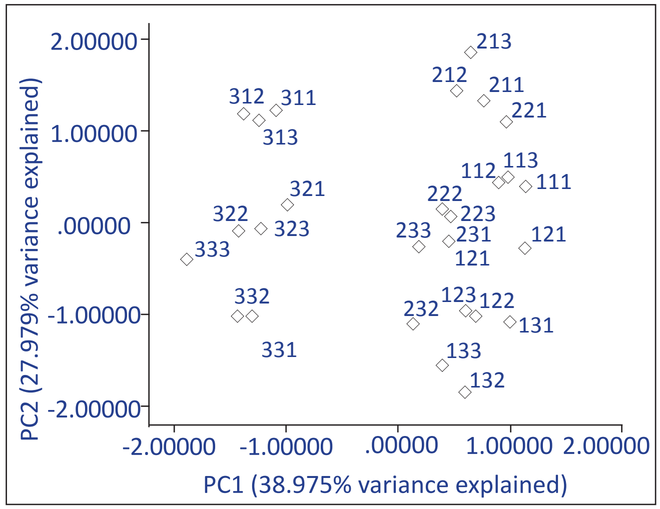


Figure 1: Scatter diagram of regression factor scores for the first and second components produced by PCA (Where 111: V1S1D1; 121: V1S2D1; 131: V1S3D1; 211: V2S1D1; 221: V2S2D1; 231: V2S3D1; 311: V3S1D1; 321: V3S2D1; 331: V3S3D1; 112: V1S1D2; 122: V1S2D2; 132: V1S3D2; 212: V2S1D2; 222: V2S2D2; 232: V2S3D2; 312: V3S1D2; 322: V3S2D2; 332: V3S3D2; 113: V1S1D3; 123: V1S2D3; 133: V1S3D3; 213: V2S1D3; 223: V2S2D3; 233: V2S3D3; 313: V3S1D3; 323: V3S2D3; 333: V3S3D3)

### *3.5. Assessment of the relationship between dependent and independent variables through multiple step-wise regression analysis*

Multiple regression analysis was used to assess the relationships between one dependent variable and many independent variables (Table 5). All the observed parameters were used as independent variables in the multiple regression analysis. The following standard regression equation showed that independent variables like shelling percentage, leaf area index (LAI), uptake of K and cob weight had a positive significant ($p\leq0.01$) relationship with grain yield (dependent variable), while available N had a negative significant ($p\leq0.01$) relationship with grain yield in year 1. But in year 2, only shelling percentage and LAI had a positive significant ($p\leq0.01$) relationship with grain yield. A significant relationship of shelling percentage ($p\leq0.01$), LAI ($p\leq0.01$) and uptake of P ($p\leq0.05$) with grain yield was recorded in the pooled analysis. Therefore, higher values of these observed variables would increase the grain yield of maize.

Table 5: Relationships between one dependent variable (grain yield) and many independent variables as assessed by multiple regression analysis

| Year | Relationship | $R^2$ | Adj. $R^2$ | $SE^{est}$ | Durbin-Watson |
|---|---|---|---|---|---|
| Year 1 | GY=0.154 SP$^{**}$+1.090 LAI$^{**}$+ 14.086 UK$^{**}$+ 0.028 CW$^{**}$- 0.036 AN$^{*}$ -13.254 | 0.976 | 0.971 | 0.556 | 1.341 |
| Year 2 | GY=2.099 LAI$^{**}$+ 0.085 SP$^{**}$-6.927 | 0.909 | 0.901 | 0.9046 | 2.357 |
| Pooled | GY=1.992 LAI$^{**}$+ 0.078 SP$^{**}$+27.908 UP$^{*}$– 11.184 | 0.992 | 0.959 | 0.597 | 2.467 |

*: Significant at ($p$=0.05); **: Significant at ($p$=0.01); GY: Grain yield (t $ha^{-1}$); SP, Shelling %; LAI: Leaf area index; UP: Uptake of phosphorus (%); UK: Uptake of potassium (%); CW: Cob weight (g)

## 4. Conclusion

LAI and shelling percentage exhibited highly positive direct effects on grain yield of hybrid maize, and hence the direct selection for two characters could be beneficial for yield improvement of hybrid maize. Thus, it can be inferred that sowing of maize hybrid 'P30V92' or 'P3396' on 20th November at a density of 83,333 plants $ha^{-1}$ can be recommended as the best crop management practice for sustainable and profitable maize production in winter (*rabi*) season of West Bengal.

## 5. Acknowledgement

The authors would like to thank Bidhan Chandra Krishi Viswavidyalaya (BCKV), West Bengal for providing necessary facilities during the course of experimentation.

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