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Selection of Dwarf Stature Yield Potential Lines from F_3 Populations of White Maize (*Zea mays* L.)

Bodrun Nessa Shompa[1], Kaniz Fatima[2], Mohammad Jony[1], Salma Sarker[3], Md Jafar Ullah[2], Abul Kashem Chowdhury[4] and Jamilur Rahman[1]*

[1] Department of Genetics and Plant Breeding, Sher-e-Bangla Agricultural University, Bangladesh
[2] Department of Agronomy, Sher-e-Bangla Agricultural University, Bangladesh
[3] Department of Plant Pathology, Sher-e-Bangla Agricultural University, Bangladesh
[4] Department of Genetics and Plant Breeding, Patuakhali Science and Technology University, Bangladesh

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****Corresponding authors:***
✉ J. Rahman
jamilsau@gmail.com

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ABSTRACT

'Dwarf stature' maize variety offers promises to withstand unfavorable growth environments of Kharif season. But, for developing such variety, dwarf stature inbred lines must be available. Here, twenty-four F_3 populations of white maize were evaluated though assessment of their genetic variability, heritability, and character association for selection of dwarf stature promising lines based on yield and growth parameters. The populations were developed from F_1 hybrids following the pedigree breeding method. Analysis of genetic variability showed that significant variations existed among the populations and the growth characters *viz*., plant height, cob height, number of grains row$^{-1,}$ and yield plant^{-1} showed the highest heritability and genetic advance. The correlation revealed that yield plant^{-1} was positively and significantly associated with plant height, cob length, cob diameter, and grains row^{-1}. The path coefficient analysis indicated that plant height, cob length, cob diameter, rows cob^{-1}, grains row^{-1} and 100-grain weight had positive and direct contributions towards yield indicating that these yield attributes might be considered for selection. Finally, based upon the criteria *viz*., plant height, maturity, base diameter, cob height, and yield potential, the lines G14 and G4 may be selected for high grain yield, while the lines G10, G11, G12, G1, G3, and G16 might be selected as promising dwarf stature lines for developing inbred lines.

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Introduction

Sustainable crop production is a major challenge posed by global climate changes coupled with ever-rising population pressure. Plant breeding is one of the means to cope with this challenge through the generation of new crop varieties manipulating genetic make-up to have a tolerance to unfavorable growth environments (Ceccarelli *et al.,* 2010). Being a C_4 plant and due to its higher adaptive ability at the unfavorable growth conditions, maize is considered to be a grain crop having higher yield productivity compared to other cereals *e.g.* rice and wheat (Ullah *et al.,* 2019). Rising global temperature, harsh light intensity, poor soil-fertility, trending pest, and disease infestations, lowering soil moisture layer and occurrence of drought are the major environmental constraints that hinder crop production to which maize has been proved to perform better than other grain-producing crops especially than rice and wheat (Kumar *et al*., 2012). To mitigate the ongoing climate change challenges and sustain generating climate-resilient crops through breeding efforts incorporating novel key features *viz*., early maturity, dwarf stature, drought, salinity tolerance, *etc.* is the only option to grow crops under such harsh unfavorable growth environments.

Maize holds the third position among the cereal crops after wheat and rice in the world concerning acreage and production (Beulah *et al*., 2018). In Bangladesh, maize is comparatively a new crop, but the crop has gained rapid popularity since the 2000s (Ullah *et al*., 2017). The cultivated area of maize in Bangladesh has significantly increased to 990 thousand acres and recently the crop ranks in 2nd position in terms of both cultivated areas and production after rice (BBS, 2018). In Bangladesh maize is cultivated in Rabi and Kharif seasons. The yield is comparatively lower in Kharif (summer and rainy) than that of the Rabi (winter) season. Lower yield production in Kharif season is due to unfavorable climatic conditions of the season such as strong wind, heavy rainfall, interrupted sunshine due to cloud cover, thunderstorm as well as few spells of drought in the growth period. Nevertheless, Kharif season has more opportunity for further horizontal expansion of maize cultivation in Bangladesh, because in this season the crop undergoes lesser crop-competition than that in rabi season. Hence, there is an ample opportunity for expanding maize cultivation in Bangladesh in Kharif season provided the appropriate maize variety developed for cultivation in this season.

As many crops have to be grown only in Rabi season, the scope lies for the farmers to grow maize in the late Rabi in February or at the early part of Kharif season in March to May in the Kharif season. In this season crop production in Bangladesh is posed to occasional moderately to heavy storm (Kalboishakhi) which causes either breaking or lodging of the standing maize crop. To overcome this constraint and grow maize in the Kharif season, developing 'dwarf stature' maize varieties is an urgent issue which could be tolerant to such turbulent stormy, windy, drought conditions that prevail generally in the season.

The key breeding features of dwarf stature maize include having a higher base diameter, dwarf plant stature, lower cob position on the plant (at the middle height of the plant), erect leaves with lower angle orientation, early maturity and higher yield productivity. Unfortunately, most of the available commercial maize varieties found in Bangladesh are tall-type (*e.g.* plant height >200cm), long duration (*e.g.* mature at >130-140 days), *etc.* (BARI, 2018) and hence, the varieties are not appropriate for cultivation in Kharif season. If a dwarf stature maize variety could be developed through incorporating the above-mentioned plant breeding features, the new breeds would complete the life cycle within a shorter period escaping the harsh environmental hazards at the pre- or post-tasseling stage. The literature review manifests that till to date very little or sporadic attempts were taken to develop such dwarf stature, early maturity and yield potential appropriate varieties of maize for cultivation in Kharif season in Bangladesh (Amiruzzaman *et al*., 2013; Khan *et al*., 2013; Matin *et al*., 2016; Karim *et al*., 2018).

The availability of appropriate maize inbred lines is a prerequisite for developing promising maize variety. Developing potential inbred lines is a fundamental research approach in maize breeding programs; the success of this depends mainly on the selection of desirable lines from the early segregating generations. In the subsequent generations, the lines are further advanced through self-fertilization to reach the homozygosity of the lines which are used as parental inbred lines in the hybrid breeding program (Kumar *et al*., 2013). Usually, desirable breeding lines are selected through assessment of their genetic variability, heritability, genetic advance, *etc.* (Mishra *et al*., 2015). Also, correlation and path coefficient analyses are applied for the selection of yield contributing traits and thus these techniques help in the understanding of effective selection criteria for yield improvement (Hossain *et al*., 2015).

This study aimed to develop promising dwarf stature promising inbred lines of white maize to use them further as parental lines for developing dwarf stature hybrid maize varieties. In this study, we investigated twenty-four F_3 populations of white maize to screen out the promising short stature, early maturity, and yield potential lines by studying their genetic variability, heritability, genetic advance, correlation, and path analyses. The selected lines are subject to be further advanced to the F_5 stage through self-fertilization to develop stable homozygous inbred lines.

Materials and Methods

Plant materials and growth conditions

Twenty-four (24) F_3 populations of white maize were used in the present investigation (Table 1). These F_3 populations were generated from successive three generations obtained through self-fertilization of eight selected F_1 hybrids following the principles of the pedigree breeding method at the Department of Genetics and Plant Breeding, Sher-e-Bangla Agricultural University (SAU), Dhaka-1207 during 2015 to 2018.

Table 1. List of twenty-four F_3 populations of white maize used in the experiment

Line	Pedigree	Line	Pedigree
G1	Plough- 201- F_3- S_1	G13	PSC-121- F_3- S_1
G2	Plough-201- F_3- S_2	G14	PSC-121- F_3- S_2
G3	Plough-201- F_3- S_3	G15	PSC-121- F_3- S_3
G4	KS-510- F_3- S_1	G16	Q-Xiangnuo-1- F_3- S_1
G5	KS-510- F_3- S_2	G17	Q-Xiangnuo-1- F_3- S_2
G6	KS-510- F_3- S_3	G18	Q-Xiangnuo-1- F_3- S_3
G7	Changnuo-6- F_3- S_1	G19	Youngnuo-3000- F_3- S_1
G8	Changnuo-6- F_3- S_2	G20	Youngnuo-3000- F_3- S_2
G9	Changnuo-6- F_3- S_3	G21	Youngnuo-3000- F_3- S_3
G10	Youngnuo-7- F_3-S_1	G22	Changnuo-1-F_3- S_1
G11	Youngnuo-7- F_3-S_2	G23	Changnuo-1-F_3- S_2
G12	Youngnuo-7- F_3-S_3	G24	Changnuo-1-F_3- S_3

This experiment was conducted using a randomized complete block design (RCBD) with three replications for each twenty-four F_3 population. Seeds of the F_3 population were sown using the line-sowing method maintaining the spacing of 60cm×25cm in a separate block ($3\times3m^2$) for every twenty-four populations. For raising good and healthy seedlings, seeds were treated with Sevin @ 2.0 g/kg of seed before sowing the seeds. All the recommended agronomic package of practices such as thinning, earthen up, fertilizer application, irrigation, weeding, insecticides spraying, *etc.* was performed as recommended for commercial maize production according to BARI annual report 2017-18 (BARI, 2018).

Plant parameters recorded

Sixteen parameters related to growth and yield contributing traits were measured in different growing periods of the crop. Five plants for each population were randomly selected to measure sixteen parameters *viz.* plant height (cm), days to 6th leaf stage, days to 50% tasseling, days to 50% silking, cob position (height) above the soil surface (cm), days to maturity, base diameter of the stem above the soil surface (cm), number of leaves plant^{-1}, number of branches tassel^{-1}, number cob bearing nodes from the soil surface, cob length (cm), cob circumference (cm), number of rows cob^{-1}, number of grains row^{-1}, 100-grain weight (g) and yield plant^{-1} (g).

Estimations and analysis

The genetic variability was estimated for all genotypes according to the formula given by Cochran and Cox **(**1957). The estimation of heritability, genetic advance and genetic advance mean's percentage was calculated according to Comstock and Robinson (1952). The genotypic and phenotypic correlation coefficient and path co-efficient were measured according to Dewey and Lu (1959). Statistical software Statistix10 and Genstat v.2017 which were used by subject to the analysis of variance for different characters was carried out using mean data of three replications to assess the genetic variability among genotypes. The level of significance was tested both at 5% and 1% using the F test.

Results

Growth and yield-related traits

Twenty-four F_3 populations of white maize were characterized by evaluating sixteen growth and yield parameters (Table 2 and Fig. 1). The average days to 6th leaf stage was recorded to be 44.64 with a range from 43.00 (G11) to 46.00 (G20), while the average days of 50% tasseling were recorded to be 73.58 with a range from 66.00 to 77.00 and among the observed lines, G11 and G12 were the earliest male flowering lines (Table 2). The average days to 50% silking was recorded 77.86 days with a range from 70.67 to 84.33, where minimum duration (70.67 days) of 50% silking was observed in the G10 line followed by G11 (71.33 days) and G12 (72.00 days). The minimum time (105.50 day) of maturity was found in the line G11 followed by G12 (107.50 days) and G10 (107.83 days) (Table 2). The highest plant height (220.61 cm) and cob height (111.33 cm) were observed in G5 and G4 lines, respectively; while the lowest values (122.33, 49.72 cm) were recorded in G10 and G12 lines, respectively (Fig. 1A).

Table 2. Mean performance over three replications of different growth parameters of twenty-four F_3 populations of white maize

Genotypes	6th leaf stage *	50% tasseling*	50% silking*	Maturity*	Base diameter**	Leaves plant^{-1}	Tassel branches	Cob bearing nodes
G1	44.00	71.67	74.67	112.33	7.12	12.94	10.67	6.11
G2	44.33	72.00	76.33	115.83	6.92	12.22	10.78	6.54
G3	44.00	73.67	77.33	115.50	7.33	12.56	11.44	6.29
G4	44.67	75.67	80.67	133.17	8.23	13.67	15.40	8.05
G5	45.33	76.00	81.33	135.17	8.14	13.73	14.98	7.82
G6	44.67	75.67	81.00	137.33	8.17	13.73	15.67	8.11
G7	45.67	72.00	75.00	124.33	6.48	12.96	12.47	6.22
G8	45.33	72.67	75.67	120.50	6.26	12.44	13.42	6.44
G9	45.33	72.33	75.00	117.83	6.17	12.72	10.45	6.44
G10	43.33	66.33	70.67	107.83	6.10	12.67	11.00	5.11
G11	43.00	66.00	71.33	105.50	6.15	9.44	9.47	5.05
G12	43.67	66.00	72.00	107.50	6.13	10.00	10.31	5.33
G13	44.33	75.33	78.33	131.50	7.58	9.89	10.89	6.78
G14	44.33	75.67	78.67	131.17	8.04	12.61	11.89	6.95
G15	44.67	77.00	80.00	133.17	8.08	13.33	12.09	6.78
G16	45.33	73.67	77.67	117.17	7.53	13.05	11.33	7.33
G17	45.00	74.33	78.33	120.83	7.62	13.00	11.67	7.11
G18	44.67	73.67	76.67	117.17	7.93	12.11	11.87	6.89
G19	45.67	76.00	82.00	121.50	6.88	13.11	14.11	7.13
G20	46.00	76.00	83.00	122.83	6.69	13.72	13.44	7.40
G21	45.67	76.33	84.33	123.83	6.81	13.55	15.33	7.44
G22	44.00	76.00	79.00	117.17	7.19	13.50	10.67	6.67
G23	44.00	76.00	79.33	117.17	7.15	13.83	12.19	7.00
G24	44.33	76.00	80.33	117.17	7.19	13.00	11.09	7.00
Mean	44.64	73.58	77.86	120.98	7.16	12.66	12.19	6.75
SE	0.58	1.55	1.69	2.55	0.25	0.63	1.54	0.31

*=Days; **=cm

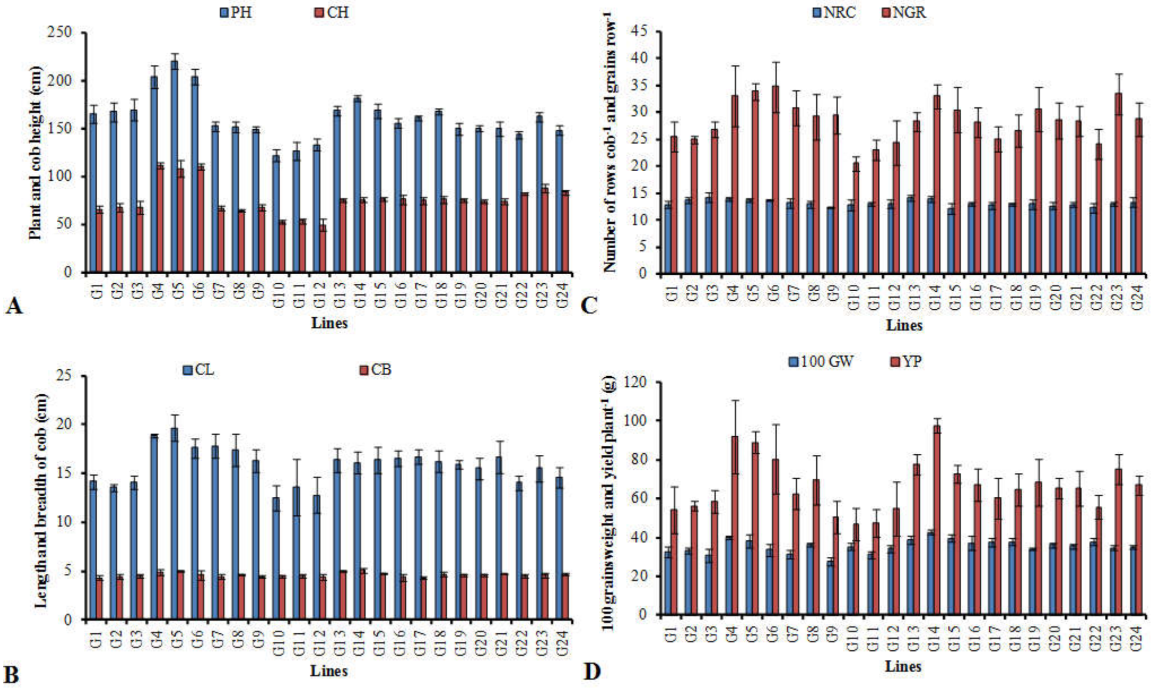

Fig. 1. Mean performance over three replications of white maize: A) plant and cob height (cm); B) the number of rows cob^{-1} and grains row^{-1}; C) length and breadth of cob (cm); D) 100 grains weight and yield plant^{-1} (g) of twenty-four F_3 populations of white maize.

The results of the growth performance of lines suggest that G10 and G12 lines are promising short stature breeding lines as the lines have the earliest tasseling, 50% silking, maturity days, and lowest plant height as well as cob height growth characteristics. Again, the highest number of rows cob^{-1} and grains row^{-1} were found in G3 (14.21) and G6 (34.72), lines, respectively; however, G5 (19.65 cm) and G14 (5.10 cm) lines showed the maximum cob length and cob breadth, respectively (Figs. 1B and 1C). Grain yield varied significantly due to different types of white maize genotypes used in the present study. The maximum 100 grains weight was found in the G14 (42.77 g) line, where G9 showed the lowest performance (27.70 g). The highest yield plant^{-1} was also recorded in the G14 line (97.67 g) followed by G4 (91.82 g), G5 (89.02 g) and G6 (80.26 g). The lowest yield performance was found by G10 (46.94 g) line followed by G11 (47.36 g) and G9 (50.67 g) (Fig. 1D). Tahir *et al.* (2008) studied the yield and yield contributing characters of different genotypes of maize and observed that the maximum grain yield was obtained from the line HG-3740. Ahmad *et al.* (2011) and Idris and Abuali (2011) compared yield and its contributing traits of maize genotypes to find out the best maize genotypes reporting the variations of the tested genotypes in different plant traits. Sesay *et al.* (2016) studied ten top-cross and three-way cross hybrids maize genotypes and compared them based on various growth and yield parameters. Recently, Ahmed *et al.* (2020) and Olawamide and Fayeun (2020) also evaluated different maize genotypes after studying their morphological and yield contributing characters.

Genetic analysis

The analysis of variance for yield and fifteen plant attributes revealed that the mean sum of squares showed significant differences for all the characters of the twenty-four F_3 populations (Table 3). The result suggested ample variations existed in the F_3 population, so there was a great opportunity to select promising lines from the studied population. Hepziba *et al.* (2013) and Nayaka *et al.* (2015) found significant differences in grain yield plant^{-1}, grains row^{-1}, plant height, cob height, and cob length in maize. The variations among the genotypes are due to the genetic or interaction of the genetics with surrounding environmental factors, while the phenotypic variance is the cumulative effect of genotypic and environmental variances. In our study, we estimated the phenotypic (PCV) and genotypic (GCV) coefficient of variation of sixteen characters of the F_3 populations of white maize (Table 3).

The results showed that PCV was higher or slightly higher than the GCV of all the characters (Fig. 2A). The slightly higher PCV values indicated that the characters were largely controlled by the genetic factors and less influenced by the environmental factors, therefore, direct selection would be effective to improve the traits. On the other hand, when the difference between PCV and GCV is higher, it indicates that the characters are highly influenced by the environment (Bartaula *et al.*, 2019) and in that case, the direct selection would not be effective for crop improvement.

In the present study, higher (> 20%), moderate (10-20%), and low (< 10%) PCV and GCV were observed in different traits. The high PCV and GCV were found in cob height (21.55 and 20.99%), while the plant height, tassel branches, cob bearing node, cob length, and grains row^{-1} showed the moderate PCV and GCV. A similar result was also found by Bartaula *et al.* (2019) and Singh *et al.* (2003) for plant height and grain row^{-1}. Again, low PCV and GCV were recorded in 50% tasseling, 50% silking, days to maturity, cob diameter, and the number of rows cob^{-1}. Therefore, low GCV indicated that there was a significant influence of the environment on the expression of these traits. Assessment of phenotypic variation alone is not an effective way for selection (Beulah *et al.*, 2018) of elite lines from the breeding populations.

Hence, estimations of heritability coupled with genetic advance (GA) have been considered as an important index in selection purposes (Bartaula *et al.*, 2019). High heritability coupled with high GA is considered as good selection criteria.

In the present experiment, high heritability coupled with high GA in the percentage of the mean was observed in plant height (92.15, 28.30), cob height (94.92, 42.13), number of cob bearing node (86.74, 22.48), number of grain row^{-1} (70.87, 21.30) and grain yield plant^{-1} (71.03, 33.05) (Fig. 2B).

Table 3. Estimation of phenotypic, genotypic, and environmental variance for different characters of twenty-four F_3 populations of white maize.

Parameters	**MSS**	**σ^2p**	**σ^2g**	**σ^2 e**
Plant height (cm)	1.88**	580.07	534.56	45.51
6th leaf stage (days)	32.56**	0.85	0.52	0.33
50% Tasselling (days)	38.43**	12.45	10.05	2.40
50% Silking (days)	1649**	14.71	11.86	2.85
Cob height (cm)	775.22*	267.47	253.87	13.60
Maturity (days)	236.29*	83.10	76.60	6.50
Base diameter (cm)	1.54**	0.56	0.49	0.06
Leaves plant^{-1}	4.46**	1.75	1.35	0.40
Tassel branches	9.60**	4.78	2.41	2.37
Cob bearing nodes	1.97**	0.72	0.63	0.10
Cob length (cm)	10.07**	4.45	2.81	1.64
Cob diameter (cm)	0.14**	0.08	0.03	0.05
Rows cob^{-1}	0.94**	0.59	0.18	0.42
Grains row^{-1}	41.45**	17.14	12.15	4.99
100-grains weight (g)	35.37**	14.80	10.29	4.51
Yield plant^{-1} (g)	548.37*	226.54	160.91	65.63

** Indicates significant at 1% level; MSS: the mean sum of the square; σ^2g: Genotypic variance; σ^2P: Phenotypic variance; σ^2e: Environmental variance.

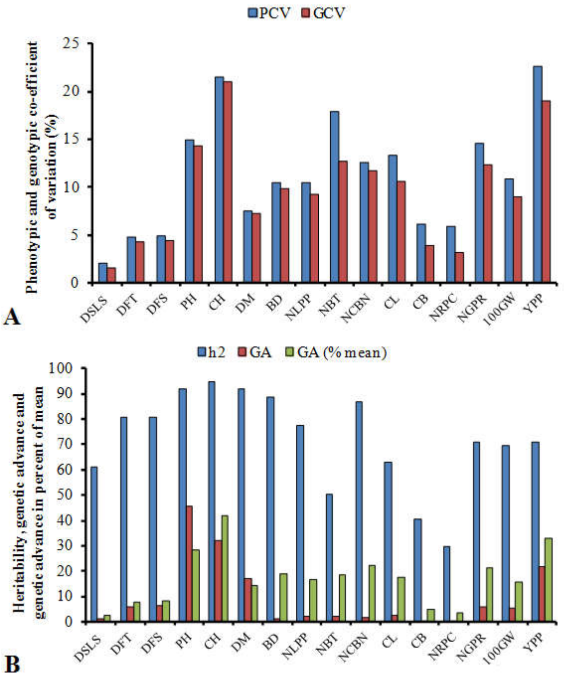

Fig. 2. Estimation of genetic parameters for different characters in white maize: A) phenotypic (PCV) and genotypic (GCV) co-efficient of variation; B) heritability (h2), genetic advance (GA), and genetic advance in percent of the mean (GA%).

The high heritability coupled with high GA in these traits were probably due to the effect of additive gene action for the expression of these traits so that direct selection based upon these characters would be effective for genetic improvement of the traits. Ghimire and Timsina (2015) and Bartaula *et al.* (2019) reported high heritability and high GA for plant height, cob height, number of grains row^{-1}, ear height, and grain yield in maize genotypes. On the other hand, number branches of the tassel (50.40, 18.62) showed moderate heritability and GA in percent of the mean, while low heritability and GA in percent of the mean was observed in the number of rows cob^{-1} that indicated the traits were controlled by non-additive gene action and direct selection for those characters would not be effective.

Correlation analysis

Knowledge about character associations helps to identify the characters correlated with yield and also to determine the extent and nature of relationship exist among the yield contributing characters. In the present study, yield plant^{-1} showed highly significant difference among the tested lines which had positive correlation with plant height (0.790), cob height (0.756), days to maturity (0.827), cob length (0.729), cob breadth (0.904), number of rows cob^{-1} (0.543), number of grain row^{-1} (0.776), 100 grain weight (0.677), 50% tasseling (0.676) and base diameter (0.753) (Figs. 3A-J).

Pandey *et al.* (2017) observed that the positive correlation was present in the association of cob length with grain yield (0.618). Sumathi *et al.* (2005) also found a strong relation between 100-grain weight and grain yield, but that relationship was negative. However, Beulah *et al.* (2018) found strong correlations between grain yield and 100-seed weight. In the present study, we found that the yield plant^{-1} was strongly and positively correlated with plant height, cob height, days to maturity, cob length, and cob breadth. So, this is an indication of the existing strong inherent correlation between the yield components and yield. Therefore, these traits could be considered for selection activity for the improvement of yield in white maize.

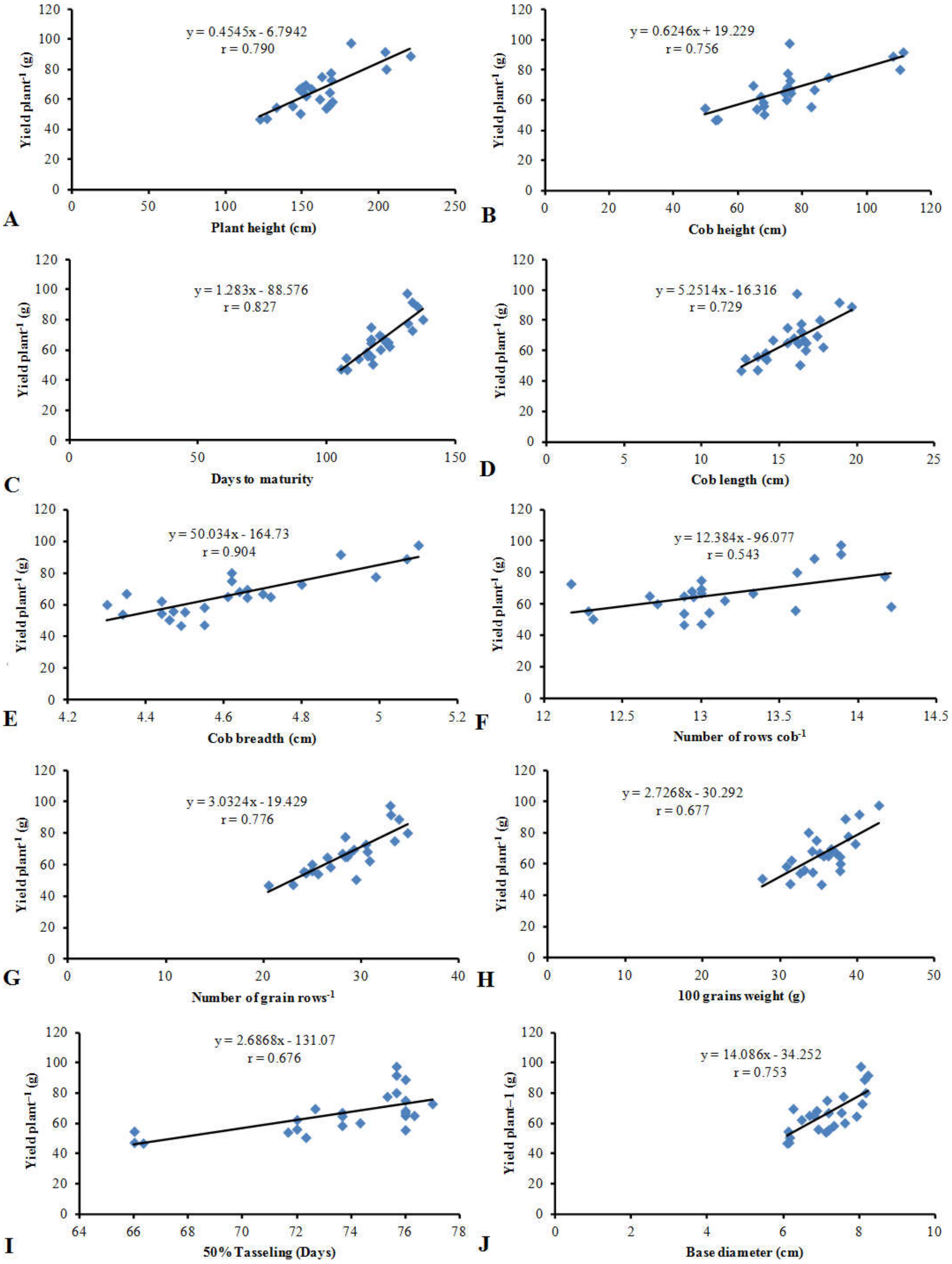

Fig. 3. Correlations between yield plant^{-1} and yield contributing traits of twenty-four F_3 populations of white maize.: A) plant height; B) cob height; C) days to maturity; D) cob length; E) cob breadth; F) rows cob^{-1}; G) number of grains^{-1}; H) 100 grains weight; I) 50% tasseling; J) base diameter.

Analysis of path coefficient

Association of characters determined by correlation analysis might not provide an exact picture of the relative proportions of direct and indirect contributions of each component traits on yield plant^{-1}. Therefore, to find out a clearer picture of the inter-relationship between yield plant^{-1} and other yield attributes, direct and indirect effects were calculated using path analysis at the genotypic level, which also measured the relative importance of each component (Table 4). The results of the present investigation on path coefficient analysis revealed that grains row^{-1} (0.669), 100 grains weight (0.502), row cob^{-1} (0.173), cob length (0.062), cob diameter (0.040), days to 50% silking (0.084) and plant height (0.005) had a highly-positive and direct effect on yield plant^{-1}. Reddy and Jabeen (2016) also found the direct effect of days to silking on grain yield plant^{-1} followed by the number of kernels row^{-1}, 100-seed weight, and ear girth. On the other hand, direct and negative effects on yield plant^{-1} were contributed through days to 6th leaf stage (-0.025), days to 50% tasseling (-0.088), cob height (-0.010), days to maturity (-0.212), leaves plant^{-1} (-0.017) and the number of cob bearing node (-0.050).

The results of a path analysis revealed that 100-grain weight and grains row^{-1} had a very strong relationship with yield plant^{-1} that means the direct selection for these traits would be convenient to improve the yield.

Selection of dwarf lines

From the above results that deciphered the agronomic performance of the twenty-four F_3 lines, heritability, the genetic advance of yield attributes and their degree and nature of associations, the traits *e.g.* plant height, days to maturity, base diameter, cob bearing node, cob breadth, number of grain row^{-1} and 100-grain weight were considered as selection parameters for identifying promising lines from the F_3 population. Rafiq *et al.* (2010) selected the best maize genotypes based on grains per row, 100-grain weight, grain rows per ear, ear length and ear diameter, while Reddy *et al.* (2012) emphasized on days to 50% tasseling, 100-seed weight, ear length, days to maturity, ear height, number of kernels per row, ear height, number of kernel rows per ear and plant height for selecting the elite genotypes, hence these traits were found to be the important direct contributors to grain yield in maize.

In another study, ear diameter, ear length, and kernel number/row were considered as selection criteria for yield improvement of sweet corn (Chozin *et al.*, 2017). In the present study, the F_3 lines - G14, G4, G5, and G6 showed the highest grain yield plant^{-1} performance (80-97g), however, these lines took maximum days for maturity (131-133 days) and showed the maximum plant height (181-202 cm), cob height (108-110 cm), cob bearing nodes (7-8) (Table 2 and Fig. 1), hence, these lines were assumed not suitable to be dwarf stature promising lines, but might be considered as high yielding and late maturity breeding lines. In contrast, the lines having the minimum plant height, early maturity, base diameter, cob height, and reasonable yield potential were selected as dwarf stature promising lines. Based upon this notion, the lines G10, G11, G12, G1, G3, and G16 were considered as the best candidates as promising dwarf stature lines. These selected F_3 lines are dwarf stature due to their minimum plant height (122-155 cm), cob height (49.72-67.83 cm), number of cob bearing node (5-6), days to maturity (105-112 days) and yield plant^{-1} (46.95-58.55g) (Table 2 and Fig. 1). Therefore, it can be assumed that having the dwarf stature nature, these breeding lines would be less affected in the unfavorable weather conditions that normally prevail in the Kharif season. So considering this, it may be said that these lines might serve as potential genetic resources for the development of promising dwarf stature inbred lines of white maize. The selection of appropriate breeding lines from early segregation generations is very important to develop inbred lines. The genetic analysis and agronomic performances of twenty-four F_3 populations of white maize showed that plant height, days of maturity, base diameter, cob height, and yield potential can serve as an excellent index for selection criteria of 'dwarf stature' breeding lines. Again, based on the selection criteria the lines, G10, G11, G12, G1, G3, and G16 were the dwarf stature promising lines, which will be advanced further to the F_5 stage to develop elite inbred lines of white maize.

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Conflicts of interest

The authors have no competing interests.

Table 4. Partitioning of the genotypic correlation coefficient into direct (bold) and indirect effects.

Parameter	**6th leaf stage**	**50% tasseling**	**50% silking**	**Plant height**	**Cob height**	**Maturity**	**Base diameter**	**Leaves plant^{-1}**	**Tassel branches**	**Cob bearing nodes**	**Cob length**	**Cob diameter**	**Rows cob^{-1}**	**Grains row^{-1}**	**100-grains weight**	**Genotypic correlation with yield**
6th leaf stage	**-0.025**	-0.056	0.058	0.001	-0.003	-0.118	0.007	-0.010	0.049	-0.036	0.052	0.004	-0.056	0.396	0.039	0.302**
50% tasseling	-0.016	**-0.088**	0.077	0.003	-0.007	-0.167	0.037	-0.012	0.044	-0.046	0.044	0.024	0.031	0.494	0.258	0.676**
50% silking	-0.017	-0.080	**0.084**	0.003	-0.007	-0.154	0.030	-0.012	0.057	-0.047	0.041	0.022	0.030	0.455	0.232	0.637**
Plant height	-0.007	-0.053	0.046	**0.005**	-0.008	-0.174	0.044	-0.007	0.045	-0.038	0.049	0.028	0.127	0.524	0.209	0.790**
Cob height	-0.008	-0.066	0.062	0.004	**-0.010**	-0.166	0.041	-0.011	0.053	-0.045	0.049	0.025	0.075	0.542	0.211	0.756**
Maturity	-0.014	-0.069	0.061	0.004	-0.008	**-0.212**	0.038	-0.008	0.055	-0.041	0.055	0.034	0.072	0.575	0.285	0.827**
Base diameter	-0.003	-0.063	0.049	0.004	-0.008	-0.159	**0.051**	-0.007	0.032	-0.038	0.037	0.025	0.089	0.403	0.341	0.753**
Leaves plant^{-1}	-0.015	-0.062	0.057	0.002	-0.006	-0.096	0.020	**-0.017**	0.050	-0.035	0.031	0.003	-0.048	0.371	0.098	0.353**
Tassel branches	-0.019	-0.059	0.073	0.003	-0.008	-0.178	0.025	-0.013	**0.066**	-0.045	0.060	0.026	0.060	0.575	0.190	0.756**
Cobe bearing nodes	-0.018	-0.080	0.079	0.004	-0.009	-0.174	0.039	-0.012	0.059	**-0.050**	0.053	0.022	0.060	0.553	0.243	0.769**
Cob length	-0.021	-0.062	0.055	0.004	-0.008	-0.189	0.031	-0.008	0.064	-0.043	**0.062**	0.026	0.050	0.578	0.190	0.729**
Cob breadth	-0.002	-0.052	0.047	0.003	-0.006	-0.180	0.032	-0.001	0.043	-0.027	0.041	**0.040**	0.129	0.462	0.375	0.904**
Rows cob^{-1}	0.008	-0.016	0.015	0.004	-0.004	-0.088	0.026	0.005	0.023	-0.017	0.018	0.030	**0.173**	0.249	0.117	0.543**
Grains row^{-1}	-0.015	-0.065	0.057	0.004	-0.008	-0.182	0.031	-0.009	0.056	-0.041	0.054	0.028	0.064	**0.669**	0.133	0.776**
100-grains weight	-0.002	-0.045	0.039	0.002	-0.004	-0.120	0.035	-0.003	0.025	-0.024	0.024	0.030	0.040	0.178	**0.502**	0.677**

Residual effect: 0.0014; ** = Significant at 1%

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