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Studies on Genetic Variability and Low Nitrogen Tolerance of S_1 Lines Derived from Local Maize (*Zea mays* L.) Germplasm

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A B S T R A C T

Ten S_1 lines along with three hybrids were evaluated in randomized block design at Instructional-cum-Research (ICR) Farm of Assam Agricultural University, Jorhat. The aim to study the genetic variability, heritability, genetic advance and low nitrogen tolerance of S_1 lines derived from local maize germplasms. The experiment consisted of two trials with the same set of genotypes in two different nitrogen levels, *viz*., 80 kg N ha^{-1} and 0 kg N ha^{-1}. Analysis of variance revealed presence of sufficient amount of variation among the genotypes for the traits except ears per plant at both N_0 and N_{80} levels. At both N_0 and N_{80} levels moderate to high estimates of GCV and PCV recorded for grain yield per plant, ear height, number of kernels per row, ear length, days to 50% pollen-shed, 100 KW, NRA and NUE indicated sufficient variability in the set of germplasms. For grain yield and nitrogen use efficiency, the S_1 lines *viz*., MIZ-2 and MEG-11 were identified as promising at N_{80} level and MEG-11 and TR-1 were identified as promising at N_0 level. MIZ-2, AR-1, MIZ-7 and TR-1 had less ASI at N_0 level. It indicates that those lines could be tolerant to low N-stress.

Introduction

Maize (*Zea mays* L.) is the third most important cereal crop next to rice and wheat and it is mainly used as staple food and animal feed in most of the developing countries. Farmers of North East India usually grow maize and many other crops under low input situation. Higher productivity in maize can be easily achieved by application of chemical fertilizers and other improved agro-techniques. Continuous application of large quantity of fertilizers year after year causes reduction in soil health and has negative impact on environment in addition to adverse economic stress on the farmers. Local maize germplasm are adapted to adverse soil and climatic situations such as low input conditions of soil. These situations include various biotic and abiotic stresses. Among the abiotic stresses, low nitrogen (N) is a major constraint to the productivity and production of the crop. The Indian soils are mainly low in organic matter and cation exchange capacity (Jones and Wild, 1975) resulting in low N availability. Considering the low soil N in maize production, it would be desirable to develop maize cultivars capable of fully exploiting available nutrients in soil, or productive under low soil nitrogen levels. This would further broaden the cultivation of maize and also offer economic and environmental benefits (Omoigui *et al.*, 2007).

Nitrogen is an important element of maize production as it promotes vegetative growth, maximizes both kernel initiation and kernel set. Nitrogen deficiency interferes with protein synthesis, induces leaf senescence and therefore, reduces the general growth of the maize plant (Bruns and Abel, 2003) thereby limiting yield. The low N tolerant cultivars are superior in the utilization of available N, either due to enhanced uptake capacity or because of more efficient use of absorbed N in grain production (Laffitte and Edmeades., 1994). N-use efficiency (NUE) is defined as grain production per unit of N available in the soil (Moll *et al.*, 1982).

Systematic investigation of germplasm for issues like tolerance to low- nitrogen and other stresses is important to identify appropriate material. Development and evaluation of inbreds from local maize germplasm may possess genes for one or more important biotic and abiotic stresses although they may possess fewer genes for grain yield. Inbreds developed from certain germplasm may possess unique alleles for yield and resistance to different stresses and such inbreds may be used for improving the parents of an elite hybrid through recycling methodology. S_1 lines may be tested for *per se* performance for grain yield and other important traits. Once identified, the number of S_1 lines may be minimised for their advancement to S_2 and subsequent selfed generations. Early testing of inbreds either for *per se* performance or general combining ability helps the breeders minimise expenditure to be incurred, space to be utilized and time to be spent. Favourable alleles for various traits are dispersed in local germplasm. It is necessary to know the nature and magnitude of genetic variation in a set of local germplasm under study. Methodology for genetic improvement of plants differ depending upon mode of pollination, nature of traits whether qualitative or quantitative and other factors. Therefore, genetic variation and its various parameters are necessary to take an appropriate decision in plant breeding strategies.

Materials and Methods

Experimental site

The experimental site is located at Instructional-cum-Research (ICR) Farm of Assam Agricultural University, Jorhat at 26°46′ N latitude, 94°13′ E longitude and 86.6 m above the mean sea level (MSL). The climate of the area is sub-tropical humid.

Experimental material

Local maize germplasms were collected from different areas of North East India. Ten S_1 lines derived from local maize germplasm were used in present study. Three hybrids namely, P-3399, P-3522 and KMH25K45 were also included (Table 1). The entries from Sl. No. 1 to Sl. No. 10 were different S_1 lines derived from different maize germplasm.

S_1 lines derived from local maize germplasm (*rabi*, 2015-2016)

During the *rabi* season (2015-16), all the ten germplasms were planted in a nursery under optimal NPK fertility condition (80 kg N ha^{-1}, 40 kg P ha^{-1} and 40 kg K ha^{-1}). The entries were grown for selfing operation. The plot of each entry had four rows with a row length of 4 m, spacing being 0.60 m between rows and 0.20 m between plants. The nursery was maintained clean of weeds by hand weeding. Operation of planting, self-pollination and harvesting was done by hand. All harvested S_1 cobs were dried properly and stored separately.

Experimental environment

The experimental site was prepared during *Kharif*, 2016 and a maize hybrid was grown in that site for reducing the variability in the soil heterogeneity resulting primarily from residual as well as inherent nutrient of the soil. All the ten S_1 lines along with three hybrid varieties were planted for evaluation in randomized block design (RBD) with two replications under two different levels of applied nitrogen i.e. N_{80} (80 kg N ha^{-1}) and N_0 (0 kg N ha^{-1}) during *rabi*, 2016-17. The amount of P_2O_5 and K_2O fertilizers and other recommended practices used (excluding organic manures) were the same in both the levels of nitrogen.

Statistical analysis

Observation of all morphological and most of the physiological parameters will be performed as per standard procedures. The plot means were subjected to the statistical and biometrical analysis and all statistical analyses and biometrical analysis were done. The variability was estimated as per procedure for analysis of variance suggested by fisher, GCV and PCV by Burton and Devane (1953) and heritability and genetic advance by Allard (1960).

Results and Discussion

Mean sum of squares due to genotypes showed significant differences for all the characters except number of ears per plant at both N_0 and N_{80} levels. This indicates the presence of sufficient genetic variation among the genotypes. Similar results were reported by Saikia and Sharma (2000) for different maize characters *i.e.* plant height, ear height and grain yield per plant. By Vashistha *et al.*, (2013) for all the characters except number of ears per plant and Selassie (2015) for the characters *viz*., plant height, shelling percentage and 1000 grain weight.

Mean performance

Morphological traits

The comparison of the mean performance of the genotypes with respect to various morphological traits revealed that, among the S_1 lines, the highest grain yield per plant was observed in MEG-11 and TR-1 which had few other favourable traits at N_0 level. MEG-11 showed highest grain yield along with shorter duration at N_0 level.

Such a line, if advanced to S_2 generation, would produce potential inbred progeny with high yield and short duration. TR-1, which was a high yielder S_1 line, also had the attributes higher ear length and low ear placement.

Among the S_1 lines**,** MIZ-7, AR-1, MIZ-3, MIZ-2 and TR-1 were *at par* for low ASI at N_0 level which was followed by MEG-11 and MAN-8. It indicates that these lines could be tolerant to low N-stress. Again, the lines *viz*., MAN-4, MIZ-3, MEG-11 and MAN-8 topped the S_1 entries tested under N_{80} level for low ASI.

Thus, the S_1 entries *viz*., MAN-4 and MIZ-3 had lower ASI at both the levels. MAN-4 was also the earliest of all genotypes. The S_1 lines *viz*., MEG-11, TR-1, MIZ-3, AR-1 and MIZ-2 exhibiting high grain yield at N_0 level could be considered tolerant to low N. However, at N_0 level, the high yielding lines *viz*., TR-1, MIZ-3, AR-1 and MEG-11 had lower estimates of ASI which is a secondary trait of low nitrogen tolerance. Thus, these S_1 lines could be considered tolerant to low-N based on both grain yield and ASI (Table 2a–2c).

Among the hybrids, P-3399 having high grain yield, low ASI and better performance for other important traits *viz*., ear length, 100 KW and kernels per row at N_0 level could be an important entry for tolerance to low N (Table 3).

Physiological traits

The comparison of the mean performance of the genotypes with respect to various physiological traits was made. Among the entries, MAN-8 at N_0 level had the highest mean performance for the traits *viz*, chlorophyll content and Leaf Area. Among the S_1 lines, MEG-11 and TR-1 gave the highest mean performance for the traits plant nitrogen, NRA and NUE at both levels of nitrogen. Similar result was found by Sindhi *et al*., (2016) (Table 4).

Table.1 List of S_1 lines and hybrids used in the evaluation

Sl. No.	Name of the entries	Entry code	Place /source
	S_1 entries:		
1	Mimban -1	MIZ-1	Mizoram
2	Medziphema Collection-2	NAG-4	Nagaland
3	Mizoram collection-1	MIZ-2	Mizoram
4	Manipur local	MAN-8	Manipur
5	Yerto	AR-1	Arunachal Pradesh
6	Mimban-2	MIZ-7	Mizoram
7	Imphal collection	MAN-4	Manipur
8	Mimpui	MIZ-3	Mizoram
9	Meghalaya-11	MEG-11	Meghalaya
10	TR-1	TR-I	Tripura
	Hybrids entries:		
11	P-3399	P-3399	M/S Pioneer Seeds Pvt. Ltd.
12	P-3522	P-3522	M/S Pioneer Seeds Pvt. Ltd.
13	KMH25K45	KMH25K45 (Kavery Bumper)	M/S Aditya B Enterprise

Table.2a Mean performance of maize genotypes for morphological traits at individual nitrogen levels

Genotypes	Days to 50% pollen-shed		Days to 50% silk		ASI		Days to 75% dry husk		Plant height (cm)		Ear height (cm)		Ear length (cm)		Ear diameter (cm)	
	N_0	N_{80}	N_0	N_{80}	N_0	N_{80}	N_0	N_{80}	N_0	N_{80}	N_0	N_{80}	N_0	N_{80}	N_0	N_{80}
MIZ-1	105.50	111.50	113.00	116.50	7.50	5.00	149.00	151.00	45.42	90.94	20.11	30.73	9.39	10.01	3.27	3.89
NAG-4	70.50	74.50	77.00	79.50	6.50	5.00	116.50	118.00	60.77	91.45	26.00	33.25	9.12	11.61	2.50	4.47
MIZ-2	62.50	66.50	67.00	71.50	4.50	5.00	114.50	120.50	77.50	111.73	19.17	46.90	9.89	10.44	3.24	4.09
MAN-8	71.00	80.00	76.50	83.50	5.50	3.50	111.00	122.00	83.00	112.27	24.65	35.42	10.16	12.20	3.51	4.32
AR-1	73.50	74.00	77.00	78.00	3.50	4.00	115.00	125.50	74.00	105.32	27.50	52.16	10.67	15.53	2.73	3.68
MIZ-7	67.50	68.50	70.50	73.00	3.00	4.50	110.50	112.50	70.50	120.66	26.89	40.46	9.00	12.38	3.44	4.10
MAN-4	62.00	63.50	66.00	66.00	4.00	2.50	108.50	114.50	71.34	114.89	24.89	41.21	8.72	11.55	3.61	4.15
MIZ-3	71.00	73.00	74.50	76.50	3.50	3.50	110.50	114.00	85.00	110.14	22.67	41.56	9.36	12.40	3.40	3.61
MEG-11	71.00	75.50	76.00	79.00	5.00	3.50	119.00	125.00	84.34	114.89	33.00	37.91	8.84	11.60	3.04	3.29
TR-I	72.00	74.50	76.00	79.00	4.00	5.00	121.50	125.50	78.50	113.62	21.04	41.58	10.13	11.20	2.60	3.89
P-3399	104.50	107.50	107.50	111.50	3.00	4.00	147.50	153.50	109.00	139.12	43.06	55.22	12.72	18.70	3.52	4.53
P-3522	98.00	101.50	104.00	106.00	6.00	4.50	146.50	150.50	109.17	137.76	37.20	53.39	13.95	18.60	3.91	4.42
KMH25K45	99.00	104.00	105.50	108.50	6.50	4.50	144.50	149.50	103.50	141.25	41.50	50.21	13.55	17.80	3.55	4.56
Grand Mean	79.08	82.73	83.88	86.92	2.40	2.09	124.19	129.38	80.92	115.69	28.28	43.08	10.42	13.38	3.25	4.07
S.Ed(±)	3.04	2.32	2.57	2.25	0.68	0.60	3.97	2.91	4.40	4.79	2.42	2.51	0.86	1.07	0.27	0.13
CD (5%)	6.08	5.06	5.61	4.78	1.49	1.32	5.81	2.25	9.58	10.43	5.28	5.48	1.87	2.32	0.58	0.28
CV%	3.84	2.80	3.07	2.82	14.23	14.42	2.78	2.25	5.43	4.14	8.56	5.84	8.22	7.97	8.20	3.13

Table.2b Mean performance of maize genotypes for morphological traits at individual nitrogen levels

Genotypes	Kernel rows per ear		Kernels per row		100 kernel weight(g)		Grain yield(g)	
	N_0	N_{80}	N_0	N_{80}	N_0	N_{80}	N_0	N_{80}
MIZ-1	9.70	14.80	12.80	17.44	20.51	23.45	62.20	74.590
NAG-4	9.10	15.00	12.20	15.49	14.12	26.27	75.25	99.025
MIZ-2	10.40	15.40	15.50	18.99	16.06	26.10	82.19	115.515
MAN-8	10.80	14.40	11.60	19.68	15.54	25.94	69.44	90.015
AR-1	9.20	12.70	16.80	19.33	13.32	31.79	82.62	88.785
MIZ-7	10.10	14.40	13.05	21.94	17.30	29.95	76.28	96.270
MAN-4	10.60	13.80	15.45	20.03	18.17	28.21	75.03	93.735
MIZ-3	10.50	12.20	15.10	21.24	16.96	27.40	84.72	88.215
MEG-11	9.90	12.00	12.50	19.31	16.38	31.44	91.73	109.905
TR-I	8.20	12.30	12.35	21.37	17.37	33.71	89.12	96.855
P-3399	11.20	14.00	17.95	29.49	19.38	41.82	124.23	168.565
P-3522	11.60	14.20	19.30	29.05	20.95	41.50	107.13	155.765
KMH25K45	13.20	16.00	19.20	29.26	24.50	40.95	116.15	136.115
Grand Mean	10.35	13.93	14.90	21.73	17.73	31.42	87.39	108.72
S.Ed(±)	0.80	0.62	2.13	1.59	0.47	0.99	11.54	12.59
CD(5%)	1.74	1.35	4.64	3.46	1.02	2.17	25.14	27.43
CV%	7.70	4.43	14.30	7.31	2.63	3.16	13.20	11.58

Table.2c Mean performance of maize genotypes for physiological traits at individual nitrogen levels

Genotypes	LA (cm^2)		Chl. content (mg g^{-1})		NRA(µmolNO_2^- /h/gm. of fresh wt)		PN (%)		GS (µmol/h/gm of fresh wt)		NUE (g g^{-1})	
	N_0	N_{80}	N_0	N_{80}	N_0	N_{80}	N_0	N_{80}	N_0	N_{80}	N_0	N_{80}
MIZ-1	191.89	352.00	3.97	5.13	1.00	1.43	0.60	0.83	315.50	332.31	260.11	74.06
NAG-4	237.62	360.04	4.34	6.22	0.96	1.40	0.70	0.84	401.34	422.42	314.66	98.32
MIZ-2	253.22	368.05	5.23	7.89	0.87	1.62	0.71	0.98	346.17	373.12	343.71	114.69
MAN-8	273.00	390.57	5.64	6.44	0.95	1.07	0.53	0.83	351.37	363.91	290.39	89.38
AR-1	235.16	368.42	3.07	9.21	1.61	2.46	0.43	0.91	429.28	459.05	345.50	88.15
MIZ-7	230.00	374.76	3.24	9.93	1.43	2.34	0.57	1.08	331.57	381.44	318.99	95.59
MAN-4	224.77	371.23	4.77	7.10	1.27	3.28	0.72	0.84	331.95	364.73	313.77	93.07
MIZ-3	224.00	414.44	5.85	7.39	1.46	3.18	0.85	0.90	351.76	383.11	354.27	87.59
MEG-11	240.00	456.23	7.12	8.34	1.28	2.64	0.88	1.15	362.23	379.78	383.58	109.12
TR-I	240.15	470.00	4.34	7.84	1.82	2.80	0.75	0.96	329.23	355.94	372.67	96.17
P-3399	348.50	480.39	5.78	8.67	1.53	2.41	0.70	0.84	392.24	423.23	519.51	167.37
P-3522	347.08	479.88	6.34	7.55	1.75	3.43	0.74	0.95	417.71	440.95	448.00	154.66
KMH25K45	342.32	477.79	5.94	8.01	1.00	3.17	1.14	1.23	409.39	437.50	485.67	135.15
Grand Mean	260.59	412.60	5.05	7.67	1.37	2.40	0.72	0.94	366.90	393.65	365.44	107.95
S.Ed(±)	21.22	20.45	0.73	0.93	0.22	0.47	0.09	0.11	20.66	15.78	48.24	12.50
CD(5%)	46.23	44.56	1.60	2.02	0.47	1.03	0.19	0.24	45.01	34.38	105.11	27.24
CV%	8.14	4.96	14.54	12.08	15.68	19.71	11.94	11.53	5.63	4.01	13.20	11.58

Table.3 Estimates of genetic parameters for different morphological traits at N_0 and N_{80} level

Genetic Parameters	GCV (%)		PCV (%)		h^2 (%)		G_s (% of Mean)		Mean±SE	
Traits	N_0	N_{80}	N_0	N_{80}	N_0	N_{80}	N_0	N_{80}	N_0	N_{80}
D 50% PS	20.49	20.35	20.85	20.54	96.06	98.13	41.49	41.52	79.08±3.04	82.73±2.32
D 50% S	20.02	19.67	20.25	19.83	97.70	98.38	40.76	40.19	83.88±2.57	86.92±2.20
ASI	29.08	12.02	32.38	12.23	80.69	96.63	53.82	24.35	4.81±0.68	4.19±0.60
D 50% DH	12.93	15.52	13.10	21.18	97.31	53.66	26.27	23.41	124.19±2.67	129.38±2.91
PH (cm)	22.41	13.55	23.06	14.17	94.45	91.47	44.86	26.69	80.92±4.40	115.69±4.79
EH (cm)	27.51	17.90	28.81	18.83	91.16	90.38	54.10	35.05	28.28±2.42	43.08±2.51
EL (cm)	16.37	22.69	18.32	24.05	79.88	89.02	30.15	44.10	10.42±0.86	13.38±1.07
ED (cm)	11.69	9.36	14.28	9.87	67.00	89.94	19.71	18.28	3.25±0.27	4.07±0.13
KR/E	10.84	8.66	13.29	9.73	66.44	79.26	18.20	15.88	10.35±0.80	13.93±0.62
K/R	23.89	20.54	27.84	21.80	73.63	88.77	42.23	39.87	14.90±2.13	21.73±1.59
100 KW (g)	16.95	20.06	17.15	20.31	97.64	97.58	34.50	40.83	17.73±0.47	31.42±0.99
GY(q)	18.79	24.61	22.96	27.20	66.95	81.87	31.67	45.87	87.39±11.54	108.72±12.59

Table.4 Estimates of genetic parameters for different physiological traits at N_0 and N_{80} level

Genetic Parameters	GCV (%)		PCV (%)		h^2 (%)		G_s (% of Mean)		Mean±SE	
Traits	N_0	N_{80}	N_0	N_{80}	N_0	N_{80}	N_0	N_{80}	N_0	N_{80}
Leaf Area (cm^2)	19.09	12.13	20.75	13.10	84.60	85.69	36.17	23.13	260.59±21.22	412±20.45
Chlorophyll content (mg g^{-1})	21.80	14.32	26.20	18.74	69.20	58.45	37.35	22.56	5.05±0.73	7.67±0.93
Nitrate Reductase Activity (µmolNO_2^-/hr/gm of fresh wt)	22.93	30.07	27.78	35.96	68.13	69.96	38.99	51.82	1.37±0.22	2.40±0.47
Plant Nitrogen (%)	23.24	11.26	26.13	16.11	79.10	48.82	42.58	16.21	0.72±0.09	0.94±0.11
Glutamine Synthetase (µmol/hr/gm of fresh wt)	9.64	9.40	11.16	10.22	74.55	84.61	17.14	17.81	366.90±20.66	393.65±15.78
Nitrogen Use Efficiency (g g^{-1})	18.79	24.61	22.96	27.20	66.94	81.87	31.66	45.87	365.44±48.24	107.94±12.50

All entries having high grain yield showed high nitrogen use efficiency and those showing low grain yield had low NUE at both the nitrogen levels. This relationship was based on the formula of NUE. The S_1 lines namely, MIZ-2 and MEG-11 recorded the highest NUE along with high yield at N_{80} level while MEG-11 and TR-1 recorded the highest NUE along with high yield at N_0 level. Another important S_1 lines, AR-1 had few good traits *viz*., high GS, NRA and NUE. Among the hybrids, P-3399 had high LA, chlorophyll content and high nitrogen use efficiency at both levels of nitrogen. Another hybrid P-3522 had the good traits namely, GS, NRA and high NUE at both levels of nitrogen.

Genotypic variation and other related parameters

Morphological traits

Variability plays an important role in crop breeding. The magnitude of variability present in a crop species is important as it provides the basis of selection. The present study revealed high to moderate estimates of GCV and PCV for all the traits except ear diameter and kernel rows per ear at N_{80} level in the set of germplasm studied indicating scope for genetic improvement through selection in respect of these traits. The estimates of genotypic coefficient of variation (GCV) reflect the total amount of genotypic variability in a population under study for a trait. In the present investigation, the PCV was estimated to be high compared to GCV for all the traits considered. Kumar *et al.*, (2014) and Abirami *et al.*, (2005) reported high PCV and GCV values for grain yield per plant and ear height in the materials studied by them. Heritability estimates were found to be high for all the traits except ASI (53.66%) indicating that genes governing these characters were less influenced by environment. Since heritability alone cannot predict the nature of genetic variation the knowledge about genetic advance coupled with heritability is most useful. Heritability coupled with expected genetic advance as per cent of mean indicates the mode of gene action in the expression of a trait which helps in choosing an appropriate breeding method. High heritability accompanied with by high to moderate expected genetic advance as per cent of mean in case of grain yield per plant, plant height, ear length, ear height, kernels per row, 100-KW, days to 50% pollen-shed, days to 50% silk, ASI and days to 75% dry husk indicated the preponderance of additive gene effects in their inheritance and simple selection may be effective for improvement of these traits. Ear diameter and kernel rows per ear exhibited moderate to high heritability along with low genetic advance indicating more role of non-additive gene action and provides limited scope for improvement of traits through simple selection. Similar results were reported by Mahmood *et al.*, (2004), Vashistha *et al.*, (2013) and Kumar *et al.*, (2014).

High to moderate estimates of GCV and PCV were recorded for all the traits at N_0 level indicating sufficient variability for the traits and suggesting scope for genetic improvement through selection. High heritability accompanied with high expected genetic advance as per cent of mean observed in case of plant height, ear height, kernels per row, ASI, days to 50% pollen-shed and days to 50% silk indicated the preponderance of additive gene effects.

Physiological traits

In the present investigation, high values of both GCV and PCV were recorded for chlorophyll content, NRA, plant nitrogen at N_0 level, and for NRA and NUE at N_{80} level. High estimates of GCV for these traits indicated a considerable amount of genetic variability, thus suggesting the potentiality of the material for further improvement. LA and NUE showed moderate magnitude of GCV and high estimates of PCV at N_0 level. Makhiziah *et al.,* (2013) stated that chlorophyll content demonstrated high genotypic variation at all N level.

The present investigation revealed that the heritability estimates were high for all the physiological traits at N_0 level of nitrogen indicating the potential for transmission of genes from parent to offspring in respect to these traits. The estimates of high heritability (>60%) for all the traits except chlorophyll content (58.45%) and plant nitrogen (48.82%) at N_{80} level. Similar results were found by Li *et al.,* (2014). Expected genetic advance as per cent of mean was high for plant nitrogen at N_0 level and for NRA and NUE at N_{80} level. LA, chlorophyll content, NRA and NUE gave moderate estimates of expected genetic advance at N_0 level while LA and chlorophyll content gave moderate magnitude of expected genetic advance at N_{80} level. All the physiological traits except GS showed high heritability with high to moderate magnitude of genetic advance as per cent of mean indicating the role of additive gene effects for the traits at N_0 level and simple selection may be effective for improvement of these traits. High heritability with low genetic advance indicated preponderant role of non-additive gene actions for GS at both levels, suggested that recurrent selection methods with progeny testing would be appropriate in exploitation of such traits.

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