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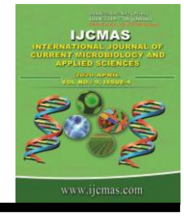

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Morphological and Genetic Variations among Advance Breeding Lines and Varieties of Brinjal Grown in Eastern Gangetic Plains of India

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A B S T R A C T

Understanding the genetic variability and diversity of a crops species provides opportunity for plant breeders to develop new and improved cultivars having both farmer-preferred and breeder-preferred traits. In the present study 11 morphological characters and 16 quantitative characters were recorded from 27 advance breeding lines/varieties to identify useful alleles for future breeding. Genotypes varied considerably in plant growth and morphological characters. The overall mean of Shannon-Wiener diversity index (H') value was 0.733 with predominant traits that exhibited wider variations were fruit colour, fruit curvature, fruit shape and growth habit, confirmed the existence of diversity among the genotypes. The genotypes BCB-40, Bidhan Super, Garia exhibited high marketable yield, and fruits of SM-6-6, Arka Nidhi, 13/BRBW RES-3 were least infested by borer attack. The genetic differences among these genotypes are potentially relevant to breeding programmes in that the variability created through hybridization of the contrasting forms could be exploited to get desirable recombinant in future.. High, genotypic coefficient of variation, heritability coupled with genetic advance for primary branches per plant, fruit length, fruit diameter, fruits per plant, fruit weight, marketable fruit yield per plant, anthocyanin content of peel, total sugar, reducing sugar, non-reducing sugar contents of fruit, shoot infestation by borer and fruit infestation by borer indicated that these traits are predominantly governed by additive gene action, so early generation selection would be helpful for improving these traits. Number of fruits per plant and fruit weight should be considered as the most important selection indices for enhancing marketable fruit yield in brinjal.

Introduction

Brinjal (*Solanum melongena* L.) is ubiquitously grown throughout the country and consumed as vegetable in every class of peoples because of its acceptability, all round availability, appreciably high nutritive, anti-oxidant and medicinal values. Brinjal is considered as one of the top 10 vegetables in terms of antioxidant capacity (Cao *et al.*, 1996), and contains a variety of antioxidants and phytochemicals ascorbic acid, phenolics, and flavonoids that provide health benefits (Akanitapichat *et al.*, 2010). The most abundant phenolic compound is chlorogenic acid (ChA), which is considered as the main contributor to the overall antioxidant capacity (Whitaker and Stommel, 2003). In purple pigmented eggplants, the antioxidant anthocyanins (delphinidin derivatives) is limited as found at the peel tissue which represents less than 5% of the total fruit weight (Plazas *et al.,* 2013).

However, nasunin (delphinidin-3-(*p*-coumaroylrutinoside)-5-glucoside), an anthocyanin isolated from the skin of purple eggplant fruit, is associated with both inhibition of hydroxyl radical generation and superoxide scavenging activity (Akanitapichat *et al.,* 2010).

The crop has large diversity for plant and fruit morphological traits (Cericola *et al.,* 2013) and large number of landraces, cultivars, varieties and hybrids have been cultivated throughout the country according to market needs and regional preference (Sidhu *et al.,* 2005; Gangopadhyay *et al.,* 2010; Chattopadhyay *et al.,* 2011). Genotypes of brinjal involving mixture of fruit shapes, sizes, and colours have been characterized in the eastern Gangetic plains of India through different studies (Hazra *et al.,* 2003; Chattopadhyay *et al.,* 2011; Shende *et al.,* 2016; Dutta *et al.,* 2019). Genotypes having desirable alleles have been identified and involved in different hybridization programme to develop some new varieties for this region. Now-a-days the strategy of brinjal breeder is to develop not only varieties with high yield and pest resistance (especially fruit and shoot borer), but also with good fruit quality that has both commercial values and antioxidant activities.

At present the productivity of brinjal is quite low (17.30 t/ha) in India (Anonymous, 2017). Hence, adequate emphasis needs to be given for the development of high yielding varieties and hybrids to increase the productivity comparable to other leading producing countries in the world. Evaluation of the potentialities of the existing germplasm is very essential because it is the genetic diversity of the initial parental material, on which depends the promise for further crop improvement. The observed variability is a combined measure of genetic and environmental causes. The heritable variability and more particularly its genetic component, is clearly the most important aspect of the genetic constitution of the breeding material, which has a close bearing on its response to selection. A measure of heritability and genetic advance give an idea about the expected gain in next generation. Thus high yield can be achieved by selection of those characters that have high heritability coupled with genetic advance. Selection of one trait invariably affects several associated traits which evokes determination of the relationship of various component traits. Knowledge, and the nature and magnitude of variation existing in available breeding materials are requisite to choose characters for effective selection of desirable genotypes to undertake planned breeding program. The present study was undertaken to identify potential brinjal genotype with respect to marketable yield and FSB tolerance, to assess variability for qualitative and quantitative traits among genotypes, and to identify set of characters for marketable yield improvement in brinjal.

Materials and Methods

Plant materials and field growing

Field experiments were conducted during 2017-18 at research plot of AICRP on Vegetable Crops, Bidhan Chandra Krishi Viswavidyalaya, Kalyani, Nadia, West Bengal. Twenty-seven advance breeding lines/varieties of brinjal collected from different places of India constituted the plant materials for this study.

Seeds, after treatment with Thiram (3 g/kg of seed), were sown in well-prepared seed bed during the 4th week of July, 2017 at a shallow depth 5 cm apart and covered with finely sieved well rotten leaf mold (leaves left to decompose for two year) which acts as soil improver and to prevent the soil drying out. Thirty days old seedlings of all genotypes were transplanted during 1st week of September, 2017 in 3.6 m × 3.6 m plot spaced at 60 cm in both ways accommodating 30 plants in each plot for each genotype in the main field randomized block design with three replications. Well rotten FYM @ 10 tons/ha was applied in the field during the final land preparation. The crop was fertilized with 150 kg N, 75 kg P_2O_5 and 75 kg K_2O/ha. Management practices as scheduled for cultivation were followed as per Chattopadhyay *et al.,* (2007).

Observations recorded

The following observations on both qualitative and quantitative characters were recorded from 10 randomly selected plants of each plot in each replication.

Qualitative parameters

Growth habit, leaf blade lobing, leaf blade tip angle, leaf prickliness, leaf blade colour, corolla colour, fruit colour, fruit curvature, fruit shape, fruit pedicel prickliness, fruit calyx prickliness, and fruit calyx colour.

Quantitative parameters

Plant height (cm), primary branches per plant, days to first flowering, fruits length (cm), fruit diameter (cm), fruits per plant, fruit weight (g), marketable fruit yield per plant (kg), shoot phenol content (mg/100 g), fruit phenol content (mg/100 g), peel anthocyanin content (mg/100 g), total sugar content (%), reducing sugar content (%), non-reducing sugar content (%), shoot borer infestation (%) and fruit borer infestation (%) were recorded. Total, reducing, non-reducing sugar and anthocyanin contents of fruit were estimated by the method of Ranganna (1986). Shoot phenol and fruit phenol contents were estimated by the method of Sadasivam and Manickam (1996).

Recording of FSB infestation

For the estimation of shoot and fruit borer infestation, number of healthy and damaged shoots was recorded at 60 days after transplanting (DAT), and fruits at 120 DAT and per cent damage of shoot and fruit was calculated. The grades were assigned for the fruit damage percentage based on the following rating as per Mishra *et al.,* (1988).

Grade	Reaction	% Fruit infestation
Grade 1	Immune	0
Grade 2	Highly resistant	1–10
Grade 3	Moderately resistant	11–20
Grade 4	Tolerant	21–30
Grade 5	Susceptible	31-40

Statistical analyses

The data were subjected to the analysis of variance for randomized block design as suggested by Panse and Sukhatme (1978). Frequency distribution was calculated from a set of morphological qualitative data from all the available variations in brinjal descriptor showing the number of occurrences (frequency) at each value or range of values. The frequency distributions were used to calculate the Shannon-Wiener diversity index (H’) for each character (Zeven and Hennink, 1991). The index is defined as:

$$H' = -\sum_{i=1}^{s}(pilnPi)$$

Where H'= diversity index; S = Total number of descriptors in the i^{-th} descriptor; Pi = fraction of individuals belonging to the i^{-th} descriptor state (number of observations/descriptor state in i^{-th} descriptor divided by the total number of characterized plants).

The genotype and phenotypic co-efficient of variations were calculated as per by Burton (1952). Heritability in broad sense (H) was estimated by the formula given by Hanson *et al.,* (1956). The expected genetic advance (GA) was calculated by the formula as suggested by Johnson *et al.*, (1955) and Lush (1949). Direct and indirect effects of component traits on marketable fruit yield were calculated through path coefficient analysis as suggested by Dewey and Lu (1959). Statistical analyses were with Windostat (ver.8.0, Indostat Services, Hyderabad, India).

Results and Discussion

Morphological characterization of genotypes

Twelve morphological characters recorded in 27 genotypes of brinjal as per the descriptors of IBPGR are presented in Table 1. Frequency distribution patterns, percent of proportion and Shannon-Weaver Diversity Index (H') were estimated from 13 qualitative characters and results are presented in Table 2. Most of the genotypes (59.26%) showed semi-erect growth habit followed by erect growth habit in 25.93 % and spreading growth habit in 14.81% genotypes (Table 2). 74.07 % genotypes had leaves with strong lobbing and 25.93 % genotypes had leaves with intermediate lobbing. Leaf blade tip angle of the genotypes varied from 92.59 % genotypes had leaf tip with intermediate angle to only 7.41 % genotypes had leaf tip with acute angle.

Propensity of prickle development was comparatively less in leaf and fruit pedicel because 96.30 % genotype had no prickles on leaf and 81.48 % genotypes had fruit pedicel without prickles. On the other hand, almost half of the genotypes (51.85 %) had prickles on the fruit calyx and rest half (48.15 %) had no prickles on the fruit calyx. Of the genotypes, 74.07 % had green leaves, 18.52 % had dark green and 7.41 % produced light green leaves. On the other hand, 26 out of 27 genotypes under this investigation had pigmented corolla (purple and light purple) while the single genotype, BRBW-3 had white flower**.** Expression of pigment in fruit calyx was different compared to that of the leaf and corolla.

Of the total number of genotypes, 55.56 % had green calyx with purple tinge and rest 44.44 % genotypes had green calyx**.** Colour development in the fruits appeared to be a pronounced character because 81.49 % genotypes under study had fruit pigmentation of different intensities. The genotypes fell in 7 colour groups *viz*., deep purple (51.85%), purple (22.22 %), green (11.11 %), green with white spot (3.70 %), green with purple stripe (3.70 %) and white (3.70%). The colour differences of fruits are basically due to two colour pigments, chlorophyll a and b and anthocyanin which are in different amounts and in combination determine the exact color of the fruit. In this investigation most of the genotypes showed fruits of three distinct shape viz., long (37.04 %), round (33.33 %) and oblong (25.93%). Fruit curvature of genotypes varied from no curvature (40.74 %) while rest of the genotypes had fruits with different types of curvature *viz*., slightly curved (33.33 %), curved (18.52 %) and snake shaped (7.41 %). Genotypic variation in plant morphological traits particularly fruit colour, fruit curvature, fruit shape and growth habit in brinjal was also documented in our previous studies (Chattopadhyay *et al.,* 2011; Lalramhlimi *et al.,* 2019).

Biodiversity in crops can be summarized with two of its components, alellic evenness and allelic richness. The descriptor and descriptor states are parallel to the locus and alleles, respectively in morphological evaluation. The allellic evenness in this study was measured using the Shannon-Wiener Diversity Index, whereas the allelic richness was measured by counting the descriptor states for each descriptor without considering their individual frequencies. The richness indicates the number of genotype present in a designated area whereas evenness stands for the relative abundance of each genotype. The value of Shannon-Wiener diversity index (H') for all characters varied from 0.42 for corolla colour to 1.408 for fruit colour.

High Shanon-Wiener diversity index with an overall mean of 73% was obtained, confirming the existence of diversity among the genotypes. The predominant traits that showed wider variations among the genotypes were fruit colour, followed by fruit curvature, fruit shape and growth habit. The Shannon-Wiener index values can range from 0 to ~ 4.6.

A value near 0 indicated that every species in the sample is the same and a value near 4.6 indicated the numbers of individual are evenly distributed between the brinjal genotypes. A low H' indicates unbalance frequency class and lack of diversity for the traits. A higher H' value indicates presence of variability or diversity for the trait (Hennink and Zewan, 1991). Values below overall mean indicate unbalance frequency class and lack of diversity for the traits. Gangopadhyay *et al.*, (2010) also studied the Shanon-Wiener diversity index and they observed highly divergent qualitative traits of indigenous and exotic collections of brinjal in India.

Mean performance of genotypes

Genotypes showed highly significant variations for different quantitative characters under study (Table 3). Plant height varied widely between 57.61 cm in 13/BRBW RES-3 and 125.59 cm in BCB-50, the mean being 88.18 cm. Primary branches per plant also varied widely between 2.09/plant in Arka Kusumkar and 6.06 in BCB-50, the mean being 4.01. Days to first flowering did not vary much among the genotypes.

Bidhan Supreme was the earliest genotype which flowered 29.32 days after planting while flower appeared late (38.39 days after planting) in 15/BRR VAR-4, the mean being 32.83 days after planting. Combination of both fruit length and diameter together determine fruit shape. Fruit length varied widely between 9.11 cm in 13/BRR VAR-1 and 20.99 cm in 13/BRBW RES-2, the mean being 13.93 cm.

The minimum fruit diameter was observed in Arka Nidhi (3.19 cm) and the maximum was observed in KS-224 (9.42 cm). Fruit number/plant varied considerably between 4.19 in 13/BRBW RES-4 and 23.36 in 15/BRL VAR-5. Fruit weight varied between 55.54 g in SM-6-6 and 246.89 g in BCB-50, the mean being 124.39 g. In case of marketable fruit yield/plant, Arka Nidhi showed minimum fruit yield (0.55 kg/plant) and BCB-40 showed maximum fruit yield (3.01 kg/plant) followed by Bidhan Super (2.33 kg/plant) and Garia (2.32 kg/plant), with the mean yield of 1.33 kg/plant. Reactions of different genotypes in terms of shoot and fruit infestations differed substantially at 60 and 120 DAT, respectively. The range of shoot infestation varied from 0.12 to 1.33 % and that of fruit infestation between 13.65 and 65.33 % (Table 3).

The maximum shoot infestation was recorded in 2015/BRL VAR-4 (1.33%) followed by 2013/BRL VAR-1 (1.03%) and the minimum was observed in 10/BRBW RES-4 (0.12%). None of the genotypes were found immune or even highly resistant against fruit borer. Fruit infestations were less than 20% in small fruited genotypes SM-6-6, Arka Nidhi, and 2013/BRBW RES-3 and were categorized as moderately field resistant. Rest of the genotypes exhibited either tolerant or susceptible reactions according to the categorization scheme (Mishra *et al.*, 1988).

No apparent relationship was observed between shoot and fruit infestation among genotypes which agreed well with our previous study (Mandal *et al.*, 2019). It was quite obvious because brinjal shoot borer bore into the shoot at the vegetative stage of the plant before the fruits are formed. After formation of fruits, the borer preferred only heavy, thick, plump and palatable fruits for their feeding.

This result amply justified the proposition of larval non-preference and antibiosis mechanisms for conferring resistance in genotypes against this insect pest. Genotypes showed highly significant variations among different fruit quality characters (Table 4). The lowest shoot phenol content of 2.48 mg/100 g fresh was recorded in small-fruited genotype 13/BRBW RES-1 and the highest of 4.59 mg/100 g fresh was observed in medium-fruited genotype Punjab Sadabahar. The lowest fruit phenol content (2.19 mg /100 g fresh) was found in small fruited genotype 13/BRBW RES -1 and the medium-fruited genotype, Punjab Sadabahar had the highest content of fruit phenol (3.52 mg /100 g fresh), the mean being 2.72 mg/ 100 g fresh was lesser than its content in the terminal shoot (3.72 mg /100g fresh). Only two genotypes (Bidhan Supreme and BCB-50) produced whitish-green fruits with very low content of anthocyanin pigment (4.71 and 1.51 mg/100 g fresh weight, respectively).

In rest of the genotypes, this pigment varied widely between 54.98 mg/100 g fresh in Garia and 103.76 mg/100 g fresh in Punjab Sadabahar. Total sugar content varied widely between 0.79 % in 13/BRBW RES -3 and 2.98 % in 13/BRL VAR-6, the mean being 1.93 %. The genotype 13/BRBW RES -3 with the fruits having the lowest total sugar content (0.79%) also had the lowest reducing sugar (0.60 %) and non-reducing sugar (0.19 %) contents. The highest reducing sugar content (2.09 %) was recorded in genotype 13/BRL VAR-3 which had very high but not the highest total sugar content (2.72 %). In the similar manner, the highest non-reducing sugar content (1.07 %) was recorded in genotype 13/BRL VAR-6 which had the highest total sugar content (2.98 %).

Vegetables are considered as important ingredient in human diet, since they diversify color of various food products and they also possess beneficial health effects (Carlsen *et al.*, 2010; Luo *et al.*, 2015). Consumption of purple/blue coloured produce is linked with increased nutrient intake and reduced risk for metabolic syndrome (Mcgill *et al.*, 2011). The anthocyanin concentration in purple fruited brinjal cultivars is higher in comparison to other deeply coloured fruits and vegetables (Wu *et al.*, 2006).

Examining the anthocyanins content of different fruit colours of brinjal, Xi-Ou *et al.*, (2017) observed that the anthocyanin content of purple-black fruit was higher than wild brinjal, while green or white fruit had the lowest levels of anthocyanin. Zhang *et al.,* (2014) reported the total anthocyanins content from purple fruited brinjal to be 1.24 mg/g dw. These results agreed well with the findings of the present study. Wide genotypic variation in total sugar and phenol contents was also observed by Shende *et al.,* (2016) and Dutta *et al.,* (2019). Small fruited genotypes which were least infested by fruit borer had comparatively higher phenol and lower sugar contents than big fruited genotypes.

Our previous study (Dutta *et al.,* 2019) also established the fact that fruit borer infestation in brinjal is negatively correlated with phenol content and positively with total sugar content of fruit. Fruit borer resistance has conferred on the small fruited genotypes in the present study through over-expression of phenolic compounds and down regulation of feeding stimulant (sugar) for this pest (Mandal *et al.,* 2019). Phenolic compounds work by producing reactive oxygen species, specifically tannins get oxidized in the guts of insects and the oxidation products have the potential to damage vital nutrients causing either insect deterrence or antibiosis (Summers and Felton, 1994). Thus incorporation of fruit borer resistance into large-fruited brinjal varieties would be a major challenge to breeders for coming years, suggesting linkage between small fruit size and borer resistance.

Genetic variability and heritability

The result on analysis of variances (ANOVA) using randomized block design revealed that the genotypes exhibited highly significant differences for all the characters studied even at 1% level of significance (Table 5) which clearly endorsed the justification of studying genetic variability of different characters employing these genotypes. Coefficient of variation was widely different ranging from low of 3.54 to moderate of 14.82 (Table 3 and 4). The nature and extent of genetic variability is one of the most important criteria in formulating an efficient breeding programme and knowledge of phenotypic coefficient of variation (PCV) and genotypic coefficient of variation (GCV) is much helpful in predicting the amount of variation present in a given assemblage of genotypes.

The genetic co-efficient of variation measures the range of genetic variability shown by the plant character and help to compare the genetic variability present in various characters (Singh *et al.,* 1974). In the present investigation, the phenotypic coefficient of variations were slightly higher than the corresponding genotypic coefficient of variations for all the characters studied (Table 6) which indicated that the apparent variation was not only due to genotypes but also due to the influence of environment in the expression of the traits. However, the influence of environment for the expression of characters was not very high suggesting appreciable genotypic worth for all the characters. Such inference could also be drawn from the magnitude of low to moderate coefficient of variation for the characters. Hence, the characters could be improved following different phenotypic selections like directional, disruptive and stabilized selections.

Phenotypic coefficients of variation (PCV) and genotypic coefficients of variation (GCV) were categorized as low (0-10%), moderate (10-20%) and high (>20%) as indicated by Sivasubramanian and Madhavamenon (1973). Accordingly, very high PCV and GCV values were recorded for shoot infestation by borer (PCV 79.49; GCV 78.10) which indicated the highest magnitude of variability for this character. High magnitude of GCV and PCV, respectively were recorded for marketable fruit yield per plant (PCV 48.36; GCV 47.16), fruits per plant (PCV 45.62; GCV 44.70), average fruit weight (PCV 44.37; GCV 44.23), non-reducing sugar content (PCV 41.14; GCV 38.39), fruit infestation by borer (PCV 37.54; GCV 36.37), total sugar content (PCV 31.29; GCV 30.05), anthocyanin content of fruit peel (PCV 29.51; GCV 29.26), primary branches per plant (PCV 29.15; GCV 27.10) and fruit length (PCV 28.38; GCV 27.52). Moderate PCV and GCV were registered for the characters plant height (PCV 16.83; GCV 16.43), shoot phenol content (PCV 15.54; GCV 14.66) and fruit phenol content (PCV 16.66; GCV 15.71).

These results corroborated with the earlier reports for plant height (Madhavi *et al.*, 2015), fruit length (Ravali *et al.*, 2017), fruit diameter (Madhavi *et al.*, 2015; Ravali *et al.*, 2017; Dutta *et al.*, 2018), fruit weight (Madhavi *et al.*, 2015; Ravali *et al.*, 2017; Banerjee *et al.*, 2018) and fruit yield per plant (Mangi *et al.*, 2016; Ravali *et al.*, 2017). High to moderate magnitude of GCV and PCV generally indicated ample scope for improvement through selection. The present findings clearly suggested the worth of marketable fruit yield per plant, fruits per plant, average fruit weight, non-reducing sugar content, total sugar content, anthocyanin content of fruit peel, primary branches per plant and fruit length for the study of genetic variability in brinjal.

Genotypic coefficients of variation do not estimate the variations that are heritable hence, estimation of heritability becomes necessary (Falconer, 1960). Heritability is of interest to the plant breeder primarily as a measure of the value of selection for particular character in various types of progenies and as an index of transmissibility (Hayes *et al.*, 1955). So the concept of heritability is important to evaluate the relative magnitude of the effect of genes and environments on total phenotypic variability. Heritability was classified as low (below 30%), medium (30-60%) and high (above 60%) as suggested by Johnson *et al.*, (1955). Considering this delineation, very high heritability values ranging from 86.0 to 98.0 percent were observed for plant height, primary branches per plant, fruit length, fruit diameter, fruits per plant, fruit weight, marketable fruit yield per plant, total phenol content of shoot, total phenol content of fruit, anthocyanin content of peel, total sugar content, reducing sugar content, non-reducing sugar content, shoot infestation by borer and fruit infestation by borer (Table 6).

High heritability indicates less environmental influence in the observed variation (Songsri *et al.*, 2008) which suggested that selection based on phenotypic expression could be relied upon as there was major role of genetic constitution in the expression of these characters. Broad sense heritability estimate was moderate for days to first flower (70.00 %). The overall scenario of broad sense heritability estimates indicated very high efficiency of selection for the almost all the characters under study. Broad sense heritability values were higher for fruit length, fruit diameter, plant height, number of fruits/plant and fruit weight which support findings of Ambade *et al.*, (2013) and Manpreet *et al.*, (2013), Banerjee *et al.*, (2018), Dutta *et al.*, (2018) and Lalramhlimi *et al.*, (2019). Genetic advance is the improvement in performance of selected lines over the original population. Johnson *et al.*, (1955) suggested that heritability estimate in combination with substantial amount of genetic advance would be more reliable than heritability alone for predicting the effect of selection in segregating generation. The estimate of genetic advance showed a wide range from very low of 0.83 % for total phenol content of fruit to 112.94 % for average fruit weight Table 6. Genetic advance as percent of mean was very high ranging from 28.49 to 158.06 percent for plant height, primary branches per plant, fruit length, fruit diameter, fruits per plant, fruit weight, marketable fruit yield per plant, anthocyanin content of peel, shoot phenol content, fruit phenol content, total sugar content, reducing sugar content, non-reducing sugar content, shoot infestation by borer and fruit infestation by borer.

One character namely days to first flowering registered moderate genetic advance as percent of mean (14.40 %). Higher value of genetic advance as percent of mean was plant height, primary branches per plant, fruit length, fruit diameter, fruits per plant, fruit weight, marketable fruit yield per plant was earlier reported by findings of Banerjee *et al.,* (2018), Dutta *et al.,* (2018) and Lalramhlimi *et al.,* (2019). It is not necessarily true that high heritability would always exhibit high genetic advance. For this reason, heritability coupled with genetic advance is more effective and reliable in predicting the results and the effect of selection (Dudley and Moll, 1969).

High heritability accompanied with high genetic advance were recorded for primary branches per plant, fruit length, fruit diameter, fruits per plant, fruit weight, marketable fruit yield per plant, anthocyanin content of peel, total sugar content, reducing sugar content, non-reducing sugar content, shoot infestation by borer and fruit infestation by borer. Several earlier reports also reported high heritability and genetic advance for plant height, primary branches per plant, fruits number plant, fruit length and fruit weight (Madhavi *et al.,* 2015; Mangi *et al.,* 2016; Ravali *et al.,* 2017; Samlind Sujin *et al.,* 2017 and Dutta *et al.,* 2018) which agreed well to the present findings.

High heritability in conjunction with high genetic advance suggests that the characters concerned are conditioned by additive gene action (Panse, 1957) and therefore, these characters were more reliable for effective selection (Nwosu *et al.,* 2014).

Selection indices

Linear correlation between any two characters may present a confusing picture because any character may exert simultaneous influence on many characters of the plant. Path coefficient analysis is more useful in establishing direct and indirect relationship among any characters, which is more realistic interpretation regarding influence of a character on a particular trait.

The path coefficient analysis using phenotypic correlation coefficients among pair of characters depicting direct and indirect effect on fruit yield/plant has been presented in Table 7.

Mean residual effect was 0.029 suggesting that inclusion of 71 % fruit yield contributing characters in this study. Only two characters which exerted over whelming, high and positive direct effect on fruit yield/plant was fruit weight (0.902), fruit number plant (0.767) and anthocyanin content of peel (0.217). Direct effect of other characters on fruit yield per plant was insignificant. Negative direct effect of fruit infestation by borer on fruit yield (-0.130) amply supported the proposition that borer infestation was non-linearly associated with total fruit biomass.

Fruit number/plant which registered significantly positive correlation with marketable fruit yield per plant also exerted high and positive indirect effect fruit yield/plant *via* fruit length (0.210), total sugar content (0.224), reducing sugar content (0.205) and non-reducing sugar content (0.202).

Table.1 Morphological characterization of 27 brinjal genotypes

Genotype	PGH	LBL	LBTA	LP	LBC	CC	FC	FCV	FS	FCP	FPP	FCC
2013/BRL VAR-1	Semi-erect	Strong	Intermediate	Absent	Green	Purple	Deep Purple	None	Oblong	Present	Present	Green with purple ting
2015/BRL VAR-2	Semi-erect	Strong	Intermediate	Absent	Green	Purple	Green with white spot	None	Oblong	Absent	None	Green
2015/BRL VAR-3	Semi-erect	Strong	Intermediate	Absent	Light Green	Purple	Deep Purple	Curved	Oblong	Present	None	Green with purple ting
2015/BRL VAR-4	Semi-erect	Strong	Intermediate	Absent	Green	Purple	Deep Purple	Slightly curved	Oblong	Absent	None	Green
2015/BRL VAR-5	Semi-erect	Strong	Acute	Absent	Green	Purple	Purple	Curved	Long	Absent	None	Green with purple ting
2013/BRL VAR-6	Semi-erect	Strong	Acute	Absent	Green	Purple	Deep Purple	Slightly curved	Long	Absent	None	Green
2015/BRR VAR -1	Semi-erect	Intermediate	Intermediate	Absent	Green	Purple						
2015/BRR VAR -2	Semi-erect	Strong	Intermediate	Absent	Dark green	Purple	Green with purple ting	None	Round	Absent	None	Green with purple ting
2015/BRR VAR -3	Semi-erect	Intermediate	Intermediate	Absent	Dark green	Purple	Deep Purple	None	Round	Present	Present	Green with purple ting
2015/BRR VAR -4	Semi-erect	Intermediate	Intermediate	Absent	Green	Purple	Purple	None	Round	Present	None	Green with purple ting
2015/BRR VAR -5	Semi-erect	Intermediate	Intermediate	Absent	Green	Purple	Deep Purple	None	Round	Present	Present	Green with purple ting
2013/BRBW RES-1	Erect	Strong	Intermediate	Absent	Green	Purple	Purple	None	Round	Present	None	Green
2013/BRBW RES-2	Erect	Strong	Intermediate	Absent	Green	Purple						
2013/BRBW RES-3	Erect	Strong	Intermediate	Absent	Green	White	Green	Slightly curved	Long	Absent	None	Green
2013/BRBW RES-4	Erect	Strong	Intermediate	Absent	Green	Light Purple	Purple	Curved	Long	Present	Present	Green with purple ting
ArkaKusumkar	Erect	Intermediate	Intermediate	Absent	Green	White	Green	Slightly curved	Long	Absent	None	Green
KashiTaru	Semi-erect	Intermediate	Intermediate	Absent	Dark green	Purple	Purple	Curved	Long	Present	None	Green with purple ting
Swarna Mani	Semi-erect	Strong	Intermediate	Absent	Green	Purple	Dark Purple	None	Round		None	Green with purple ting
KS-224	Semi-erect	Intermediate	Intermediate	Absent	Dark green	Purple	Purple	Slightly curved	Round	Absent	None	Green with purple ting
SM-6-6	Semi-erect	Strong	Intermediate	Absent	Dark green	Light purple	Deep Purple	None	Slightly longer than broad	Absent	None	Green with purple ting
ArkaNidhi	Erect	Strong	Intermediate	Absent	Green	Purple	Deep Purple	Curved	Long	Absent	None	Green
Bidhan Supreme	Semi-erect	Strong	Intermediate	Absent	Light green	Purple	Green with purple strip	Slightly curved	Oblong	Absent	None	Green
Bidhan Super	Spreading	Strong	Intermediate	Absent	Green	Purple	Deep Purple	None	Round	Present	None	Green with purple ting
BCB-40	Spreading	Strong	Intermediate	Absent	Green	Purple	Deep Purple	Slightly curved	Oblong	Absent	Present	Green with purple ting
BCB-50	Spreading	Strong	Intermediate	Present	Green	Purple	Off white	None	Round	Absent	None	Green
Garia	Spreading	Strong	Intermediate	Absent	Green	Purple	Deep Purple	Slightly curved	Oblong	Present	None	Green with purple ting
Punjab Sadabahar	Erect	Strong	Intermediate	Absent	Green	Purple	Deep Purple	Snake shape	Long	Present	None	Green

Plant growth habit= (PGH), Leaf blade lobing = (LBL), Leaf blade tip angle = (LBTA), Leaf pricklinesss = (LP), Leaf blade colour = (LBC), Corolla colour =(CC), Fruit colour =(FC), Fruit curvature = (FCV), Fruit shape = (FS), Fruit calyx prickliness = (FCP), Fruit pedicel prickliness = (FPP), Fruit calyx colour = (FCC)

Table.2 Frequency distribution, proportion and Shannon-waver diversity index (H’) of qualitative traits of 27 brinjal genotypes

Characters	Morphological description	Frequency distribution		H’-index
		Number of genotypes in the group	Percent (%)	
Growth habit	Erect	7	25.93	0.944
	Semi erect	16	59.26	
	Spreading	4	14.81	
Leaf blade lobing	Strong	20	74.07	0.573
	Intermediate	7	25.93	
Leaf blade tip angle	Intermediate	25	92.59	0.264
	Acute	2	7.41	
Leaf pricklinesss	Absent	26	96.30	0.159
	Present	1	3.70	
Leaf blade colour	Green	20	74.07	0.728
	Dark green	5	18.52	
	Light green	2	7.41	
Corolla colour	Purple	24	88.89	0.420
	Light purple	2	7.41	
	White	1	3.70	
Fruit colour	Deep Purple	14	51.85	1.408
	Purple	6	22.22	
	Purple with green ting	1	3.70	
	Green	3	11.11	
	Green with white spot	1	3.70	
	Green with purple stripe	1	3.70	
	White	1	3.70	
Fruit curvature	Slightly curved	9	33.33	1.238
	None	11	40.74	
	Curved	5	18.52	
	Snake shaped	2	7.41	
Fruit shape	Round	9	33.33	1.207
	Long	10	37.04	
	Oblong	7	25.93	
	Slightly longer than broad (Half-long)	1	3.70	
Fruit pedicel prickliness	None	22	81.48	0.479
	Present	5	18.52	
Fruit calyx prickliness	Present	14	51.85	0.693
	Absent	13	48.15	
Fruit calyx colour	Green	12	44.44	0.687
	Green with purple tinge	15	55.56	
Overall mean of H’				0.733

Table.3 Mean fruit yield and yield components, and infestation of fruit and shoot borer of 27 brinjal genotypes

Genotype	Plant height (cm)	Primary branches/ plant	Days to first flowering	Fruit length (cm)	Fruit diameter (cm)	Fruits per plant	Fruit weight (g)	Marketable fruit yield per plant (kg)	Shoot infestation by borer (%)	Fruit infestation by borer (%)	Reaction against fruit borer
2013/BRL VAR-1	96.94	3.41	37.97	17.37	7.67	12.07	133.68	1.60	1.03	65.33	Susceptible
2015/BRL VAR-2	73.95	3.43	31.13	13.12	6.31	13.34	77.59	1.04	0.20	27.70	Tolerant
2015/BRL VAR-3	79.25	4.73	35.19	14.90	4.72	14.99	95.97	1.44	0.13	25.02	Tolerant
2015/BRL VAR-4	111.26	3.93	30.77	13.41	5.08	16.72	81.84	1.41	1.33	22.20	Tolerant
2015/BRL VAR-5	93.09	5.09	30.85	15.96	4.03	23.36	72.31	1.61	0.89	19.39	Moderately Resistant
2013/BRL VAR-6	89.19	3.17	31.07	11.46	4.52	14.24	106.37	1.53	0.41	39.37	Susceptible
2015/BRR VAR -1	101.98	3.46	38.58	9.11	7.10	7.27	154.91	1.12	0.16	32.38	Susceptible
2015/BRR VAR -2	89.26	4.78	31.60	10.98	9.11	7.55	151.31	1.13	0.34	37.48	Susceptible
2015/BRR VAR -3	93.73	2.44	37.70	9.34	7.81	8.03	191.08	1.52	0.68	45.66	Susceptible
2015/BRR VAR -4	78.14	4.26	38.39	9.44	9.30	6.89	129.36	0.91	0.36	32.12	Susceptible
2015/BRR VAR -5	77.36	4.98	30.93	9.75	7.60	5.84	120.88	0.70	0.13	34.56	Susceptible
2013/BRBW RES-1	84.76	3.88	31.28	15.83	5.33	7.23	79.43	0.57	0.20	20.41	Tolerant
2013/BRBW RES-2	72.60	2.47	31.81	20.99	3.69	9.55	94.20	0.89	0.13	35.40	Susceptible
2013/BRBW RES-3	57.61	2.89	35.97	17.61	3.25	5.14	68.31	0.45	0.14	16.66	Moderately Resistant
2013/BRBW RES-4	92.57	2.76	32.23	16.83	3.51	4.19	76.86	0.33	0.12	26.58	Tolerant
Arka Kusumkar	75.47	2.09	32.67	16.45	3.31	14.61	82.92	1.23	0.49	20.27	Tolerant
Kashi Taru	82.98	4.71	30.38	20.32	4.80	13.86	73.51	1.02	0.19	20.92	Tolerant
Swarna Mani	85.99	3.76	37.60	9.31	9.24	5.25	239.93	1.30	0.28	40.71	Susceptible
KS-224	102.27	5.22	30.26	10.01	9.42	8.73	129.00	1.12	0.46	34.30	Susceptible
SM-6-6	83.01	5.59	30.99	9.98	5.62	17.23	55.54	0.96	0.37	13.65	Moderately Resistant
Arka Nidhi	87.01	5.14	34.34	19.64	3.19	8.63	64.03	0.55	0.40	15.64	Moderately Resistant
Bidhan Supreme	88.37	3.14	29.32	16.75	5.95	14.45	144.14	2.28	0.52	37.16	Susceptible
Bidhan Super	92.62	4.81	31.34	9.21	8.41	12.41	188.25	2.33	0.29	38.53	Susceptible
BCB-40	81.28	4.95	31.26	15.03	6.72	15.33	197.27	3.01	0.27	39.81	Susceptible
BCB-50	125.59	6.06	30.53	11.88	7.15	6.65	246.89	1.64	0.15	42.03	Susceptible
Garia	115.36	4.87	30.64	12.13	4.61	11.70	199.08	2.32	0.24	40.51	Susceptible
Punjab Sadabahar	69.26	2.30	31.59	19.34	4.18	22.87	90.76	2.08	0.28	24.20	Tolerant
Mean	**88.18**	**4.01**	**32.83**	**13.93**	**5.99**	**11.41**	**124.37**	**1.33**	**0.38**	**29.15**	-
C.V. (%)	3.63	10.74	5.43	6.95	6.20	9.12	3.54	10.73	14.82	9.29	-
C.D. at 5%	5.25	0.71	2.92	1.59	0.61	1.71	7.21	0.23	0.09	4.44	-

Table.4 Mean fruit quality components of 27 brinjal genotypes

Genotype	Shoot phenol content (mg/ 100 g fresh)	Fruit phenol content (mg/ 100 g fresh)	Anthocyanin content in peel (mg/100 g)	Total sugar content (%)	Reducing sugar content (%)	Non Reducing sugar content (%)
2013/BRL VAR-1	3.94	3.44	82.07	2.11	1.59	0.51
2015/BRL VAR-2	4.09	3.60	84.71	2.38	1.74	0.65
2015/BRL VAR-3	3.61	2.72	92.16	2.72	2.09	0.67
2015/BRL VAR-4	3.59	3.06	86.22	2.35	1.67	0.66
2015/BRL VAR-5	3.22	2.37	86.53	2.65	1.90	0.77
2013/BRL VAR-6	3.53	2.55	90.75	2.98	1.88	1.07
2015/BRR VAR -1	3.44	2.47	84.44	1.66	1.26	0.40
2015/BRR VAR -2	2.52	2.22	86.59	2.18	1.52	0.66
2015/BRR VAR -3	3.28	2.45	83.38	2.09	1.53	0.52
2015/BRR VAR -4	3.55	2.49	82.23	1.75	1.56	0.27
2015/BRR VAR -5	4.08	2.34	82.82	2.59	1.95	0.58
2013/BRBW RES-1	2.48	2.19	87.11	1.31	0.96	0.35
2013/BRBW RES-2	3.60	2.53	87.00	1.58	1.28	0.30
2013/BRBW RES-3	3.43	2.53	87.04	0.79	0.60	0.19
2013/BRBW RES-4	3.57	2.79	89.14	1.03	0.77	0.52
Arka Kusumkar	4.53	2.02	89.25	1.24	0.92	0.29
Kashi Taru	3.93	2.76	85.34	2.70	1.96	0.73
Swarna Mani	3.67	2.45	83.62	2.15	1.67	0.48
KS-224	4.25	3.03	81.92	2.02	1.52	0.52
SM-6-6	3.07	2.61	86.04	0.89	0.71	0.19
Arka Nidhi	4.36	3.08	89.84	1.38	1.01	0.39
Bidhan Supreme	4.55	3.43	4.71	1.76	1.40	0.35
Bidhan Super	3.51	2.43	92.60	1.47	1.13	0.36
BCB-40	4.49	3.22	93.77	2.03	1.53	0.51
BCB-50	3.53	2.34	1.51	1.86	1.40	0.45
Garia	4.00	2.68	54.98	2.54	1.86	0.69
Punjab Sadabahar	4.59	3.52	103.76	2.03	1.54	0.49
Mean	**3.72**	**2.72**	**79.98**	**1.93**	**1.44**	**0.50**
C.V. (%)	5.15	5.53	3.83	8.74	9.20	14.78
C.D. at 5%	0.31	0.25	5.02	0.28	0.22	0.12

Table.5 Analysis of variance for different characters of 27 brinjal genotypes

Source	Replication	Treatments	Error
Degrees of fredom	2	26	52
Plant Height (cm)	0.16	640.29**	10.27
Primary branches/ Plant	0.18	3.73**	0.19
Days to first flowering	4.8	25.66**	3.18
Fruit length (cm)	1.32	45.03**	0.94
Fruit girth (cm)	0.11	12.74**	0.14
Fruits/ plant	2.02	79.15**	1.08
Fruit weight (g)	3.14	9095.23**	19.37
Marketable fruit yield per plant (kg)	0.02	1.20**	0.08
Total phenol content of shoot (mg/ 100g Fresh)	0.03	0.93**	0.04
Total phenol content of fruit (mg/ 100g Fresh)	0.05	0.57**	0.02
Anthocynin content in peel (mg/100g)	3.14	1652.90**	9.37
Total sugar content (%)	0.03	1.04**	0.04
Reducing sugar content (%)	0.02	0.53**	0.03
Non reducing sugar content (%)	0.01	0.12**	0.02
Shoot infestation by borer (%)	0.13	0.26**	0.04
Fruit infestation by borer (%)	14.38	344.51**	7.34

** Significant at 0.01 level of probability

Table.6 Genetic variability parameters for yield components, fruit quality and infestation of fruit and shoot borer

Characters	Phenotypic Coefficient of variation (PCV)	Genotypic Coefficient of variation (GCV)	Heritability in broad sense % (H)	Genetic Advance (GA) at 5% selection intensity	Genetic Advance (GA) as % of Mean
Plant height (cm)	16.83	16.43	95.00	29.15	**33.06**
Primary branches/plant	29.15	27.10	86.00	2.08	**51.90**
Days to first flowering	9.95	8.34	70.00	4.73	**14.40**
Fruit length (cm)	28.38	27.52	94.00	7.66	**54.96**
Fruit girth (cm)	34.80	34.24	97.00	4.15	**69.40**
Number of fruits/plants	45.62	44.70	96.00	10.30	**90.23**
Average fruit weight (g)	44.37	44.23	99.00	112.94	**90.82**
Marketable fruit yield per plant (kg)	48.36	47.16	95.00	1.26	**94.72**
Total phenol content of shoot (mg/ 100g)	15.54	14.66	89.00	1.06	**28.49**
Total phenol content of fruit (mg/ 100g)	16.66	15.71	89.00	0.83	**30.52**
Anthocyanin content of peel (mg/100g)	29.51	29.26	98.00	47.81	**59.77**
Total sugar content (%)	31.29	30.05	92.00	1.15	**59.44**
Reducing sugar content (%)	29.26	27.77	90.00	0.78	**54.31**
Non reducing sugar content (%)	41.14	38.39	87.00	0.37	**73.80**
Shoot infestation by borer (%)	79.49	78.10	97.00	0.60	**158.06**
Fruit infestation by borer (%)	**37.54**	**36.37**	**94.00**	**21.16**	**72.59**

Table.7 Path coefficient analysis for different characters on marketable fruit yield per plant at phenotypic level

Character	Plant height (cm)	Primary branches/ plant	Days to first flowering	Fruit length (cm)	Fruit girth (cm)	Fruits per plant	Fruit weight (g)	Phenol content of shoot (mg/ 100g)	Phenol content of fruit (mg/ 100g)	Anthocyanin content of peel (mg/100g)	Total sugar content (%)	Reducing sugar content (%)	Non-reducing sugar content (%)	Shoot infestation by borer (%)	Fruit infestation by borer (%)	Phenotypic correlation with marketable fruit yield per plant (kg)
Plant height (cm)	**-0.053**	0.004	0.013	-0.002	-0.021	-0.058	0.427	-0.006	-0.004	-0.058	0.006	-0.019	-0.002	-0.003	0.051	0.275
Primary branches/ plant	-0.018	**0.01**	0.026	-0.001	-0.025	0.003	0.181	-0.006	-0.01	-0.025	0.005	-0.021	-0.001	0.001	0.001	0.12
Days to first flowering	0.005	-0.002	**-0.113**	-0.001	-0.018	-0.256	0.155	-0.006	-0.012	0.025	-0.003	0.006	0.002	-0.001	0.012	-0.207
Fruit length (cm)	0.016	-0.003	0.017	**0.008**	0.055	0.21	-0.458	0.015	0.029	0.008	-0.003	0.014	0.001	0	-0.009	-0.1
Fruit girth (cm)	-0.012	0.003	-0.024	-0.004	**-0.067**	-0.251	0.553	-0.008	-0.006	-0.015	0.004	-0.024	0	0	0.04	0.189
Fruits per plant	0.003	0	0.036	0.001	0.027	**0.767**	-0.298	0.012	0.032	0.017	0.007	-0.027	-0.002	-0.004	-0.006	0.565**
Fruit weight (g)	-0.021	0.002	-0.018	-0.003	-0.048	-0.246	**0.902**	0.001	-0.013	-0.053	0.004	-0.02	0	0.001	0.064	0.552**
Phenol content of shoot (mg/ 100g)	0.005	-0.001	0.012	0.002	0.013	0.189	0.02	**0.057**	0.051	-0.014	0.003	-0.016	0	0	0.024	0.345
Phenol content of fruit (mg/ 100g)	0.002	-0.001	0.014	0.002	0.005	0.255	-0.127	0.026	**0.102**	-0.005	0.003	-0.016	-0.001	-0.002	0.032	0.289
Anthocynin content of	0.022	-0.002	-0.022	0	0.01	0.108	-0.402	-0.006	-0.004	**0.217**	0	0.004	-0.001	0	-0.045	-0.121

peel (mg/100g)																
Total sugar content (%)	-0.01	0.002	0.012	-0.001	-0.014	0.224	0.146	0.006	0.013	-0.002	**0.033**	-0.092	-0.007	-0.002	0.042	0.35
Reducing sugar content (%)	-0.009	0.002	0.006	-0.001	-0.02	0.205	0.183	0.008	0.015	-0.005	0.023	**-0.09**	-0.006	-0.002	0.044	0.353
Non-reducing sugar content (%)	-0.012	0.001	0.023	0	0.003	0.202	0.011	0	0.01	0.01	0.02	-0.068	**-0.007**	-0.002	0.03	0.221
Shoot infestation by borer (%)	-0.015	-0.001	-0.005	0	-0.004	0.3	-0.106	0.001	0.022	0.003	0.005	-0.016	-0.002	**-0.013**	0.023	0.192
Fruit infestation by borer (%)	-0.021	0.09	-0.01	0.06	-0.024	-0.023	-0.297	0.009	0.042	-0.04	-0.01	-0.033	-0.002	-0.002	**-0.13**	-0.391*

*,** Significant at 0.05 and 0.01 level of probability, respectively
Bold letters in the diagonals = Direct effects
Residual effect = 0.029

Similarly, fruit weight which also registered significantly positive correlation with marketable fruit yield per plant also exerted high and positive indirect effect fruit yield/plant *via* plant height (0.427), primary branches per plant (0.181) and fruit diameter (0.553). High and positive direct effect on fruit yield/plant through fruit weight (0.902), fruit number plant (0.767) was earlier reported by Banerjee *et al.*, (2018), Dutta *et al.,* (2018) and Lalramhlimi *et al.*, (2019).

The present study illustrated significant variation among genotypes for both qualitative and quantitative traits. The overall mean of Shannon-Wiener diversity index (H) value of 0.733 amply suggest the existence of diversity among the genotypes under study. Moderately resistant genotypes had comparatively lower mean fruit weight than other categorized groups, revealing the fact that small fruited genotypes are linked with fruit borer resistance. Adoption of appropriate breeding strategies involving big fruited, high yielding (BCB-40, Bidhan Super and Garia) and moderately fruit borer resistant (SM-6-6, Arka Nidhi and BRBW VAR-3) genotypes might have develop desirable recombinants in future.

Primary branches per plant, fruit length, fruit diameter, fruits per plant, fruit weight, marketable fruit yield per plant, anthocyanin content of peel, total sugar, reducing sugar, non-reducing sugar contents of fruit, shoot infestation by borer and fruit infestation by borer exhibited high heritability in conjunction with high genetic advance which suggests that the characters concerned are conditioned by additive gene action and therefore, these characters would be more reliable for effective selection. The maximum positive direct effects were exerted by number of fruits per plant and fruit weight and had positive and significant correlations with marketable fruit yield per plant.

This suggests that the correlation has revealed the true relation and direct selection through these traits could be effective to enhance marketable fruit yield of brinjal. The information generated through this study will help the breeders to develop high yielding and fruit borer resistant varieties of brinjal.

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